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To Carolin

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Introduction

"Antitrust is back"[1] – this appears to describe not just a US but a global trend. In the last years, increasing market concentration, the power of digital platforms, and problems in the patent system have been frequent and prominent topics in the scientific as well as in the public debate. These debates have spurred intensified antitrust enforcement as well as legal reforms, and they continue to do so. One example is the 10$^{\text{th}}$ amendment to the German Act Against Restraints of Competition (GWB) in 2020, which allows the German Federal Cartel Office to identify firms with *paramount significance across markets.* The amendment is tailored towards big digital companies such as Google, Amazon, Facebook, and Apple (the so-called GAFA companies) and offers novel instruments to regulate their behavior and market power. At the European level, the proposal for the Digital Markets Act, which has a similar aspiration, is in the public consultation process at the time of this writing. It will be exciting to witness how these developments unfold in the upcoming months and years.

My work on this thesis has been accompanied and partially motivated by this comeback of antitrust enforcement. It presents four essays on competition economics and contributes to selected antitrust topics closely related to the debates mentioned above. Chapter 1 contains an empirical investigation of platform most-favored nation clauses (PMFN, also called best price clauses), which restrict sellers' prices and conditions across distribution channels. It is coauthored by Matthias Hunold, Ulrich Laitenberger, and Reinhold Kesler. Chapter 2 presents a novel theory of how a PMFN can harm consumers. Chapter 3 is coauthored by Matthias Hunold and contains a theoretical essay on partial ownership in vertically-related industries. The last chapter, coauthored by Benno Buehler and Matthias Hunold, presents a theoretical analysis of no-challenge clauses in patent licensing, which prevent a licensee from challenging the validity of a patent.

Chapters 1 and 2. The first two chapters of this thesis deal with platform most-favored nation clauses. One characteristic of modern e-commerce is that sellers of goods and services use several distribution channels in order to reach consumers. In particular, the importance of digital platforms—such as the Amazon Marketplace or online travel agents like Booking.com—as intermediaries that facilitate transactions between sellers and consumers has vastly increased over the last decade. They lower search costs and provide convenience benefits to consumers but also charge commission rates from the sellers for the transactions completed on the platform. In several cases, such digital platforms imposed platform most-favored nation clauses, which are a contractual obligations for a seller to not offer better prices and conditions on another distribution channel. Platforms argue that such clauses are necessary to secure their investments against opportunistic seller behavior

[1] Eric Posner (2021), "Antitrust is Back in America."

– so-called showrooming. Showrooming occurs if consumers search via the platform but complete the purchase on another channel on which the seller can avoid the platform's commission. In contrast, sellers complain extensively that such a clause restricts their price-setting abilities across different distribution channels. Similarly, several competition authorities prohibited PMFNs in various instances. Moreover, the current proposal for the Digital Markets Act suggests banning PMFNs for designated gatekeepers altogether.[2]

Against this backdrop, Chapter 1 contains an empirical investigation of PMFNs in online hotel bookings. In particular, Booking.com had to waive its PMFN in Germany in February 2016. We exploit this natural experiment using meta-search price data of nearly 30,000 hotels in different countries. Our results show that PMFNs influence the pricing and availability of hotel rooms across online distribution channels. In particular, hotels publish their offers more often at Booking.com when the online travel agent does not use a PMFN, and also tend to promote the direct online channel more actively. Moreover, the abolition of Booking.com's PMFN is associated with the direct channel of chain hotels having the strictly lowest price more often.

The second chapter also deals with PMFNs. The chapter presents a novel theory of how such clauses can harm consumers. In particular, this chapter investigates the incentive and ability of a platform to limit the extent of competition between the sellers it hosts. Absent contractual restrictions, a platform has an incentive to ensure competition between the sellers. As I show, this incentive can change with the introduction of a PMFN. Such clauses therefore can align the interests between sellers and platforms to restrict competition. Moreover, the analysis illustrates that a platform can stabilize seller collusion to its own benefit. These results complement existing concerns regarding PMFNs and offer a novel rationale to treat them with scrutiny.

Chapter 3. In this chapter on partial vertical ownership, we analyze minority shareholdings between vertically-related firms in a supply chain. Vertical ownership is prevalent in various industries. Examples include cable operators and broadcasters, banks and payment providers, financial exchanges and clearing houses, as well as automobile producers and their suppliers. The economic effects of ownership between firms in a supply relationship (vertical ownership), however, is not fully understood. We contribute to the developing theoretical literature on this topic by demonstrating novel anti-competitive effects of partial ownership that arise when the upstream firm's tariffs are non-linear. This contrasts well-established findings that are based on linear tariffs and thereby adds to the current debate on how to treat partial shareholdings in merger control.

Chapter 4. This chapter presents a theoretical analysis of frequently-used and highly-contested no-challenge clauses that prevent a licensee from challenging the validity of

[2] See the European Commission's Proposal for a Regulation on Digital Markets Act, Article 5 (b).

a patent. The analysis contributes to the broader debate about how the patent system should balance the protection of intellectual property with the goal of free and competitive markets. The starting point is the empirical and legal evidence documenting that a substantial fraction of patents does not deserve patent protection, and the frequently-expressed expectation that licensees can help to identify and eliminate invalid patents. As no-challenge clauses contractually prevent licensees from challenging invalid patents, they are therefore considered to be detrimental.

In sharp contrast to this intuitive reasoning, we show that the expectation that licensees will help to eliminate invalid patents can be misguided: Even absent a no-challenge clause, a patent holder may well be willing and able to avoid patent challenge by means of an appropriate design of the license tariffs. Importantly, such a strategy can have detrimental price effects and banning no-challenge clauses may therefore not be desirable. Moreover, the analysis contributes to the question of whether licensees can further be motivated to challenge an invalid patent. In particular, we study the Supreme Court judgment *MedImmune vs. Genentech*[3], which aims at improving prospects of patent challenges for licensees. Contrary to the intentions of this judgment, we find that it can even have increased the fraction of patents that remain unchallenged as it increased a patent holder's risk to face a patent challenge and hence increases its incentives to avoid such a challenge.

[3] *MedImmune, Inc. vs. Genentech, Inc.*, 549 US 118 (2007).

Chapter 1

Evaluation of Best Price Clauses in Online Hotel Bookings

with Matthias Hunold, Ulrich Laitenberger, and Reinhold Kesler[1]

Published in: *International Journal of Industrial Organization (2018), 61, 542 – 571.*

[1]This chapter presents a substantially extended and improved version of my master thesis written at the Rheinische-Friedrich-Wilhelms-Universität Bonn.

1.1 Introduction

Motivated by recent proceedings against best price clauses (BPCs) imposed by online travel agents (OTAs), we empirically investigate the effects of such clauses using meta-search price data of nearly 30,000 hotels in various countries.[2] Under a BPC, an OTA obliges the hotel not to offer better prices or conditions on distribution channels other than the OTA. Various national competition authorities in Europe agreed that best price clauses could restrict competition between OTAs for commission rates, but eventually arrived at different assessments and decisions.[3] These differences trigger the question of how BPCs actually affect the market outcome. The theoretical literature on this topic is developing rapidly and shows that BPCs can harm consumers (Boik and Corts, 2016; Edelman and Wright, 2015; Johnson, 2017; Wang and Wright, 2017), but can also be welfare-enhancing (see in particular Johansen and Vergé, 2017). However, empirical research on this topic is still very limited. With this article we start to fill the gap.

We exploit the variation in the BPCs due to different enforcement policies across various countries and over time. The different national decisions seem to be due to differences in the assessments rather than to fundamental differences in the market characteristics in each country (see Hunold, 2016). For instance, the French competition authority had accepted Booking.com's commitments to narrow down the parity clauses in April 2015, only to be overruled by the French parliament which completely prohibited BPCs of OTAs in July 2015. These different decisions provide a quasi-experimental set-up for assessing the effects of different BPC policies.

Interestingly, according to a large hotel survey the standard commission rates of OTAs did not change following the prohibition of BPCs.[4] Our focus is therefore on analyzing how the abolition of a BPC has influenced the choice of distribution channels on which hotels publish prices (OTAs and their direct channel) and the pricing of the same hotel room across these channels.[5] A BPC can restrict price differentiation as it forbids hotels from charging higher room prices at the OTA, which imposes the clause, than on other channels covered by the clause (narrow BPCs cover only the direct channel, wide BPCs also other OTAs).[6] There are related clauses, such as availability requirements, which

[2] In this article, we generally refer to hotels as the typical accommodations on offer at a booking platform. In its general terms and conditions, Booking.com uses the term "accommodation." Other types of accommodation present on OTAs include, for example, holiday apartments.

[3] See Appendix A for a list of the different decisions.

[4] In 2016, a HOTREC study finds that for more than 90% of over 2,000 hoteliers in Europe the effective commission rates have not decreased over the past one year (see press release on www.hotrec.eu; last accessed December 1, 2017).

[5] Note that in the context we study hotels essentially set the sales prices on the OTAs. We refer to this as the *agency model* which is in contrast to the *merchant model* under which the platform would set the retail price.

[6] Under a *wide* BPC, an OTA obliges the hotel not to charge a higher price on the OTA than on almost any other booking channel, which in particular includes other OTAs and the hotel's own direct sales channels. *Narrow* BPCs prohibit the hotel from publishing lower prices on its direct online sales

further restrict a hotel's sales strategy. If a hotel faces less parity restrictions, it might thus price differentiate more across channels. In particular, a hotel could lower the prices on its direct channel, where the marginal distribution costs are potentially lowest. A hotel might also start using an OTA that has relaxed its parity clauses, and could start using other channels which were previously less attractive to use in view of these restrictions.

The main data source are price data from the website Kayak that covers the period January 2016 to January 2017. Kayak is a travel meta-search engine that displays the prices of the same hotel room on different online distribution channels, in particular the OTAs and the hotel website which we refer to as a *direct online channel*. We complement this data set with data from two additional sources. First, we add data from the OTA website Booking.com, which allows us to distinguish between chain and independent hotels. Second, we gathered time series data of travel-related search queries from Google Trends. These data date back before the beginning of our observation period and allow us to control for other developments in the analyses that are not BPC-related.

Our empirical approach is twofold: In view of different BPC policies across countries, we use cross-sectional statistics to investigate the channel choice and pricing across channels. Moreover, we analyze the removal of Booking.com's narrow BPC in Germany since February 2016.[7] By means of regression analyses, we compare the changes in the market outcome in Germany with the changes in other countries without such a regulatory treatment of the BPCs in the course of 2016.

We find that the price of the direct channel among hotel chains is more often strictly lower than the prices on all other visible online sales channels following the abolition of Booking.com's narrow BPC in Germany. At the same time, the price at Booking.com is less often the lowest among hotel chains in Germany. This suggests that Booking.com's BPC did restrict the hotels' price setting. The result is consistent with a simple cost-based pricing in case the hotel has lower distribution costs on the direct online channel relative to the OTAs that typically charge commission rates for each mediated booking. The result is also consistent with free-riding in the sense that hotels might use the OTAs to show their rooms, but induce customers with lower prices to eventually book directly.

With respect to the availability of hotel room offers on different distribution channels, we find that more hotels start using Booking.com as a distribution channel following the abolition of Booking.com's price parity and minimum availability clauses in Germany – also relative to the developments in unaffected countries. This result suggests that a fraction of the hotels indeed responds to parity clauses by not being active at an OTA that imposes them. Similarly, hotels that had already been active on Booking.com increasingly often publish prices there once the clause is removed. Moreover, we observe a

channels than at the OTA that imposes the clause. A narrow BPC does *not* contractually restrict the hotel's room prices at other OTAs.

[7] We also partly capture a legislative prohibition of BPCs in Austria.

distinctive increase in the availability of the direct online channel of chain hotels at Kayak in Germany, also relative to other countries. This indicates that these hotels increasingly promote the direct channel when they are not constrained by Booking.com's narrow BPC.

In France and Austria, we partly observe similar developments as in Germany. In particular, we observe that in these countries more hotels have started using Booking.com as a distribution channel. In Austria, hotels which had already been active at Booking.com more often publish prices at this OTA. These patterns support the results we have found in Germany as they can be related to changes in the BPCs in these countries. The Austrian parliament passed a law in November 2016 that prohibits BPCs of OTAs from January 2017 onward, following an intensive public debate and consultation process in 2016. In France, all BPCs of OTAs were prohibited in August 2015 with the *Loi Macron*, and in November 2016 the commercial court in Paris also prohibited the OTAs from using availability parity clauses.[8]

The remainder of the article is structured as follows. We discuss the related literature in the next section, introduce the data and present descriptive statistics in Section 1.3, discuss conjectures, methodology and identification in Section 1.4, show the analysis of the pricing in Section 1.5 as well as price publications across channels in Section 1.6, present various robustness checks in Section 1.7 and conclude in Section 1.8.

1.2 Related Literature

Theory in Relation to BPCs. Recent theoretical research finds support for the main theory of harm of various competition authorities that BPCs could restrict competition between OTAs for commission rates and that the resulting high commission rates could induce the hotels to charge higher retail prices (Boik and Corts, 2016; Edelman and Wright, 2015; Johnson, 2017). OTAs argue that BPCs prevent free-riding which would occur when consumers search on the OTA and then book on the hotel website or at another OTA if the price is lower there. Several competition authorities have accepted narrow BPCs as a compromise which only requires parity with respect to the direct online channel and, in principle, still allows for price differentiation across OTAs. According to Wang and Wright (2017), narrow BPCs may be beneficial for consumers if OTAs would leave the market otherwise. Wals and Schinkel argue that narrow BPCs can, however, have the same anti-competitive effects as wide BPCs when an OTA combines them with a best price guarantee.[9]

[8]See Appendix A for details and references of the various decisions with respect to BPCs of OTAs in Europe.

[9]Under a best price guarantee, an OTA promises to refund any price difference to hotel room offers with exactly the same characteristics on another distribution channel – if customers booked at the higher price and request this refund.

In contrast to the contributions above, Johansen and Vergé (2017) offer a divergent view to the main theory of harm. They show that BPCs do not necessarily lead to higher commission rates and consumer prices if hotels can decide whether to be active on the OTA. Moreover, they conclude that narrow BPCs do not increase competition between intermediaries when compared to wide BPCs. These findings could explain the observation that the base commission rates of OTAs have apparently remained largely unchanged in Europe following the move of Booking.com in 2015 to use only narrow BPCs.

Empirical Literature in Relation to OTAs. As there are different theoretical predictions on the competitive effects of BPCs, it remains an empirical question as to whether and – if yes – how the wide and narrow BPCs of OTAs affect the market outcome. To our knowledge, there are not yet any research articles available which address this question.[10]

A related contribution is the case study of Lu et al. (2015) who find that the introduction of a new online direct sales channel of a hotel chain in 2002 led to a significant reduction of the prices at physical travel agents, which suggests that there is competition between different forms of sales channels for hotel distribution. Lu et al. do not study BPCs, which is the focus of our study. De los Santos and Wildenbeest (2017) compare the agency model and the merchant model in the e-book market and find that retail prices for e-books are significantly higher when publishers set the prices on the sales platform (agency model).

Our article also relates to studies that characterize online pricing. Gorodnichenko and Talavera (2017) report that there is considerable online price dispersion for narrowly defined product categories and frequent price adjustments. We also document considerable price dispersion for hotel room offers across distributions channels and study how this is affected by BPCs.

1.3 Data and Descriptive Statistics

1.3.1 Data Sources

Prices and Hotel Characteristics from Kayak and Booking.com. We use data on prices of hotel rooms on different online sales channels such as Booking.com, Expedia, and the hotels' direct online channel from the travel meta-search engine Kayak. We understand that Kayak does not post own prices and receives the hotel offers either directly from the

[10] Various European competition authorities conducted an evaluation of BPCs in hotel bookings in 2016 using meta-search data. They found that price dispersion increased across OTAs following the reduction of price parity clauses. They did not address the direct channel as we do. We provided input for this exercise in early 2016, including our research set-up. See "Report on the Monitoring Exercise carried out in the Online Hotel Booking Sector by EU Competition Authorities in 2016," available at http://ec.europa.eu/competition/ecn/hotel_monitoring_report_en.pdf (last accessed December 1, 2017).

OTAs or from a booking engine of the hotels or a third party.[11] Kayak then redirects customers to the hotel website or the OTA websites where bookings eventually take place. In case customers choose an OTA to book a hotel room, it is important to note that the OTA typically only acts as an intermediary between the hotel and customer while the hotels generally set the prices at the OTAs.

Best price clauses (if they exist) are specified in the contracts between the hotels and the OTAs. As a consequence, changes in the BPCs, which are induced by national competition law enforcement or new laws, target the contracts between the hotels in the respective jurisdiction and the affected OTA.[12] In order to study BPCs, we collect prices of hotels located in countries which differ in their BPC policies: Countries without BPCs (Austria, France, HRS and Booking.com in Germany), narrow BPC countries (Italy and Sweden) and wide BPC countries (Canada).[13]

We collect data from January 26, 2016, onward from Kayak for all listed hotels from a wide range of cities: the 25 biggest German cities, a list of the 15 biggest cities and 15 popular tourist destinations for the five countries Austria, Italy, Sweden, France, and Canada, as well as a selection of 20 pairs of German and non-German cities near the German border.[14] Prices are collected for overnight stays for two persons in one room on the same day and the 7th, 14th, 21st and 28th day ahead.

For each hotel, Kayak provides general information and booking conditions from the different distribution channels and displays them to the customer when clicking on a particular hotel offer. We collect the data from the overview page that lists all the available hotels in the cities of interest. In addition, the Kayak data also contains hotel-specific characteristics like user rating and stars. Information about chain affiliation is retrieved by the hotel profile website on Booking.com.[15]

Hotel chains might have different distribution and marketing strategies and may benefit from economies of scale or react differently to contract changes. Moreover, they might have more bargaining power toward OTAs and occasionally might be able to negotiate contracts that differ from the standardized contracts between OTAs and independent hotels. In order to account for the heterogeneity between these different hotel types, we conduct the analyses separately for chain and independent hotels.[16]

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[11]Booking engines such as Fastbooking, Travelclick or Derbysoft offer the services necessary to connect the hotel to Kayak.

[12]See for instance par 6.1 of the commitments given by Booking.com in April 2015 (last accessed December 1, 2017) and point 1 of page 3 in the Bundeskartellamt's decision against Booking.com (full reference is in Appendix A).

[13]See Appendix A for details such as timing.

[14]The corresponding list of locations and starting dates for data collection can be found in Appendix B.

[15]For a small fraction of the hotels, where no profile website was available on Booking.com, we conducted analogously a manual classification into chain and independent hotels.

[16]We discuss the concern of further unobserved heterogeneity and present robustness checks in this regard in Section 1.7.

OTA Popularity and Tourism Flow Measures from Google Trends. We also retrieve time series data from Google Trends for the time period January 2015 to January 2017 to approximate: (1) the popularity of different OTAs among customers, and (2) the tourism demand for hotels in particular cities. The data comprise the aggregated search volume of specific queries on Google over time.[17]

1.3.2 Summary Statistics of the Kayak Data

The data set contains around 30,000 hotels over the observation period January 2016 to January 2017. Each observation in the data set refers to a hotel room on a specific travel date which is on offer at a certain search date (which we refer to as *Kayak request*). It contains the price offers of all sales channels of the hotel as listed on Kayak. In total, the data set consists of approximately 20 million observations. Table 1.1 depicts summary statistics for chain hotels and independent hotels.

	Mean by hotel type			**All observations**			
Variable	All	Chain	No chain	Std. Dev.	Min	Max	N
Kayak request level							
Number of listings	4.93	7.06	4.11	3.14	1	24	20,115,292
At least two listings (%)	83.67	95.72	79.02	36.96	0	100	20,115,292
Mean price in EUR	120.37	128.41	117.27	95.89	10	2,000	20,115,292
Std. Dev. price	12.66	14.80	11.65	44.73	0	4,615	16,954,059
Strict minimum price exists (%)	48.11	51.69	46.43	49.96	0	100	16,830,677
Diff. (str.) two lowest prices (%)	13.71	9.35	15.98	47.08	0	16,100	8,164,931
Avg. days before travel date	12.74	12.59	12.80	9.63	0	28	20,032,766
Share of non-listed hotels (%)	63.89	60.37	65.25	15.79	0	100	20,073,996
Kayak hotel rating	7.97	7.90	8.00	0.87	2	10	19,810,437
GT city	76.67	77.60	76.32	15.12	4	100	20,115,292
GT Booking.com	63.50	65.26	62.82	15.53	32	100	20,115,292
GT Expedia	68.02	70.72	66.97	14.82	6	100	20,115,292
GT HRS	69.57	69.79	69.49	18.28	0	100	20,115,292
Hotel level							
Number of rooms	52.08	123.55	31.83	74	1	1,590	27,123
Hotel chain (%)	20.50	100.00	0.00	40.37	0	100	29,497
Hotel category in stars	2.92	3.23	2.85	0.86	1	5	29,497
Kayak hotel rating	8.04	7.89	8.08	0.89	2	10	27,445
Number of ratings	628.42	1248.75	464.76	937.91	1	19515	28,564

Table 1.1: Basic variables by hotel type

A Kayak request includes, on average, 5 online sales channels (OTAs and direct channel)[18] and in 84% of all observations we find that hotels have published prices on at least

[17]Similar data have already been used as a predictor of actual tourism data in other studies (Coyle and Yeung, 2016; Siliverstovs and Wochner, 2018). The collection and validation of these data is further explained in Appendix C.

[18]This is consistent with Stangl et al. (2016) who find that for Germany, Austria, and Switzerland hotels have published prices at 3.6 OTAs.

two channels. The average price across all listings is at 120 EUR, ranging from 10 EUR to 2,000 EUR.[19] The average standard deviation of the prices is 13 EUR for the Kayak requests with offers from at least two distribution channels. In 48% of all observations with at least two listings, there exists a strict minimum price.[20] For the observations with a strict minimum price, the average relative difference between the lowest and second lowest price is at 14% of the lowest price.

Kayak displays for every city the number of available hotels and the total number of hotels that are generally listed. We use the fraction of hotels currently not available at Kayak as one measure of hotel occupancy in a city. It has an average value of 64% across all Kayak requests. The Google Trends measures are normalized by the maximum of the search volume in the observation period and scaled to values between zero and 100.

We report characteristics of the cross-section of hotels in the sample in the bottom panel of Table 1.1. The average hotel has 52 rooms, 2.9 out of 5 stars[21] and a Kayak rating of 8 out of 10. We identify 21% of all hotels as belonging to a hotel chain.[22] Interestingly, 28% (not reported in the table) of our Kayak requests come from chain hotels, which shows that these hotels are listed on Kayak more often. Accordingly, we find that chain hotels, on average, use more distribution channels (an average of 7 listings and in 96% of all cases at least two listings), are larger (124 rooms) and of higher quality (3.2 stars). The differences in Kayak hotel rating between chain hotels and independent hotels reveal that the customers are slightly more satisfied with independent hotels even though these hotels have fewer stars on average. In Appendix D we compare hotel features across distribution channels and do not find substantial differences.[23]

Availability of Price Offers Across Channels

Table 1.2 depicts basic information on the availability of price offers across the main distribution channels. In total, we observe 76 distinct sales channels in the Kayak data which can be classified as OTAs and direct channels. We observe that hotels publish prices most often at Booking.com, Expedia, and HRS as well as at the related OTAs of the same company groups.[24] Booking.com is the channel that exhibits the highest penetration as 96% of all hotels have published prices there at least once, followed by Expedia with 67% (Table 1.2, first data column). Across countries, 31% of all hotels make use of HRS. In

[19] We excluded prices below 10 EUR and above 2,000 EUR.

[20] Strict in the sense that the second lowest price is higher. We refer to the strictly lowest price of a response to a Kayak request also as "price leader."

[21] Holiday apartments without stars were removed from the analyses.

[22] The chain classification (including subchains) distinguishes 884 distinct chains in the cities that we study. All hotels not belonging to one of these chains are treated as "independent."

[23] We further note that when distinguishing between chain and independent hotels, the average characteristics of the respective hotels across countries are quite similar (country statistics not reported).

[24] For our analyses we take into account that some OTAs belong to the same company group (see Appendix D for details).

Channel as displayed at Kayak (major channels only)	Fraction of hotels that used channel at least once	Frequency of channel use (given hotel used it at least once)
Direct channel (total)	16%	87%
Direct channel (independent hotel)	5%	71%
Direct channel (hotel chain)	11%	91%
Booking.com	96%	91%
Expedia	67%	91%
HRS	31%	78%
Base	All 29,497 hotels observed during the observation period	All Kayak requests of hotels after hotels have listed for the first time

Table 1.2: Channel use

contrast, for Germany, around three-quarters of all observed hotels had offers listed at least once at HRS. This could be due to HRS being a German incumbent.[25] The high listing frequencies of the OTAs Booking.com, Expedia, and HRS are consistent with a survey by HOTREC from 2016 among more than 2,000 European hoteliers.[26]

Kayak displays a direct channel price of a hotel and provides a link to the hotel's own website for approximately 16% of all hotels. Out of these hotels, about two-thirds can be identified as chain hotels, whereas the other third are independent hotels. Among the 20 million Kayak requests, a direct channel offer is contained in 17% (not reported). It is not guaranteed that the direct channel listing observed on Kayak is fully representative of all hotels with direct online channels. According to Eurostat, 74% of all enterprises in the accommodation sector in Europe had a website that provided online ordering, reservation or booking opportunities in 2015.[27] However, it is also not obvious why hotels with direct prices visible at Kayak should react in a systematically different way. Direct prices of chain hotels are over-represented on Kayak in relation to the direct prices of independent hotels, which is why we also distinguish between chain hotels and independent hotels.

Hotels do not always post prices at OTAs or list direct channel offers at Kayak (Table 1.2, second data column). A usage frequency of a channel below 100% arises if a hotel occasionally does not offer hotel rooms on the particular channel on Kayak. As we control

[25]Distinguished by countries, Booking.com is the mostly used channel with a frequency ranging from 84% in Italy to 94% in Sweden and Austria, followed by Expedia with frequencies from 45% in Austria to 83% in Canada. HRS is especially present in Germany (60%) and Austria (24%), while it appears only in 3% of all Canadian Kayak requests. Note that these figures are per listing.

[26]Compared to 2013, bookings via OTAs have increased by 3 percentage points (pp) to 22%. Direct bookings account in total for 55% of all bookings and have dropped by 4 pp, while the direct online channel has remained constant at close to 7% (HOTREC Survey on Hotel Online Distribution, http://www.hotrec.eu/newsroom/press-releases-1714/dominant-online-platforms-gaining-market-share-in-travel-trade-no-signs-of-increased-competition-between-online-travel-agents-unveils-european-hotel-distribution-study.aspx; last accessed December 1, 2017).

[27]See Statistics on ICT use in tourism, http://ec.europa.eu/eurostat/statistics-explained/index.php/Statistics_on_ICT_use_in_tourism (last accessed December 1, 2017).

for the date when a hotel starts to use a channel, these figures are a measure of the hotels' ability to react flexibly to changing market conditions on this channel. On average, a hotel that is listed at least once on Booking.com or Expedia offers rooms there in more than 90% of all Kayak requests. The direct channel of hotel chains exhibits a similar frequency, while the direct channel of independent hotels is only used in 71% of all requests. Potentially, the lower listing frequency of independent hotels can be explained by different technologies of transmitting information to Kayak. Among all independent hotels that also list their direct channel on Kayak, more than 90% employ a third-party booking engine. In contrast, we find that around 85% of all chain hotels have their own booking engine to transfer data to Kayak (not reported).

1.4 Conjectures, Identification, and Methodology

1.4.1 Conjectures

Pricing Across Channels

There are various reasons why a hotel might want to charge different prices on different distribution channels. On the one hand, direct channel customers might have a lower price elasticity than OTA customers, as finding another hotel should be easier at an OTA. This could favor higher direct channel prices. On the other hand, the marginal costs of a hotel for bookings on the direct channel are likely to be significantly lower than for bookings through an OTA because of the per-booking commission.[28] The "Book Direct" campaign of HOTREC[29] and similar measures of hotel associations indicate that hotels often favor direct channel bookings and might thus prefer to charge lower direct channel prices. The theoretical work of Shen and Wright (2017) confirms that when intermediaries (such as OTAs) determine the commission fees that sellers pay per transaction, the sellers have incentives to charge lower direct prices.

Both wide and narrow BPCs typically forbid hotels from having a lower price on the direct channel than on the OTAs. We therefore expect that without a BPC in place the direct channel will more often have the strictly lowest price. We test the following:

Conjecture 1.1. The hotel's direct online channel has the strictly lowest price (is the price leader) more frequently if the hotel faces no BPCs.

[28]Booking.com (and other major OTAs) typically act as "agents" for the hotels. In this agency business model, the customer formally does not purchase the hotel service from Booking.com, but does so from the hotel directly. Moreover, the hotel is responsible for the price setting on the OTA as on all other distribution channels. In return the OTA receives a commission payment from the hotels for every mediated booking.

[29]See http://www.hotrec.eu/bookdirect.aspx (last accessed December 1, 2017).

Decision on which Channels a Hotel Publishes Prices

A price parity clause requires the hotel to not charge lower prices on certain other channels. Such a clause can make it unprofitable for some hotels to sign a contract with that OTA. A reduction of the parity clauses could therefore induce more hotels to sign a contract with the OTA and start publishing room prices there. Hence, we test

Conjecture 1.2. If an OTA stops using parity clauses, more hotels become active at the OTA.

For those hotels that have used the OTA before, the removal of the BPC might have two opposing effects. On the one hand, as a hotel is less constrained in its price setting, it could find it profitable to use the less constrained distribution channel(s) more intensively. In particular, it might have been unprofitable for the hotel to promote the direct channel when the hotel could not make the channel more attractive by means of a lower price.

Conjecture 1.3. More hotels use the direct channel and make it visible at Kayak more often if they face less (stringent) parity clauses.

On the other hand, we understand that the parity also requires some form of room availability.[30] If the availability requirements exceed the number of offers a hotel would like to offer on the OTA, one might expect that a hotel will offer rooms less often at an OTA once it is allowed to do so. On the contrary, a hotel might nevertheless be inclined to use the OTA more frequently following the removal of the BPC because it can now also differentiate between the other channels (in particular the direct channel) and that OTA channel by means of a lower direct price – instead of not listing at the OTA at all. We therefore test

Conjecture 1.4. Hotels publish offers more frequently at an OTA if the OTA does not use parity clauses.

1.4.2 Identification and Methodology

As a first step, we investigate the pricing Conjecture 1.1 by means of cross-sectional statistics which capture differences across countries. In particular, we compare prices between channels in case of wide BPCs (as in Canada) with those in case of narrow and no BPCs (as in Europe). The identifying assumption here is that differences across countries are due to the different BPC regimes. We cannot exclude, however, that there are also other country-specific differences which affect the pricing across channels and the publishing of hotel offers online.

[30] Even Booking.com's narrow BPCs require the hotel to make a minimum allocation of rooms available on the OTA website.

To account for country-specific differences, we test all our conjectures by investigating the effects of the latest prohibition decision in Germany, which was taken by the competition authority in December 2015 against Booking.com, with the obligation that Booking.com removes the narrow BPC by February 2016.[31] In particular, we compare a change in certain market outcomes in Germany with changes in other countries where the BPC policies did not change in 2016.

We are not aware of other relevant regulatory changes for the investigated jurisdictions during our observation period. We have checked for relevant changes in taxation for our investigated countries by means of the IBFD tax research platform. There were (slight) changes in the value added tax for accommodations in Austria in May 2016 and the corporate taxation in Italy in January 2017. To the extent that they apply to hotels, these should only slightly affect a hotel's profit after taxes, and independently of the distribution channels used. As a consequence, these changes should have no significant impact on the participation of hotels in sites such as Booking.com and the pricing across distribution channels.

While we are not aware of any policy change in Canada, there were, however, changes in the BPC policies in Europe prior to 2016. Across the whole European Union, Booking.com reduced the scope of its BPCs from "wide" to "narrow" by July 2015.[32] This took place well before our observation period and if it had any effect at all, it should have affected all European member states equally. In the case of France, in addition the parliament prohibited BPCs of all OTAs in the summer of 2015. We therefore compare the developments in Germany with the developments in the countries of the control set one by one. By showing that the developments of our dependent variables are distinctively different from the developments in all (or at least most) of our control countries, we are confident that our results are not driven by certain other developments in a particular control country.

In our main specification, we compare the *trends* in the market outcome in Germany in the course of 2016 with the trends in other countries without such a change of the BPCs. Our identifying assumption for this approach is that the *difference-in-trends*[33] can be attributed to the removal of Booking.com's narrow BPC in Germany and that have been no other country-specific developments since January 2016 which affect the pricing across channels and the publishing of hotel offers online, except for demand and OTA popularity, which we control for with the following variables:

[31] See Appendix A for an overview of the decisions.

[32] See footnote 6.

[33] This closely resembles a difference-in-differences approach as a trend is a difference over time. Because of the short pre-treatment period, we rely on the null hypothesis that the trends in the different countries over one year should not vary systematically from the German trend if the change in the BPC regime in Germany has no effect. In Appendix G we provide evidence that a standard difference-in-differences specification yields qualitatively the same result.

1. The share of non-listed hotels at the city-level, according to Kayak, which approximates the occupancy rate at the travel date from the perspective of the search date,

2. The worldwide search volume for hotels in each city of our data set on Google, as an approximation of the actual demand on the search date, and

3. The country-specific search volume for each of the three main OTAs on Google, which accounts for a potentially different development of the popularity among customers.

We conduct various auxiliary analyses to ensure that we correctly identify the effects of the removal of the BPC in Germany (see Section 1.7 for details):

1. We address the concern that within-year changes could be due to a particular seasonality in Germany by analyzing the development over a year, both by means of a linear trend over the period January 2016 to January 2017 as well as by using two-months-country fixed effects and comparing the base period of the beginning of 2016 with the fixed effect of the first month in 2017.

2. We analyze short-term changes in Germany relative to the other countries. The closeness in time between the policy change and distinct changes in the dependent variables can be seen as an indication of a causal relationship. As we only have a short pre-treatment period in the detailed Kayak data, we additionally study time series which go back to the years before 2016 to rule out that Germany is on a different long term-trend than the control countries.

For the main regressions, we estimate several equations of the following kind:

$$y_{i,c,t,d} = \beta_1 trend_t + \beta_2' trend_t I_c + \beta_3' X_{i,c,t,d} + \varepsilon_i + \epsilon_{i,c,t,d}, \tag{1.1}$$

where i denotes the hotel, c the country (which is constant for each hotel), t the travel date and d the booking date (when appropriate). The dependent variable $y_{i,c,t,d}$ is a dichotomous variable. Depending on the conjecture to be tested, this is an indicator of a certain channel having the lowest price or of the availability of a hotel offer on a channel. We measure changes over time in our reference country (Germany) by including a linear trend. To capture diverging developments in other countries, we interact this trend variable with indicator variables for other countries (I_c).

The vector X controls for other time-varying factors. If not stated differently, we include as control variables the time interval between booking date and travel date, the weekday of the first travel day, the rating of the hotel as it is displayed at Kayak. To control for demand and OTA popularity, we also include the share of non-listed hotels for that travel date in the city where the hotel is located and the Google Trends time series, as discussed above.

We control for time-constant heterogeneity between hotels by means of hotel fixed effects ε_i. For instance, factors like the hotel size or the hotel's sales strategy might influence where a hotel publishes prices and how it sets prices across channels. To the extent that the influence stays constant in the course of our observation period, it is captured by the hotel fixed effects. This leaves us with the within-hotel variation. As a consequence, other time-constant observed variables, such as hotel stars or the country, are not included in the regression analyses.[34]

As we also observe whether a hotel belongs to a hotel chain or is an independent hotel, we explicitly allow for heterogeneity between these different types of hotels. For our main analyses, we therefore conduct the fixed effects regressions separately on the population of chain hotels and independent hotels in order to identify hotel-type-specific developments.

For the analysis of changes in the general availability of hotels on specific channels over time, we change model (1) slightly and estimate the following model:

$$y_{i,c,t} = \beta_1 trend_t + \beta_2' trend_t I_c + \beta_3' X_{i,c,t} + \varepsilon_i + \epsilon_{i,c,t}. \tag{1.2}$$

In model (2), the subscript d is dropped as we aggregate the observations to the hotel-month-level such that we have one observation for hotel i in country c in month t. Correspondingly, vector X contains only the average monthly share of non-listed hotels in this month in the corresponding city, the aggregated hotel rating in this month and the monthly averages of the Google Trends data.

Due to the high computational effort in case of fixed effects, we conduct the regressions on dichotomous indicator variables with the linear probability model (LPM) rather than with an index model such as probit and logit. Although a non-linear model is generally more appropriate for prediction purposes, our focus is to estimate the partial effect of the BPC prohibition averaged across the population of hotels. We follow Wooldridge (2010) who argues that the differences between LPM and (theoretically more rigorous) non-linear models may not be important in this instance and that the LPM often seems to give good estimates of these partial effects. We compute standard errors that are robust to heteroscedasticity and serial correlation at the hotel-level.[35]

[34] As a robustness test, we run regressions without fixed effects in Appendix F.

[35] As a robustness check, we have computed standard errors also at the city-level and the country-chain level, but found that our main results were mainly unaffected.

1.5 Pricing Across Channels

1.5.1 Cross-Sectional Observations

Finding 1: the direct channel price is more often below the Booking.com price in Germany and France (largely no BPCs) than in Canada (wide BPCs).

To investigate the pricing across distribution channels, we first compute how often the direct channel price is strictly below or above the price of the major OTAs at the country-level. Table 1.3 shows for each country and hotel type the share of Kayak requests in which the Booking.com price is above the direct channel price (B>D) and vice versa (D>B).[36] The share of observations with price parity (D=B) is implicitly given as 100% minus both shares. We group the countries by BPC regime. The numbers in parentheses show for each country the number of Kayak requests in which both Booking.com and the direct channel are listed.

The price relation is possibly measured with some error, although we have not found any indication of a systematic measurement error.[37] A potential error may thus materialize in both directions (B>D versus D>B) with the same likelihood. On this basis, we can compute a conservative measure of the frequency of the event (D<B), called *difference,* by subtracting the fraction of Kayak requests in which the direct price is larger than Booking.com (D>B) from the fraction in which the direct price is smaller than the Booking.com price (B>D). The *difference* leaves us with a lower bound of the frequency with which hotels price the direct channel cheaper than Booking.com, which would materialize if all observed (D>B) cases were due to an unsystematic error.

Table 1.3 shows that in Canada this *difference* – taken as a conservative measure of the fraction with a lower direct channel price – is at minus 3.6% for hotel chains and at 1.4% for independent hotels. This suggests a possibly high compliance toward wide BPCs in Canada.[38] In contrast, in countries where there are no BPCs in place the aggregated measure of a lower direct channel price is considerably higher and between 16% for France and 20% for Germany (aggregated values not reported in the table). This comparison confirms Conjecture 1.1, that the direct channel is more frequently below the price at an OTA if no BPC is in place.

Table 1.3 also shows that in the countries with narrow BPCs the direct channel is more often cheaper than Booking.com. This observation strongly suggests that direct channel prices covered by a narrow BPC are below the price at Booking.com in a considerable

[36] The analogous computations for the relation between the direct channel and Expedia as well as HRS yield similar results.

[37] See Section 1.7 and Appendix C for details.

[38] A certain degree of non-compliance even in case of wide BPCs is plausible. For instance, the monitoring report of various European competition authorities states that "evidence from the NCA antitrust cases suggests that many hotels did not fully comply with their parity obligations under wide parity" (footnote 17 therein).

	Chain			No Chain		
Country	B>D	D>B	Difference	B>D	D>B	Difference
No BPC						
Germany* (n=648,620)	31.4	14.7	16.4	65.4	16.8	48.6
France (n=1,086,796)	28.9	18.1	10.8	65.0	15.4	49.6
Narrow BPC						
Italy (n=359,831)	31.4	22.5	8.9	55.2	19.9	35.3
Sweden (n=129,203)	41.5	23.9	17.6	52.1	29.9	22.2
Austria** (n=143,145)	31.0	21.2	9.8	52.6	21.3	31.3
Others (n=165,736)	35.9	26.2	9.7	37.8	26.5	11.3
Wide BPC						
Canada (n=676,509)	29.2	32.8	-3.6	34.7	33.0	1.4

The column variables indicate the share of Kayak requests (in %) for which the particular relation (e.g., B>D) holds. The net effect is the difference between the two numbers to control for potential measurement errors. *Booking.com removed the narrow BPC in February 2016. **In Austria, narrow BPCs were in place until December 2016.

Table 1.3: Relation between Booking.com and direct channel

number of cases. The fact that we do not observe similar results for the narrow BPC countries as for Canada suggests that OTAs in these countries cannot enforce price parity between the direct channel and the OTA in the same way as it is feasible in Canada. This observation is interesting as one might expect the same compliance in relation to the direct channel price under a narrow and a wide BPC because both restrict the direct channel price from being lower than the OTA price. Less compliance in case of narrow BPCs might be due to other restrictions that are relaxed in the narrow parity clauses of Booking.com, such as limited punishments in case of non-compliance. The competition policy cases run against Booking.com might have also weakened the enforcement power of Booking.com.

The comparison between chain hotels and independent hotels indicates that the direct channel is more often cheaper than Booking.com among independent hotels, which suggests a lower compliance with the parity clauses of the latter. Moreover, according to our data, independent hotels in Germany and France – where Booking.com was not allowed to use parity clauses anymore in our observation period – most often price the direct channel cheaper than Booking.com.

Finding 2: Kayak shows one channel as price leader across sales channels in about half of all observations.

For Kayak requests with prices from at least two channels, Table 1.4 displays the cross-sectional frequencies of the event that the second lowest price is strictly higher than

Country	Existence price leader		Share direct channel		Share Booking.com	
	Share	Deviation	Chain	No chain	Chain	No chain
No BPC						
Germany* (n=4,169,477)	39.4	10.9	10.7	41.8	5.3	12.3
France (n=4,741,024)	48.9	9.2	15.0	42.2	8.4	15.1
Narrow BPC						
Italy (n=6,327,717)	50.0	19.6	8.4	27.8	6.5	24.1
Sweden (n=596,213)	44.2	10.1	10.8	18.6	12.2	14.5
Austria** (n=1,032,744)	50.2	12.6	10.2	39.5	8.3	23.8
Others (n=1,416,241)	57.8	17.8	11.6	14.6	9.6	24.9
Wide BPC						
Canada (n=1,831,876)	53.1	10.3	9.0	10.4	10.7	23.4

The first two columns indicate the share of Kayak requests with at least two listings (in %) with a strict price leader (1) and the average relative deviation to the second lowest price (2). Columns 3 to 6 show by hotel type how frequently the direct channel and Booking.com are the price leader among the requests in which they are listed. *Booking.com removed the narrow BPC in February in 2016. **In Austria, narrow BPCs were in place until December 2016.

Table 1.4: Share of Kayak requests with price leader and frequency of direct channel and Booking.com as price leader by chain

the lowest price (existence of a strict price leader). The absolute numbers should be interpreted very cautiously as they might suffer from measurement error, similar to the price relations presented before.

It is more insightful to compare the figures across countries as this is robust to unsystematic data errors (for instance, due to the delayed updating of prices by Kayak). An interesting observation is that the direct channel of independent hotels is the price leader more often in countries where OTAs largely do not have best price clauses, foremost France and Germany (data column 4). The fraction is also relatively high in Austria, where the legal prohibition was arguably already foreseeable for hotels in the course of 2016. Moreover, the direct channel is by far least often the price leader in the wide BPC country Canada. This finding is consistent with Conjecture 1.1. For chain hotels, the pattern is similar in that France has the highest share of direct price leadership and Canada the lowest fraction, but the shares are more similar and, overall, the pattern is less clear (data column 3).

In order to control for potential time-constant country and hotel-specific differences across BPC regimes, we analyze the effects of Booking.com's removal of the narrow BPC in Germany on the price leadership of the direct channel and Booking.com in the next subsection.

1.5.2 Effects of Booking.com's Removal of the Narrow Best Price Clause in Germany on Pricing

Finding 3: the direct price of chain hotels in Germany is increasingly often the strictly lowest online channel price.

According to Conjecture 1.1, the hotels' direct online channel should more often have the strictly lowest price on offer (price leader) following the removal of the narrow BPC of the largest OTA, Booking.com. In Germany, the formerly largest OTA, HRS, had already been prohibited from using any BPC in 2013, whereas the investigation of the narrow BPCs of the third largest OTA Expedia is still ongoing. For hotels that do business with Expedia, a narrow BPC might therefore still be in place and would formally not allow them to offer a lower direct price. However, our anecdotal evidence – derived from several phone calls with hoteliers in Germany in 2016 – suggests that hoteliers might not respect Expedia's clause very much in light of the ongoing investigation and the previous prohibitions against HRS's wide, and in particular Booking.com's narrow, BPCs.

Table 1.5 displays regression results separately for chain hotels and independent hotels. The dependent variable is equal to 100 if the direct channel (first and third data column) or Booking.com (second and fourth data column) has the strictly lowest price on offer, and is 0 otherwise. The linear country-specific trend captures whether the particular distribution channel becomes price leader more often. For the regressions we only include observations of hotels that have used the particular channel already at the beginning of the observation period and Kayak requests that contain a Booking.com and a direct channel listing.[39] In Germany, there is a positive trend of the direct channel of chain hotels being the price leader (0.36 pp per month, see Table 1.5, data column 3). For all other countries the coefficients indicating the difference from the German trend are negative, with particularly large and significant values for France, Italy, and Sweden. For Austria, which went through the process of a legislative prohibition of the BPCs in 2016, there is no significantly different trend from Germany. We obtain the same result for Canada.

By contrast, for the independent hotels (data column 1) there is no significant time trend with respect to the direct channel. Recall that independent hotels in Germany, on average, price the direct channel relatively often lowest (Table 1.4), and in particular below their price at Booking.com (Table 1.3). It might therefore be that these hotels are generally less compliant than chain hotels and therefore responded less strongly in their pricing to the removal of the narrow BPC of Booking.com.

[39]For all countries with the exception of Austria the beginning of the observation period is defined as hotels that have used the particular channel already in February 2016. As the data collection for Austria started later, we extend this time frame for Austria until April 2016.

	No chain		Chain	
	(1) Direct	(2) Booking.com	(3) Direct	(4) Booking.com
Trend (Base: Germany)	−0.68	0.46*	0.36***	−0.20***
	(0.60)	(0.26)	(0.09)	(0.04)
Δ Trend France	0.39	−0.39	−0.77***	0.28***
	(0.69)	(0.28)	(0.11)	(0.06)
Δ Trend Italy	1.44*	−0.37	−0.58***	0.33***
	(0.78)	(0.30)	(0.16)	(0.08)
Δ Trend Sweden	−1.05	−0.21	−1.61***	0.04
	(0.97)	(0.33)	(0.30)	(0.12)
Δ Trend Austria	0.49	−0.89**	−0.31	−0.21**
	(0.80)	(0.35)	(0.20)	(0.10)
Δ Trend Canada	0.21	−0.75**	−0.17	0.18**
	(0.63)	(0.32)	(0.11)	(0.08)
Δ Trend Other countries	0.16	−0.07	−0.23	0.36**
	(0.66)	(0.31)	(0.21)	(0.16)
Share of non-listed hotels	0.01	0.02	0.02***	−0.02***
	(0.03)	(0.02)	(0.01)	(0.01)
Kayak hotel rating	−4.00	3.66**	1.61	1.67*
	(3.03)	(1.47)	(1.11)	(0.98)
GT city	−0.02	0.05***	0.03***	0.02**
	(0.03)	(0.01)	(0.01)	(0.01)
GT Booking.com	−0.01	0.06***	0.01*	0.18***
	(0.02)	(0.01)	(0.01)	(0.01)
7 days before	−1.60***	−1.49***	0.06	−1.64***
	(0.47)	(0.25)	(0.17)	(0.14)
14 days before	−1.34***	−0.90***	−0.14	1.16***
	(0.49)	(0.29)	(0.18)	(0.17)
21 days before	−0.25	−1.55***	0.98***	−2.04***
	(0.58)	(0.30)	(0.22)	(0.16)
28 days before	0.05	−2.20***	1.45***	−3.71***
	(0.62)	(0.32)	(0.23)	(0.18)
Weekdays	Yes	Yes	Yes	Yes
Popularity other OTAs	Yes	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes	Yes
Observations	481,064	495,315	2,486,955	2,408,906
R^2	0.466	0.202	0.388	0.137
Adjusted R^2	0.465	0.201	0.387	0.136

Standard errors (clustered by hotel) not reported. Only observations of hotels were included that have used the particular channel already at the beginning of the observation period and that contain a direct channel and Booking.com listing. Dependent variables are equal to 100 if the particular channel is the price leader and 0 otherwise. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.5: Channel has the strictly lowest price

While the direct channel is more often the price leader within the group of chain hotels, we find that Booking.com is significantly less often the price leader (minus 0.20 pp per month, data column 4) among these hotels in Germany. In particular, this development is different in France, Italy and Canada, where the frequency of Booking.com as price leader does not decrease. As regards the price leadership of Booking.com among independent hotels, the regression results suggest that these hotels, on average, price Booking.com more often lowest (0.46 pp per month, data column 2). However, this trend in Germany is in itself only weakly significant and is not significantly different from the trend in various other countries, including Italy and Sweden. If we pool all hotels together, the result that the direct channel becomes the price leader significantly more often in Germany prevails, while Booking.com is the price leader significantly less often (see Appendix F, Tables 1.23 and 1.24 for details). Chain hotels set the strictly lowest price on their direct online channel more often and less often on Booking.com when more hotels in their city are not listed. They also set a strictly lowest price more often – both on the direct channel and Booking.com – when demand is high (as measured by GT city). The respective results for independent hotels are less conclusive, as coefficients are partly not significantly different from zero. However, for both hotel types the popularity of Booking.com (measured by GT Booking.com) positively affects the likelihood of setting a strictly lowest price on Booking.com.

In additional robustness analyses, we observe that the direct channel is more often the price leader, even if we define a price leader as having a discount of at least 5% to the second lowest price. This result lets us conclude that the hotels that are inclined to change their price setting do so up to a price adjustment of 5%. For an average price of 120 EUR in our data, this means that the direct channel is more often 6 EUR or even more below the second lowest price. The result on the price leadership of Booking.com is only robust to a threshold of 1%. However, note that the event of an OTA price being, for instance, 5% below the second lowest price is not really influenced by the abolition of a narrow BPC.[40]

Taken together, the regression results are consistent with Conjecture 1.1 in that the direct channel in Germany is becoming the price leader more often in response to the removal of Booking.com's narrow BPC. At the same time, the OTA Booking.com is less often the price leader in Germany. The finding that the direct channel becomes the price leader more often is driven by the chain hotels which we found to be more compliant in general. For this group of hotels, we find that only around 6% of the observations from Germany list the direct channel as a price leader at the beginning of the observation period. The regression results suggest that this fraction increases by 4.32 pp throughout

[40]More specifically, following a suggestion of a referee, we reran the regressions with a more restrictive definition of price leadership. In particular, we defined a price leader only if the corresponding price was at least 1% (5% and 10%) lower than the second lowest price. The corresponding results are available upon request.

the observation period. This implies an increase of 70% in observations with a direct price leader compared to the level of the beginning of 2016.

1.6 Analysis of Hotel Room Availability Across Channels

In this section we study the effects of Booking.com's removal of the narrow best price clause in Germany on the availability of online price offers. Across all the countries in our data, the frequency of price publications at Booking.com increases over time (Figure 1.1). This indicates Booking.com's growing importance in online hotel distribution. The frequency in Germany starts from an average level of around 73% and exhibits a drastic increase at the beginning of the observation period.[41]

We analyze below whether the increased listing frequency can be attributed to the abolition of Booking.com's BPC in Germany, as the implied less restrictive contract terms might make it more attractive for hotels to list on Booking.com. The following regressions address the intensive and extensive publication decisions (Conjectures 1.2, 1.3 and 1.4).

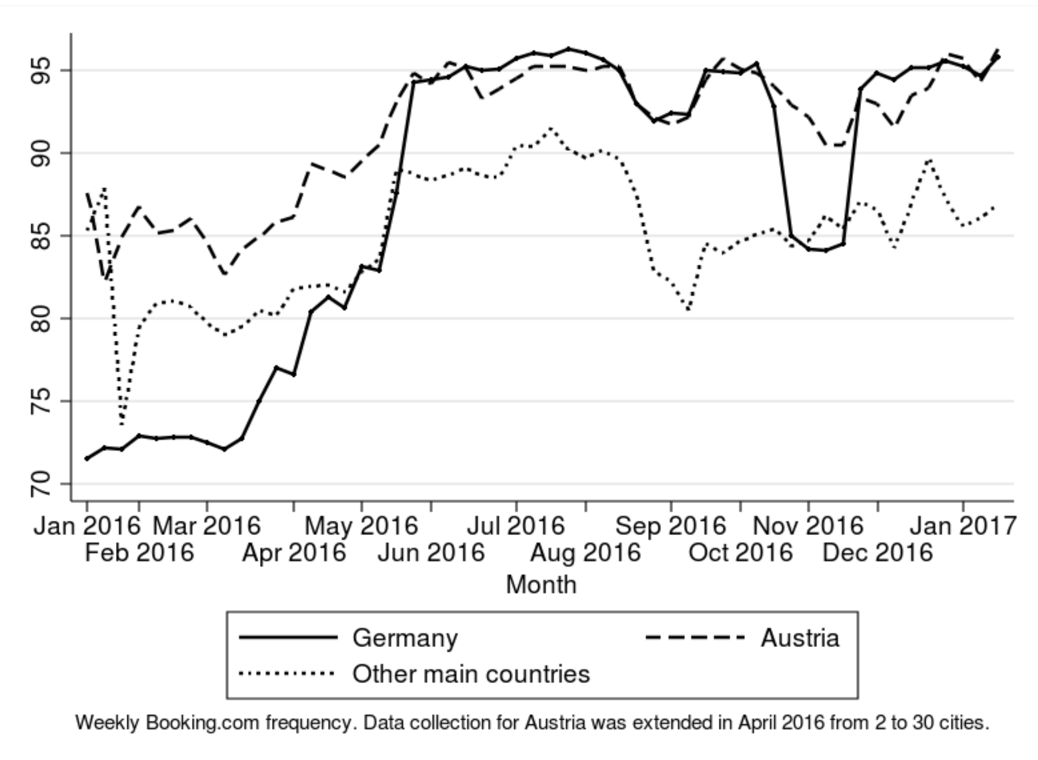

Figure 1.1: Booking.com listing frequency at Kayak by country

[41] During November 2016 one can observe a drop of around 10% in the frequency of the Booking.com listings for Germany. We understand from hoteliers that technical problems with the interface occurred during this period, which could explain the temporary non-availability of hotels as shown in our data. Additionally, a new API by Booking.com was rolled out in this month, which could also have had an impact.

Finding 4: more hotels make price publications at Booking.com in Germany following the removal of the narrow BPC (extensive margin).

According to Conjecture 1.2, a reduction in the scope of a BPC should yield an increase in price publications at the extensive margin, especially for the OTA that narrows down its BPC. This can be tested for Germany where Booking.com had to waive its narrow BPC from February 2016 onward.

Again, we test this conjecture separately for chain and independent hotels. For this analysis we use a data set where each observation corresponds to a hotel in a specific month. The dependent variable equals 100 if a particular channel (such as Booking.com) was used by the hotel at least once in that month according to the Kayak data, and 0 otherwise. The linear country-specific trend captures whether hotels use the channel in later months but not early in 2016 (extensive use). The hotel rating, the Google Trends data, and the share of non-listed hotels are aggregated to the monthly average for the respective hotel or destination.[42] We report the regression results in Table 1.6.

The second and fourth data column of Table 1.6 show a positive trend in the share of hotels in Germany using Booking.com at least once each month. The share increases on average by 1.7 pp per month for independent hotels and by 2 pp per month for chain hotels. The coefficients on the interactions of the time trend with the other countries (i.e., the deviations from the German trend) are significantly negative (except for one case of insignificance). These time trends are thus less pronounced for the other countries, where no change in the BPC regime took place in the investigated time frame. The negative and significant deviations (in absolute values) from the German trend range from 0.65 pp in France (independent hotels) to approximately 2 pp in Canada and Sweden (chain hotels). As a result, in these countries the trend of Booking.com's extensive price publications is close to zero.

The significant and positive coefficient on the extensive direct channel use of 0.09 pp for independent hotels in data column 1 might allude to the fact that Booking.com's narrow BPC indeed put a constraint on the direct channel. After its abolition, it might be reasonable for more independent hotels to engage in direct online sales. For chain hotels we do not find an increase in the extensive direct channel use (possibly because they were already marketing the direct channel more actively).

The regressions on the extensive channel use of Booking.com confirm Conjecture 1.2: There is a significant positive trend in the extensive channel use of Booking.com following the removal of its narrow BPC in Germany. This trend is significantly stronger than in the other countries. The regression results suggest that this increase is at 20.1 (24.1) pp for independent hotels (chain hotels) in Germany. To put this into perspective, we relate this increase to the extensive Booking.com use in Germany at the beginning of the observation

[42] The control variables for the time interval between booking and travel date and the weekday of the first travel day are not included.

	No chain		Chain	
	(1) Direct	(2) Booking.com	(3) Direct	(4) Booking.com
Trend (Base: Germany)	0.09***	1.68***	0.01	2.01***
	(0.02)	(0.07)	(0.05)	(0.11)
Δ Trend France	0.04	−0.65***	0.08	−1.35***
	(0.05)	(0.09)	(0.07)	(0.12)
Δ Trend Italy	−0.13***	−0.02	−0.15	−0.89***
	(0.03)	(0.08)	(0.10)	(0.17)
Δ Trend Sweden	−0.01	−1.89***	−0.19**	−2.09***
	(0.10)	(0.09)	(0.09)	(0.12)
Δ Trend Austria	−0.09	−0.91***	0.26*	−1.51***
	(0.07)	(0.10)	(0.14)	(0.14)
Δ Trend Canada	−0.10*	−1.77***	−0.04	−1.91***
	(0.05)	(0.08)	(0.07)	(0.11)
Δ Trend Other countries	−0.14***	−1.70***	0.58***	−1.90***
	(0.05)	(0.07)	(0.19)	(0.13)
Avg. share of non-listed hotels	−0.00	−0.11***	0.01	−0.12***
	(0.00)	(0.01)	(0.01)	(0.02)
Avg. Kayak hotel rating	0.23	1.79***	0.87	0.48
	(0.19)	(0.54)	(0.98)	(1.29)
Avg. GT city	0.00	−0.03***	0.00	−0.03***
	(0.00)	(0.00)	(0.01)	(0.01)
Avg. GT Booking.com	−0.00	0.15***	−0.01	0.13***
	(0.00)	(0.00)	(0.01)	(0.01)
Weekdays	No	No	No	No
Popularity other OTAs	Yes	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes	Yes
Observations	212,673	212,673	70,716	70,716
R^2	0.874	0.523	0.950	0.483
Adjusted R^2	0.859	0.467	0.946	0.435

Standard errors (clustered by hotel) not reported. Dependent variable is equal to 100 for all months in which a hotel used the particular channel at least once and 0 otherwise.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.6: Extensive channel use (at least once in a month)

period in Germany, which is around 75%. In relation to the implied increase of extensive Booking.com use, this suggests that extensive Booking.com use has increased by 26.4% (31.7%) for independent hotels (chain hotels) in Germany compared to the initial level at the beginning of 2016.

The direct sales channel of independent hotels in Germany also seems to be positively affected by the abolition of Booking.com's narrow BPC (although the development is less Germany-specific). That we observe a rather strong increase in the fraction of hotels using Booking.com at all is in line with the argument underlying Conjecture 1.2 that hotels are now particularly more willing to register with this OTA as they are no longer constrained by its BPC.

Finding 5: hotels make price publications more frequently at Booking.com following the removal of the narrow BPC (intensive margin).

We now analyze the intensive channel use of Booking.com and the direct channel. We measure the intensive channel use as the frequency with which prices for a hotel on a particular channel are available in those Kayak search responses with at least one price offer for that hotel. We conduct the analysis of hotels for which we observe prices on this channel already at the beginning of the observation period in the Kayak data. According to Conjectures 1.3 and 1.4, we expect that BPCs lead to less frequent price publications, both at the OTA using the clause as well as at channels covered by the clauses. In Germany, Booking.com had to abolish its narrow BPC that explicitly only restricted the price setting on the direct online channel. As a consequence, the removal of the BPC should have increased the frequency at Booking.com and the presence of direct prices at Kayak because hotels were now able to use these distribution channels more flexibly.

We test this conjecture with separate regressions for each of the channels. The dependent variable equals 100 if the channel price is shown in response to the Kayak request, and 0 otherwise. Again, we split the sample into hotel chains and independent hotels and – as mentioned above – only include observations of hotels which are using the respective channel already at the beginning of the observation period.[43] This measures whether the channel is used more intensively in later months than early in 2016. Note that we control for the hotel rating, OTA popularity according to Google as well as local supply-demand balance by means of the share of non-listed hotels at Kayak and the Google Trends measure of the destination popularity.

We find that both independent and chain hotels increase the frequency of price publications at Booking.com significantly over time in Germany (Table 1.7 data columns 2 and 4). The negative deviations from the Germany trend suggest that the changes in the intensive use of Booking.com are weaker in most of the other countries. An exception is Austria,

[43]See footnote 39.

where the trend in the intensive channel use of Booking.com is significantly stronger for both types of hotels. These results might indicate that Austrian hotels undergo a similar development as in Germany, as narrow BPCs were in the public legislative process of being prohibited in Austria in 2016. Interestingly, the popularity measure for the OTA Booking.com indicates that hotels of all types particularly rely on this distribution channel in destinations and at times in which many (potential) customers search for hotel rooms via Booking.com. Accordingly, in these instances the direct channel is used less intensively.

For the direct channel of independent hotels we do not see a trend in Germany that is statistically different from zero. However, we observe negative significant coefficients for France and Italy. In contrast, for the direct channel of chain hotels we find that the listing frequency increases significantly by 0.4 pp per month (data column 3). The coefficients for the deviations in the other countries are mostly significantly negative. For the direct channel of hotel chains we observe statistically significant deviations from the German trend in France, Sweden, and Canada. The trends in Austria and Italy are not significantly different from the German trend, indicating similar developments as in Germany. Hence, this confirms Conjectures 1.3 and 1.4 for the chain hotels (and partly also for the independent hotels) because the hotel chains in particular harness the less restrictive contract terms in order to offer hotel rooms more frequently at Booking.com and their direct channel (as is visible at Kayak).

Taken together, the regression results confirm Conjectures 1.3 and 1.4 by indicating that the abolition of Booking.com's narrow BPC is related to an increase in the intensive channel use for those hotels that had already adopted Booking.com. The results show that chain hotels use both Booking.com and the direct channel more intensively by 4.8 pp in the span of the observation period. Compared to the intensive channel use at the beginning of 2016, which is around 90% for both channels, this implies that chain hotels make 5.2% more use of Booking.com and the direct channel. Similarly, the results suggest that the independent hotels in Germany make 2.4% more use of Booking.com relative to an initial channel use of around 95%.

The narrow BPC required the direct online channel price to not be lower than the price at Booking.com. Now hotels publish their prices more often at Booking.com. A possible reason for this is that it is now (contractually) possible to be visible at Booking.com and to set lower prices at the direct channel than at Booking.com, whereas with the parity restriction in place they might have opted not to publish offers at Booking.com in order to boost their direct sales.

1.7 Robustness Checks

We summarize our various robustness checks in this section. In Subsection 1.7.1, we look at within-year variations, including possible seasonality effects. In 1.7.2, we analyze

	No chain		Chain	
	(1) Direct	(2) Booking.com	(3) Direct	(4) Booking.com
Trend (Base: Germany)	−0.33	0.18***	0.40***	0.40***
	(0.46)	(0.04)	(0.09)	(0.03)
Δ Trend France	−1.33**	−0.08	−0.36***	−0.48***
	(0.55)	(0.06)	(0.11)	(0.05)
Δ Trend Italy	−3.13***	−0.59***	−0.03	−0.39***
	(0.57)	(0.06)	(0.17)	(0.11)
Δ Trend Sweden	−0.35	−0.10	−0.57***	−0.05
	(0.78)	(0.07)	(0.22)	(0.06)
Δ Trend Austria	−0.28	0.28***	0.39	0.28***
	(0.76)	(0.09)	(0.24)	(0.11)
Δ Trend Canada	−0.43	−0.19***	−0.22*	−0.04
	(0.54)	(0.07)	(0.12)	(0.05)
Δ Trend Other countries	−0.58	0.02	−0.32	−0.08
	(0.60)	(0.05)	(0.24)	(0.07)
Share of non-listed hotels	−0.43***	−0.25***	−0.29***	−0.34***
	(0.03)	(0.01)	(0.01)	(0.01)
Kayak hotel rating	−0.29	0.68	−0.71	−0.83
	(3.50)	(0.53)	(1.13)	(0.86)
GT city	−0.17***	−0.06***	−0.07***	−0.10***
	(0.03)	(0.00)	(0.01)	(0.00)
GT Booking.com	−0.16***	0.03***	−0.02***	0.05***
	(0.02)	(0.00)	(0.01)	(0.00)
7 days before	1.51***	0.15**	0.19**	−0.33***
	(0.26)	(0.06)	(0.08)	(0.07)
14 days before	2.01***	0.14**	0.58***	−0.09
	(0.28)	(0.07)	(0.09)	(0.09)
21 days before	2.23***	0.10	0.51***	0.09
	(0.32)	(0.08)	(0.10)	(0.09)
28 days before	2.56***	−0.09	0.54***	0.02
	(0.35)	(0.08)	(0.11)	(0.10)
Weekdays	Yes	Yes	Yes	Yes
Popularity other OTAs	Yes	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes	Yes
Observations	755,437	11,375,241	2,967,784	4,909,284
R^2	0.510	0.233	0.273	0.120
Adjusted R^2	0.509	0.232	0.273	0.119

Standard errors (clustered by hotel) not reported. Only observations of hotels included that have used the particular channel already at the beginning of the observation period. Dependent variables are equal to 100 if the particular channel is present at the Kayak request and 0 otherwise. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.7: Intensive channel use (if used at the beginning of observation period)

long-term trends that our Kayak data cannot fully capture. In 1.7.3 we elaborate on potential measurement errors in the Kayak data.

1.7.1 Potential Parallel Developments and Seasonality

Our identifying assumption for our empirical investigation is that the distinct development in Germany relative to the other countries is attributable to the removal of Booking.com's narrow BPC in Germany. In order to substantiate our claim that no other country-specific developments other than the BPC drive our result, we conduct the following robustness checks.

First, we address the possibility that country-specific seasonality is responsible for the observed results with a specification that allows more flexibly for country-specific seasonal developments than the linear trend. By estimating two-month indicators for each country, we can directly compare the base period of the beginning of 2016 with the first period in 2017. This comparison yields a seasonality-adjusted measure of our estimates. The results are comparable to those obtained for the linear trend specification (see Appendix G).

Second, we restrict the sample to the period January to July 2016 in order to look for short-term effects. In addition, we also focus on hotels that change their listing or pricing behavior and run regressions without hotel fixed effects. Again, the results are comparable to the main specification (see Appendix F).

Finally, we investigate the comparability of the initial listing frequencies of Booking.com in Germany and the control group. In the spirit of a matching approach, we show that the results concerning the listing frequencies of prices at Booking.com are also obtained when restricting the control group to cities which had a listing frequency that was comparable to the German cities initially in our observation period. This provides a strong indication that the developments in Germany are not just a simple "catch-up" process due to possibly different initial listing frequencies of hotels across countries (see Appendix E).

1.7.2 Long-Term Trends

The Kayak data that we use in our analysis covers the period January 2016 to January 2017. In order to address the concern that the developments found in our Kayak analysis might be due to longer term trends that started before our observation period, we also compare developments in the relevant outcomes for the different countries prior to our Kayak observation period.

To substantiate the finding that the ban of Booking.com's BPC in Germany led to an increase in hotel registrations on Booking.com, we collected registration dates of the hotels

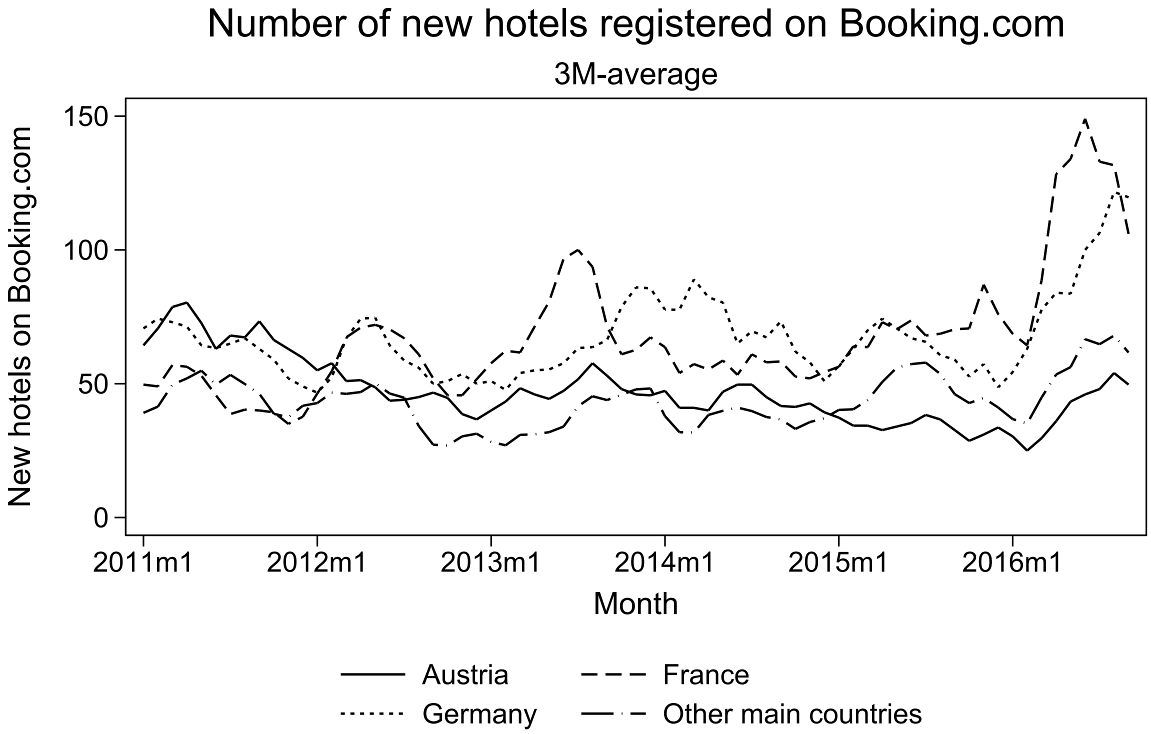

Figure 1.2: Number of new hotels registered on Booking.com (3 months moving average)

in our sample directly from Booking.com.[44] This allows us to study the development of registrations by hotels on Booking.com for Germany, Austria, France, and the other main countries as a moving three-month average in Figure 1.2. Similar to the Kayak data plots in Figure 1.1, there is a sharp increase in the number of newly registered hotels Germany in 2016. This increase is clearly higher than any increase in the previous five years. This also confirms that the evolution of listing frequencies as observed at the meta-search site Kayak is plausible. Another sharp increase can be observed slightly earlier in France. This might be related to the removal of all BPCs in France by law in the second half of 2015. More importantly, the graph suggests for the remainder that the developments of registrations are similar across time and countries.

Furthermore, we study the development of the popularity of Booking.com over time for each country in Figure 1.3. The graphs confirm that there is no obvious Germany-specific development in the popularity of Booking.com from the customer perspective, when comparing across time and country. This reassures us that our main results are not driven by a longer term trend which is not fully captured in our Kayak data.

[44]For this, we queried the website Booking.com directly for the same set of travel destinations in September 2016 over a time period of four weeks. We subsequently accessed the respective hotel profile websites on Booking.com and gathered the official entry date ("…has been welcoming Booking.com guests since…") as of the end of September.

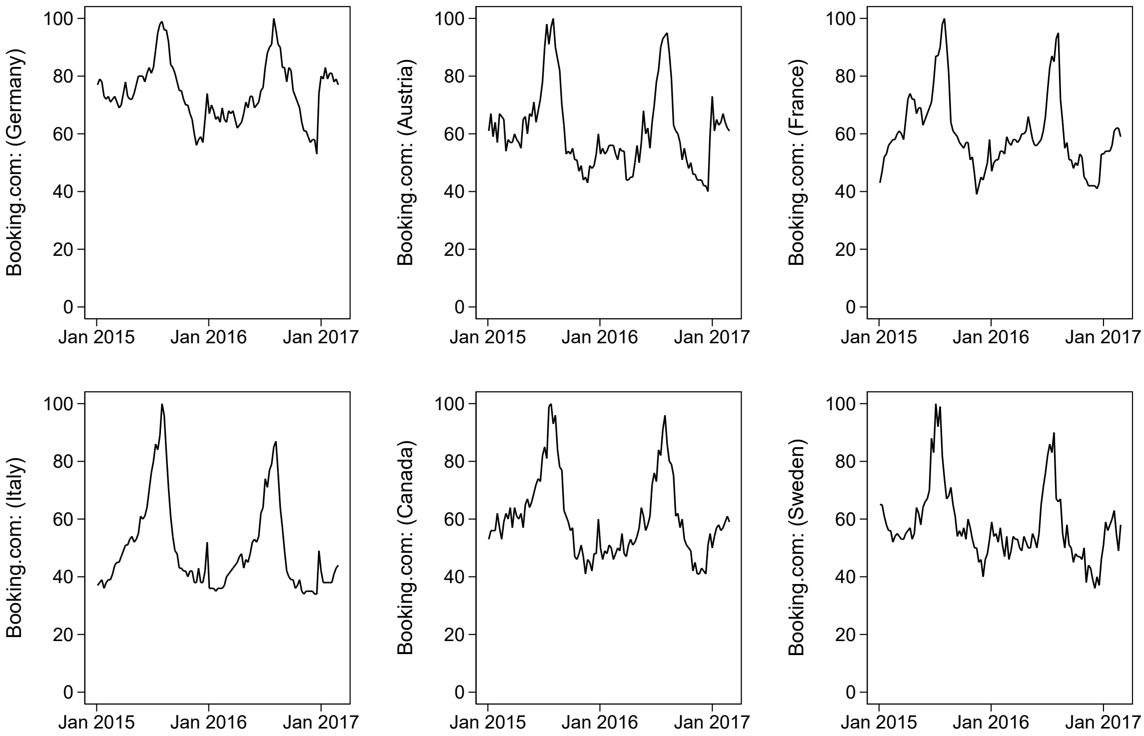

Figure 1.3: Relative search volume directed to Booking.com on Google

1.7.3 Measurement Error

One may be concerned about whether there is a potential measurement error in the Kayak prices. For example, in response to one of our Kayak requests, Kayak might return the up-to-date price of Booking.com but a slightly older price for the direct channel, where in the meantime the actual price has changed. To assess the potential impact of such a potential measurement error, recall that we conduct two different types of analysis:

1. We study whether a hotel makes any offers available on certain channels at a certain point in time at all or not (Section 1.6). For this analysis it is not critical whether Kayak compares exactly the same offers.

2. We compare prices across distribution channels (Section 1.5). For this analysis it is relevant that we can make a meaningful comparison.

In order to address the concern that the availability and price structure of hotel room offers as displayed at Kayak are measured accurately, we manually conducted a comparison of prices and qualitative features between hotel offers on `www.kayak.de` with the offers on the websites of the major OTAs. The comparison sample includes 171 booking requests for travel dates ranging from June to August 2016. With regard to the order of prices across channels, we find that the price leader among qualitatively comparable offers is correctly detected by Kayak in more than 90% of all cases. Furthermore, we have not found patterns in the deviations that indicate a favorable treatment of a particular channel by Kayak. For a detailed description of the validation analysis see Appendix C. Reassured by our checks, we eventually base our analysis on the assumption that Kayak is comparing equal offers with each other as this is the core of the business model of a price comparison site.

We cannot rule out, though, that there might still be differences across the offers in some of the cases even though Kayak posts these prices for comparison. Even if there are some differences across the offers, our analyses of the different price changes across countries are still valid as long as these unobserved differences between offers do not change over time in a way that is mistakenly interpreted as a change due to the BPCs. For instance, for the result of the direct channel having the strictly lowest price more often once the BPC has been removed to be flawed, it would need to be the case that Kayak in the year 2016 increasingly often wrongly presented the direct channel price as the lowest price, but only for hotels in Germany. We have no indication that the Kayak search results have this very particular bias.

1.8 Conclusion

Motivated by recent proceedings against best price clauses imposed by online travel agents, we have empirically investigated the effects of such clauses using the meta-search price data of nearly 30,000 hotels in various countries from January 2016 to January 2017. We capture the abolition of Booking.com's narrow BPC in Germany during our observation period, so that we are able to particularly address the competitive effects of narrow BPCs.

We have found that more hotels publish prices at Booking.com in Germany following the removal of the narrow BPC (extensive margin), and hotels which already used Booking.com before publish offers more frequently there (intensive margin). These are Germany-specific trends which distinctively differ from the main developments in the control group. In addition, more independent hotels, which initially did often not make direct channel prices available at Kayak, started doing so more often in Germany once the BPC of Booking.com had been removed. Consistent with having previously posted direct prices more often on Kayak, chain hotels in Germany increase the frequency of listing direct channel prices once the BPC is removed. These results indicate that hotels increasingly promote the direct channel when they are not constrained by Booking.com's narrow BPC.

We also find that once the BPCs had been removed in Germany, chain hotels more frequently set the direct online channel price below all other available online prices, as visible at Kayak. Again, this trend differs from the main developments in the control group. This suggests that Booking.com's narrow BPC did indeed restrict the hotels' price setting. We do not observe such a trend for independent hotels, which is consistent with the observation that independent hotels already initially had a direct channel price below the price of Booking.com much more often than chain hotels, indicating a higher non-compliance with BPCs.

More generally, across the different countries and BPC regimes, the observed direct channel prices are below the prices at Booking.com in a significant fraction of the cases. Even when accounting for the possibility that the Kayak data is imprecise to some degree, the numbers suggest that there could be a significant non-compliance with the existing price parity clauses. While the degree of non-compliance appears to be rather similar across the different European countries with narrow BPCs and without BPCs, it appears to be significantly lower in Canada – the only country in our data set where the major OTAs still use wide BPCs. This could be interpreted as an indication that the original wide BPCs are more effective in disciplining the price setting of hotels than the narrow clauses. To see this note that the narrow BPCs of Booking.com in Europe (and indirectly of Expedia which aligned its clauses) are the result of commitments that Booking.com gave to the competition authorities of France, Italy and Sweden. These commitments include certain clauses that prevent Booking.com from enforcing compliance with the narrow BPCs.[45] Moreover, the prominent policy actions against the OTAs might have discouraged OTAs in Europe from actually enforcing the clauses and similarly might have encouraged part of the hoteliers to not comply.

As prohibitions of BPCs generally aim at enhancing OTA competition, one would expect to observe changes in the commission rates that hotels have to pay for every mediated booking. Yet, to our knowledge, the standard commission rates of the major OTAs have not changed since the competition policy interventions in Europe.[46] One reason could be that the effects of BPCs are limited overall. To the extent that hotels did not comply with the parity clauses or that the clauses were not binding because hotels charged higher direct prices than OTA prices, it is natural that their abolition had limited effects. Another reason for why the standard commission rates have not yet changed could be that the (large) OTAs still have enough power to sustain such commission rates even without parity clauses. In addition, the OTAs might have incentives to not create evidence in the sense that commission rates decrease in countries without parity clauses in view of possible future competition law enforcement.

We see scope for more empirical research with respect to the best price clauses of online travel agents. Future empirical research should assess the long-term effects and welfare implications of BPCs, including the level of consumer prices as well as possible changes in the effective commission rates of online travel agents.

[45] Such measures could include e.g. de-listing of non-compliant hotels. See Section 4 of the Booking.com commitments (http://www.konkurrensverket.se/globalassets/english/news/13_596_bookingdotcom-commitment.pdf; last accessed December 1, 2017).

[46] See Appendix H for details.

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Appendix

Appendix A: Public Decisions with Respect to BPCs of OTAs

Date	Country	Decision body	Content	Reference
12/2013	Germany	Bundes-kartellamt	Prohibition	Decision of 20.12.2013, B 9 – 66/10 – HRS - Hotel Reservation Service
01/2014	UK	OFT	OFT decision	Decision 31.01.2014, OFT1514dec – Case reference CE/9320/10
04/2015	Sweden	Konkurrens-verket	Acceptance of Booking.com's commitment to at most narrow BPCs with effect of July 2015	Decision of 15.04.2015 – 596/2013 – Booking.com
"	France	Autorité de la concurrence	"	Decision of 21.04.2015 – 15-D-06 – Booking.com
"	Italy	Autorità Garante della Concorrenza e del Mercato	"	Decision of 21.04.2015 – I779 – Booking.com
2015	UK	Court decision	OFT decision was annulled on appeal on procedural grounds	CMA press release, 16.09.2015, CMA closes hotel online booking investigation.[a]
07/2015	EU/EEA	Expedia	Announces to use narrow BPCs in Europe	Expedia press release 01.07.2015; „Expedia Amends Rate, Conditions and Availability Parity Clauses".[b]
07/2015	France	French parliament	Law that prohibits BPCs for OTAs in France	„Loi Macron" 10.07.2015.[c]
12/2015	Germany	Bundes-kartellamt	Prohibitions of Booking.com's narrow BPCs by February 2016. Announcement to continue investigation with Expedia	Bundeskartellamt, decision of 23.12.2015, B 9-121/13 – Booking.com.
07/2016	Austria	Austrian parliament	Government bill to prohibit narrow BPCs for OTAs in Austria by January 2017	Nationalrat, decision of 18.10.2016 government bill (1251 d.B.)
11/2016	France	Tribunal de commerce de Paris	Prohibitions of availability parity clauses	Decision of 29.11.2016 - No. RG: 2014027403 - Booking.com

Table 1.8: List of public decisions with respect to BPCs

[a] https://www.gov.uk/government/news/cma-closes-hotel-online-booking-investigation (last access Dec. 1, 2017).

[b] http://www.expediainc.com/news-release/?aid=123242&fid=99&yy=2015 (last access Dec. 1, 2017).

[c] http://www.hotelnewsnow.com/Article/16460/Frances-end-to-rate-parity-creates-grey-areas (last access Dec. 1, 2017).

Country	Cities covered	Start
Germany	25 biggest cities	25/01/2016
Various	20 pairs of cities near German border	27/01/2016
Italy	15 biggest cities and 15 tourist destinations	10/02/2016
Sweden	15 biggest cities and 14 tourist destinations	12/02/2016
Canada	15 biggest cities and 15 tourist destinations	12/02/2016
France	15 biggest cities and 15 tourist destinations	18/02/2016
Austria	15 biggest cities and 15 tourist destinations	20/04/2016

Table 1.9: Countries covered in the data set

Appendix B: Additional Information About the Data Set

Countries and cities covered in the data set

There are three types of countries for which we collect data:

1. Countries without BPCs:
   (a) France (general prohibition of OTAs' BPCs by law in July 2015)
   (b) Germany (HRS prohibited in December 2013, Booking.com since February 2016; Expedia still has a narrow BPC)
   (c) Austria (narrow BPCs since July 2015, prohibition by January 2017, this had already been subject to public debate in 2016).
2. Narrow BPC countries: This includes nearly all other European Union (EU) member states as regards the major OTAs Booking.com and Expedia (see exceptions above). Our data captures mainly Italy and Sweden, as well as various cities close to the German border.
3. Wide BPC countries: Today only non-EU countries as regards at least the major OTAs Booking.com and Expedia. We have collected data for Canada.

Tables 1.9 until 1.13 show the selected countries and cities covered in our data set. Data collection started for the 25 biggest German cities (Table 1.10) and a control sample of 20 pairs of German and non-German cities along the German border (Table 1.11) in January 2016. In order to cover all three different BPC regimes in the data and to gather data for countries in which future decisions on BPC are possible, the additional countries depicted in Table 1.9 were subsequently included. For these countries, we chose a composition of the 15 biggest cities and 15 largest travel destinations with the objective to gather representative data across touristic and urban destinations for these countries.

Germany TOP 25 cities				
Berlin	Stuttgart	Leipzig	Bochum	Karlsruhe
Hamburg	Düsseldorf	Dresden	Wuppertal	Mannheim
Munich	Dortmund	Hanover	Bielefeld	Augsburg
Cologne	Essen	Nuremberg	Bonn	Wiesbaden
Frankfurt am Main	Bremen	Duisburg	Munster	Gelsenkirchen

Table 1.10: Germany - TOP 25 cities

Pair	German City	Non-German neighbor	Country of neighbor
1	Flensburg	Kolding	Denmark
2	Puttgarden/Fehmarn	Rodby	Denmark
3	Wilhelmshaven	Groningen	The Netherlands
4	Borkum	Schiermonnikoog	The Netherlands
5	Rheine	Enschede	The Netherlands
6	Aachen	Maastricht	The Netherlands
7	Heringsdorf	Wolin	Poland
8	Greifswald	Stettin	Poland
9	Cottbus	Zielona-Gora	Poland
10	Trier	Rosport	Luxembourg
11	Monschau	Eupen	Belgium
12	Pruem	St. Vith	Belgium
13	Saarbrücken	Metz	France
14	Karlsruhe	Strasbourg	France
15	Freiburg	Basel	Switzerland
16	Konstanz	St. Gallen	Switzerland
17	Oberstdorf	Bad Ischl	Austria
18	Garmisch-Partenkirchen	Innsbruck	Austria
19	Nuremberg	Pilsen	Czech Republic
20	Dresden	Prague	Czech Republic

Table 1.11: Twin cities along German border

Italy	Canada	France	Sweden	Austria
		Biggest Cities		
Rome	Toronto	Paris	Stockholm	Vienna
Milan	Montreal	Marseille	Göteborg	Graz
Naples	Vancouver	Lyon	Malmö	Linz
Turin	Calgary	Toulouse	Uppsala	Salzburg
Palermo	Edmonton	Nice	Västeras	Innsbruck
Genoa	Ottawa	Nantes	Örebro	Klagenfurt
Bologna	Québec	Strasbourg	Linköping	Villach
Florence	Winnipeg	Montpellier	Helsingborg	Wels
Bari	Hamilton	Bordeaux	Jönköping	St. Pölten
Catania	Kitchener	Lille	Norrköping	Dornbirn
Venice	London	Rennes	Lund	Wiener Neustadt
Verona	Victoria	Reims	Umea	Steyr
Messina	Saint Catharines	Le Havre	Gävle	Feldkirch
Padua	Halifax	Saint-Étienne	Boras	Bregenz
Trieste	Oshawa	Toulon	Eskilstuna	Leonding
		Tourist Destinations		
Lecce	Regina	Grenoble	Växjö	Zell am See
Viareggio	St. John's	Cannes	Lulea	Kitzbühel
Matera	Fredericton	Chambéry	Falun	Bad Hofgastein
Sanremo	Charlotte Town	Annecy	Varberg	Hermagor
Mantova	Whitehorse	Aix-les-Bains	Visby	Schladming
Vasto	Yellowknife	Menton	Ystad	Mittelberg
Merano	Niagara On The Lake	Albertville	Kiruna	Neustift
Caltagirone	Whistler	Bayeux	Strömstad	Bad Gastein
Montecatini Terme	Banff	Argelès-sur-Mer	Ronneby	Velden am Wörther See
Narni	Jasper	Chamonix	Jokkmokk	Finkenstein am Faaker See
Abano Terme	Tofino	Évian-les-Bains	Grebbestad	Kirchberg in Tirol
Ischia	Dawson City	Cavalaire-sur-Mer	Marstrand	St. Kanzian
Monte Argentario	Churchill	Saint-Gervais-les-Bains	Jukkasjärvi	Mayrhofen
San Felice Circeo	Bay of Fundy	Gruissan	Stöllet	Seefeld in Tirol
Santa Margherita Ligure	Thousand Islands National Park	Sainte-Marine		Sölden

Table 1.12: Cities covered in the data set

Country	Type	Source
Italy	Listing of health resorts	wikipedia.de
	Ten most popular beaches	telegraph.co.uk
	Beyond Rome and Florence: 12 alternative Italian destinations	cnn.com
Sweden	Top 10 Places in Sweden	neverstoptraveling.com
	Top 10 Green Attractions	visitsweden.com
Canada	Travelers Choice	tripadvisor.com
	Tourist attractions	planetware.com
	Places to Go	de-keepexploring.canada.travel
France	The top 10 beach holidays	telegraph.co.uk
	Travelers Choice Destinations	tripadvisor.com
	16 Top-Rated Tourist Attractions in the French Alps	planetware.com
Austria	Most popular winter destinations	austriatourism.at
	Most popular summer destinations	austriatourism.at

Table 1.13: Sources for travel destination selection

Selection of the Travel Destinations

For Italy, Sweden, Canada, France, and Austria we selected the travel destinations in two steps. First, we looked up the 15 biggest cities in terms of population on Wikipedia respectively. Additionally, for each country, we collected information about popular tourist destinations from travel guides and official tourism websites. We then ordered all these destinations by population and took again the 15 biggest locations. For Italy, France, Sweden, and Canada the websites were all accessed in January and February 2016. The Austrian cities were selected in April 2016 after the Austrian competition authority announced they proceed against the narrow BPC later in 2016.

The sources of the travel destinations can be found in Table 1.13.

Appendix C: Collection and Validation of the Data

Details About the Kayak Data

A typical search request at Kayak requires a travel destination, the travel dates, the number of travelers, and the number of rooms as inputs, for instance, two persons looking for one room in Rome for an overnight stay in two weeks from today. In response to a search request, Kayak displays a list of available hotels. For every hotel, Kayak lists the prices of the available sales channels.[47] We refer to the list of all available sales channels for a particular hotel at a particular travel date as a *Kayak request*.

[47] Also, Kayak sometimes includes itself in the list of hotel price offers. However, a click on the “Kayak offer” redirects to OTAs which also belong to the Priceline Group, such as Booking.com. Therefore,

We use the German edition of the Internet site www.kayak.de. We have done anecdotal checks and found that the offers which were available at Kayak.de were also available at Kayak websites in other languages, such as Kayak.fr. Kayak has been a subsidiary of the Priceline Group since 2013, which previously also acquired the online travel agencies Booking.com (2004) and Agoda.com (2007). We understand that Kayak derives revenues from advertising placements on its websites and mobile apps as well as from sending referrals to travel service providers, OTAs, and hotels.[48] Kayak sometimes presents a "Kayak" price. However, we found that this always corresponded to one of the other posted offers of, for instance, Booking.com.

Validation of the Kayak Data

Kayak's business model aims at comparing hotel room offers of different distribution channels. We understand that Kayak derives revenue from referring customers to the websites of OTAs or other booking providers. As such it should seek to offer customers a convenient and reliable comparison facility. In order to facilitate the comparison of hotel offers, Kayak collects general information on room types, bed types, and booking conditions from the different distribution channels and displays them to the customer when clicking on the detailed overview for one particular hotel. As mentioned in Section 1.3.1, in order to validate the accuracy of the offers listed on Kayak, we have compared prices and qualitative features of 171 hotels on Kayak with corresponding offers on the websites of the major OTAs and the hotel websites.

We generated our validation sample as follows. From all hotels that we observed in our data we took a random draw of 115 hotels. We augmented the sample with 56 hotels from Germany, Austria, and Sweden which we observed as frequently offering a direct sales channel on Kayak. We did this to obtain more observations with direct channel prices as well as HRS prices and to have a better coverage of the countries Germany, Austria, and Sweden. Consequently, the sample consists of observations from Canada, Italy, Sweden, Germany, Austria, and France plus a few observations for the Czech Republic, Switzerland, and Poland. For 40 hotels of our sample Kayak did not display any information during the enquiry period for various travel dates.

From the overview page for a particular hotel on Kayak, we obtain room rates for all available sales channels and information on room features (e.g., double bed) and booking conditions (e.g., free cancellation, free breakfast, etc.). In cases where Kayak displayed several offers for one single distribution channel (e.g., if Kayak displays the offers for a

whenever we observe a Kayak entry, we substitute it with the corresponding underlying Priceline OTA and eliminate potential duplicates.

[48]Priceline Group Inc. Annual Report 2015 (p.2). See http://ir.pricelinegroup.com/annuals.cfm (last accessed December 1, 2017). Hotels report that they have to pay a monthly fee for having their direct channel listed at Kayak, and also a fee whenever a Kayak user is forwarded to the hotels' website. Source: Phone interviews that we conducted with European hoteliers in 2016.

two-bed room and for a three-bed room on Expedia), we focus the analysis on the offer with the same qualitative features as on the other distribution channels. We used the forwarding links on the Kayak website to reach the corresponding offer on the OTAs and the hotel websites.

With the gathered data we conducted two kinds of consistency validations. First, we compare the prices and qualitative characteristics of a room offer on Kayak with the corresponding offer on the OTAs or on the hotel website. Second, we verify whether the price structure between the major OTAs and the direct sales channel shown on Kayak is consistent with the price structure on OTAs and hotel websites. In eight cases (9% of all observations with at least two distribution channels on Kayak) the qualitative features as displayed on Kayak differed across the distribution channels.[49] As prices are not comparable across channels in these cases, the observations are excluded from the analysis of the price structure.

As shown in Table 1.14 we observe that prices coincide in more than two-thirds of all observations on both sources. For this comparison, we have assumed that prices coincide if the difference amounts to less than 3 EUR in order to capture differences in rounding and exchange rates.[50] For deviating prices, the data suggest that prices on Kayak are most often higher than the prices on OTAs and websites and that only in a few cases are prices on Kayak lower than on the actual sales channel. The sales channel that is measured most accurately is the direct sales channel. On average, prices on Kayak and prices on the OTAs or the hotel websites deviate from each other by approximately 5 EUR. Comparing the room features and booking conditions on both sources, we found that this information on Kayak is identical to the information provided on the OTA or the hotel website, whenever rooms were available on both sources.

	N	Kayak price higher	Kayak price equal	Kayak price lower
Booking.com	106	26%	69%	5%
Expedia	64	34%	66%	0%
HRS	34	29%	68%	3%
Direct channel	51	12%	80%	8%

Table 1.14: Frequency of price deviations of Kayak from OTAs and hotel websites

In order to ensure comparability among sales channels in the second consistency validation, we only compared the hotel offers of different sales channels with each other if these

[49]Deviations are due to different cancellation policies or the inclusion of breakfast and do not seem to affect room offers or sales channels systematically.

[50]Expedia displays an exact amount including euros and cents for a hotel room, while Booking.com usually adjusts prices upwards to the next integer. Moreover, prices from Sweden or Canada sometimes were displayed in domestic currencies. For the sake of comparability, we converted the prices in EUR using the exchange rate of the booking date (www.finanzen.net/waehrungsrechner/; last accessed December 1, 2017).

offers were qualitatively identical. In more than 90% the offers find qualitatively comparable room offers regarding room features and booking conditions on the distribution channels. Among these offers we identify a price leadership whenever the lowest price is at least 1 EUR lower than the second lowest price. Table 1.15 shows that the information on whether one sales channel is the price leader (i.e., offers a price strictly lower than the second best and a qualitatively identical offer) is consistent between Kayak and the actual sales channels in approximately 90% of the cases. If there is a distinct price leader the average difference between the lowest price and the second lowest price is around 7.50 EUR both on Kayak and on the sales channels.

Price leadership	N	Price leadership consistent
Booking.com	67	93%
Expedia	50	91%
HRS	29	91%
Direct channel	39	89%

Table 1.15: Consistency of price leadership

Collection and Validation of the Google Trends Data

We also retrieve time series data from Google Trends for the time period January 2015 to January 2017 to approximate: 1) the popularity of different OTAs among customers, and 2) the tourism demand for hotels in particular cities. The data comprise the aggregated search volume of specific queries on Google over time. Similar data have already been used as a predictor of actual tourism data in other studies (Coyle and Yeung, 2016; Siliverstovs and Wochner, 2018).

For the first purpose, we collect weekly country-specific data for search queries directed to each of the OTA websites of Booking.com, Expedia, and HRS.[51] For the second purpose, we retrieve weekly data for the worldwide search queries consisting of the keywords "City Name + Hotel".[52] In order to validate the informative quality of the data, we gathered monthly occupancy rates for all German cities in our sample from the regional statistical offices. Accordingly, correlations with the corresponding Google Trends time series turn out to be positive and significant. As an illustration, we plot both time series in Figure 1.4 for four cities. For our regressions, we then disaggregate each time series inferred from Google Trends from a weekly to a daily level and merge by the search date of the Kayak request and the country or city respectively.

[51]In the case of Expedia, Google Trends provides two options for websites to which search queries are directed, which we both use and aggregate.

[52]For a few cities, where the search volume for this expression was so low that Google Trends does not provide it, we collected data on the search query "City Name."

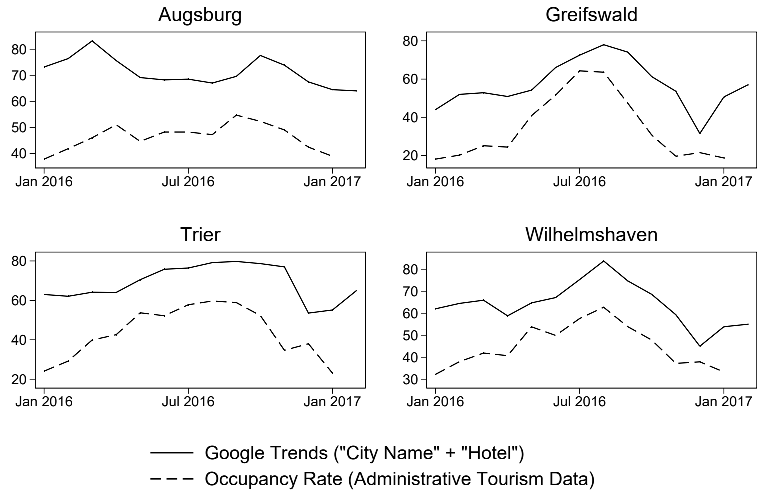

Figure 1.4: Google Trends “City Name + Hotel” and actual occupancy rates

Appendix D: More Details About Distribution Channels

Hotel features Across Distribution Channels

Table 1.16 compares the hotel features across distribution channels. In each column it reports the average hotel feature for the group of hotels that have used the particular distribution channel at least once. We observe that, generally, hotel features are comparable across distribution channels. Especially the dimensions that differ the most between hotel types exhibit less variation across distribution channels. In particular, for the independent hotels, the average number of rooms ranges between 32 and 66 rooms and the average number of ratings ranges between 474 and 857 ratings per hotel across the distribution channels. In contrast, chain hotels on all distribution channels are considerably larger (average number of rooms ranges between 123 and 137) and also have a higher number of ratings, which ranges on average between 1,259 and 1,594 across distribution channels. This finding is an indication that it is generally useful to distinguish between hotel types in order to consider more comparable hotel populations in terms of observed (and unobserved) characteristics in the analyses. We further note that when distinguishing between chain and independent hotels, the average characteristics of the respective hotels across countries are quite similar (country statistics not reported).

	Booking.com	Expedia	HRS	Direct
Independent hotels				
Number of rooms	32.10	37.23	48.17	66.33
Hotel category in stars	2.86	2.87	3.13	3.46
Kayak hotel rating	8.11	8.05	7.97	8.31
Number of ratings	474.03	599.34	749.16	856.56
Chain hotels				
Number of rooms	123.45	126.81	136.26	137.82
Hotel category in stars	3.24	3.28	3.44	3.30
Kayak hotel rating	7.92	7.92	8.01	7.90
Number of ratings	1259.39	1291.25	1594.28	1281.99

Table 1.16: Hotel characteristics by platform and hotel type

Definition of OTAs and Direct Sales Channels

In our data set, we observe 76 distinct sales channels that list hotel rooms on Kayak. These can be classified into OTAs like Booking.com and the direct hotel channel. Taking together all hotel offers out of all Kayak requests, we observe in total more than 108 million price offers. Table 1.17 lists the 15 most observed sales channels that account for almost 90% of all observed price offers. Booking.com is the most frequent channel in our data set accounting for 17% of all price observations.

Sales Channel	No.	%
BOOKINGDOTCOM	18,534,188	17.1
HOTELSDOTCOM	16,235,725	15.0
EXPEDIAHOTEL	16,208,094	15.0
EBOOKERSHOTEL	11,156,665	10.3
AGODA	5,420,055	5.0
HRS	5,338,770	4.9
HOTELRESERVIERUNG	4,350,524	4.0
HOTELOPIA	3,935,577	3.6
AMOMA	3,659,841	3.4
TRIPADVISOR	2,674,348	2.5
HOTELSCLICK	2,338,775	2.2
OTEL	2,003,584	1.8
LOWCOSTHOLIDAYS	1,361,933	1.3
TOURICO	1,310,164	1.2
VENERE	1,093,568	1.0
Total	108,411,643	100.0

Table 1.17: Sales channels observed on Kayak

It is noteworthy that the well-known OTAs Booking.com, Expedia, and HRS belong to company groups which own further OTAs (Table 1.21). Together the three company groups account for more than two-thirds of our price observations. For these Kayak requests in which two OTAs of the same company group are observed together (column 4), we computed how often the prices are identical (column 5).

As a benchmark, we also compared the primary OTAs Booking.com, Expedia and HRS in Tables 1.18 and 1.19. Table 1.18 shows how frequently the OTAs appear together in one Kayak request. For those Kayak requests in which two OTAs are observed together, we find that prices are equal in less than 50% (Table 1.19).

Table 1.18: Contingency of OTA listings

	Booking.com	Expedia	HRS
Booking.com	18,534,188		
Expedia	13,792,646	16,208,094	
HRS	4,669,818	4,305,990	5,338,770

	Booking.com	Expedia	HRS
Booking.com	100%		
Expedia	42%	100%	
HRS	52%	46%	100%

Table 1.19: Price coherence on major OTAs

We conducted the same analysis with OTAs belonging to the same company group. The OTA Agoda that belongs to the Priceline Group appears in more than 80% with the primary website Booking.com. For the OTAs belonging to Expedia Inc. (Hotels.com, Venere, ebookers) the mutual appearance with the primary website Expedia is at almost 100% of all observations. The Expedia website prices are also very often equal to the prices at Hotels.com and Venere,[53] which suggests treating them as one entity. For ebookers an abrupt change in pricing policy can be observed between May and June 2016. While ebookers used to have a price parity with Expedia in only 18% of all Kayak requests until May, this value increased in June and July to 90%. Therefore, Expedia and ebookers are also treated as one entity.

Interestingly, the correspondence between Booking.com and Agoda is quite low. As a consequence, we treat them as separate OTAs. Finally, we also treat HRS and Hotel.de as separate as the mutual appearance between HRS and Hotel.de is at only 39% and also the coherence is only moderate.

[53] Note that the OTA Venere is observed on Kayak only in January and February 2016.

Group	OTA	Share in total price listings	Appearance with primary website	Price coherence with primary website
Priceline	Booking.com	17%	100%	100%
	Agoda	5%	87%	38%
Expedia Inc.	Expedia	15%	100%	100%
	Hotels.com	15%	98%	90%
	Venere	1%	98%	98%
	ebookers	10%	98%	75%
HRS Robert Ragge GmbH	HRS	5%	100%	100%
	Hotel.de	1%	39%	71%

Table 1.21: Price coherence within company groups

Appendix E: Increase of Booking.com's Listing Frequency in Germany

The Booking.com price publication frequency in Germany starts from a considerably lower level than the frequencies in the other countries at the beginning of the observation period in 2016 (Figure 1.1). One might, therefore, wonder whether the increase in the publication frequencies of Booking.com in Germany can be fully attributed to the prohibition of its narrow BPC by the Bundeskartellamt.

An alternative hypothesis could be that Booking.com might have undergone a general catch-up process in regions where it was less established. To descriptively verify the robustness of our result, we conducted a comparison between the evolvement of Booking.com's listing frequency in Germany and in a control group. The control group consists of nine non-German cities that, on average, exhibit the same Booking.com listing frequency as can be observed in Germany at the beginning of 2016. The cities of the control group were selected as follows:

At the city-level, we computed for every month the average Booking.com frequency. Taking the nine non-German cities with the lowest Booking.com frequency in February yields approximately the same average Booking.com frequency as for Germany as a whole (74.5%, while 72.6% in Germany). These cities are Rome, Venice, Ischia (all Italy), Rodby (Denmark), Dawson City, Yellowknife, Gananoque (Ottawa), Tofino, St. Catharines (all Canada). Figure 1.5 shows how weekly Booking.com frequencies evolve over time for the two groups. In Germany the frequency increases sharply from 73% in February to 96% in June and July and remains at the same level for most of the remaining observation period. The listing frequency of the control sample has the same frequency level at the beginning of the year. But in contrast to Germany, the Booking.com frequency of the control sample does not show a similar increase and only fluctuates between 59% and 80% during the whole observation period.

Hence, we conclude from the comparison of Germany with a control sample consisting of nine cities from Europe and Canada that there is no general catch-up process in regions with low Booking.com frequencies that drives the development in Germany. In turn, this result is taken as supporting evidence that the abolition of Booking.com's BPCs in Germany can be contributed to the especially sharp increase of Booking.com listings in Germany.

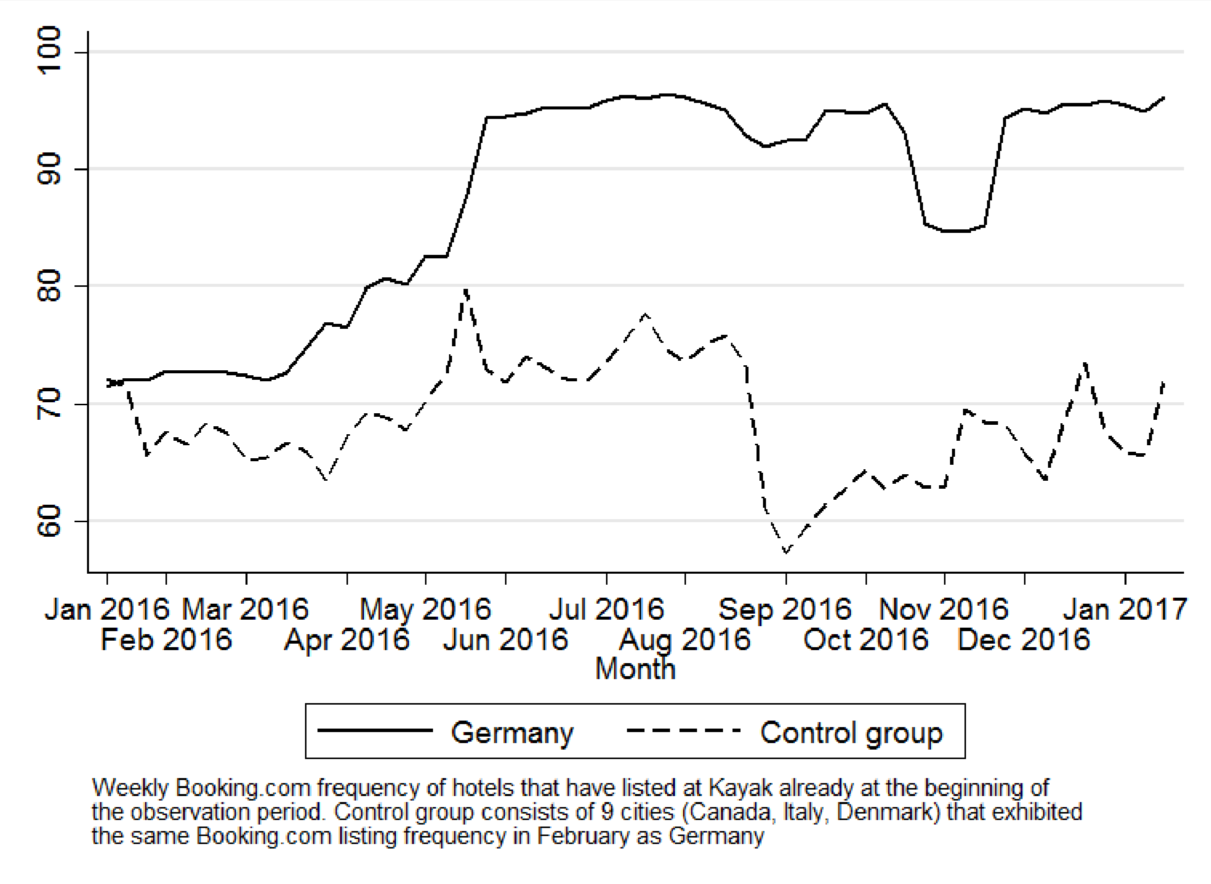

Figure 1.5: Booking.com frequency (Germany and control group)

A related regression on the intensive channel use of the direct channel and Booking.com with the control sample reveals the same result as in the descriptive representation. The intensive channel use of Booking.com increases significantly while the significant and negative trend deviations for the other countries show that the trend in the control sample is, in total, approximately zero.

	(1) Direct	(2) Booking.com
Trend (Base: Germany)	0.19***	2.32***
	(0.03)	(0.08)
Δ Trend Italy	−0.17***	−2.37***
	(0.04)	(0.14)
Δ Trend Canada	−0.06	−1.99***
	(0.19)	(0.38)
Δ Trend Denmark	−0.72***	−4.08***
	(0.10)	(0.17)
Share of non-listed hotels	−0.08***	−0.23***
	(0.00)	(0.01)
Kayak hotel rating	0.08	2.49**
	(0.34)	(1.27)
GT city	−0.01***	−0.04***
	(0.00)	(0.01)
GT Booking.com	−0.00	0.25***
	(0.00)	(0.01)
7 days before	0.05	−0.13
	(0.03)	(0.08)
14 days before	0.08**	0.04
	(0.03)	(0.09)
21 days before	0.11***	0.25**
	(0.04)	(0.10)
28 days before	0.13***	0.50***
	(0.04)	(0.11)
Weekdays	Yes	Yes
Popularity other OTAs	Yes	Yes
Hotel FE	Yes	Yes
Observations	6,515,918	6,515,918
R^2	0.880	0.404
Adjusted R^2	0.880	0.404

Standard errors (clustered by hotel) in parentheses. Dependent variables are equal to 100 if the particular channel is present at Kayak request and 0 otherwise. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.22: Intensive channel use

Appendix F: Split Samples and Hotel Characteristics

We test the robustness of our main regression results concerning three variations to the main specification (Table 1.23 to Table 1.28). Column 1 reports the main specification as in Sections 1.5 and 1.6 for comparison. In general, we find that our results are robust with respect to different specifications.

In column 2, we restrict the observation period to the time frame between January 2016 and July 2016. Recall from Figure 1.1 that we observe a strong adaption process of the

Booking.com listing frequency shortly after the removal of the narrow BPC. In line with this observation, the regression coefficients for the German-specific trend for our main dependent variables of interest are larger in magnitude than the coefficients for the main regression which takes data until January 2017 into account.

There is a share of hotels that exhibit no variation in the dependent variables during the observation period. Therefore, in column 3 we seek to identify the fraction of hotels that indeed react to the removal of Booking.com's narrow BPC in Germany by changing their listing or pricing *strategy*.[54] To do so, we drop all observations from hotels that do not change their strategy during the observation period. By definition, these hotels exhibit a zero time trend and we find that coefficients are larger in magnitude than those in the main regressions.

Finally, in column 4, we report the main regression without hotel fixed effects. In turn, we are able to include the time-invariant observed hotel characteristics, like the number of rooms and the stars.[55] Even though the significance level and the sign of the coefficients generally coincide with the main regression, we find differences in the magnitude of the coefficients. This finding reassures us that we are able to capture unobserved heterogeneity by employing hotel fixed effects.

[54]For the regressions on the Kayak request level (intensive channel use and price leadership) the share of hotels that does not change their *strategy* ranges between 0.1% (direct channel as price leader) and 12% (Booking.com as distribution channel). For the regressions on the extensive channel use these figures are considerably higher as the unit of observation is on the hotel-month level. Accordingly, all hotels that use, for example, Booking.com at least once every month, in which we observe them, exhibit no variation in the dependent variable "Extensive Booking.com use." Only 5% (Booking.com) and 18% (direct channel) of all hotel-month observations exhibit variation in this respect.

[55]The time-invariant characteristics are centered around the mean.

	(1) Main reg.	(2) Until July	(3) Strategy	(4) No FE
Trend (Base: Germany)	0.30***	1.47***	0.30***	0.33***
	(0.09)	(0.18)	(0.09)	(0.10)
Δ Trend France	−0.69***	−1.11***	−0.70***	−0.76***
	(0.12)	(0.23)	(0.12)	(0.13)
Δ Trend Italy	−0.35**	−0.88***	−0.35**	−0.53***
	(0.17)	(0.29)	(0.17)	(0.19)
Δ Trend Sweden	−1.66***	−2.59***	−1.66***	−1.62***
	(0.29)	(0.42)	(0.29)	(0.27)
Δ Trend Austria	−0.34	−0.62	−0.34	−1.25***
	(0.22)	(0.49)	(0.22)	(0.32)
Δ Trend Canada	−0.20*	−0.98***	−0.20*	−0.39***
	(0.11)	(0.21)	(0.11)	(0.12)
Δ Trend Other countries	−0.50***	−0.73**	−0.50***	−0.70***
	(0.18)	(0.34)	(0.18)	(0.22)
Share of non-listed hotels	0.02**	0.02***	0.02**	0.10***
	(0.01)	(0.01)	(0.01)	(0.02)
Kayak hotel rating (centered)	0.40	−0.63	0.37	3.80***
	(1.01)	(1.30)	(1.01)	(0.58)
GT city	0.03***	0.02*	0.03***	0.01
	(0.01)	(0.01)	(0.01)	(0.02)
GT Booking.com	0.01	−0.06***	0.01	−0.00
	(0.01)	(0.01)	(0.01)	(0.01)
France				7.88***
				(1.44)
Italy				−0.47
				(1.82)
Sweden				11.84***
				(2.73)
Austria				10.16***
				(3.31)
Canada				−0.50
				(1.21)
Other countries				3.00
				(2.52)
Hotel category in stars (centered)				−0.93*
				(0.53)
Number of rooms (centered)				−0.03***
				(0.00)
Constant				6.47***
				(2.46)
Weekdays	Yes	Yes	Yes	Yes
Days before travel date	Yes	Yes	Yes	Yes
Popularity other OTAs	Yes	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes	No
Observations	2,968,019	1,792,366	2,964,607	2,921,753
R^2	0.426	0.461	0.426	0.028
Adjusted R^2	0.425	0.460	0.425	0.028

Standard errors (clustered by hotel) in parentheses. (1) is the regression from the main analysis aggregated for all hotel types. (2) only contains data until (end of) July 2016. (3) excludes all hotels that exhibit no variation in the dep. variable ("strategy"). (4) includes no hotel fixed effects and controls for all observed hotel characteristics that are centered around the mean. The dep. variable is equal to 100 if direct channel is price leader and 0 otherwise. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.23: Robustness check – Price leadership of direct channel

	(1) Main reg.	(2) Until July	(3) Strategy	(4) No FE
Trend (Base: Germany)	−0.14***	−0.35***	−0.14***	−0.21***
	(0.04)	(0.07)	(0.04)	(0.04)
Δ Trend France	0.22***	0.30***	0.22***	0.16***
	(0.06)	(0.11)	(0.06)	(0.06)
Δ Trend Italy	0.27***	−0.29**	0.27***	0.33***
	(0.07)	(0.13)	(0.07)	(0.08)
Δ Trend Sweden	0.07	−1.10***	0.07	−0.01
	(0.11)	(0.27)	(0.11)	(0.13)
Δ Trend Austria	−0.28***	−0.79***	−0.28***	−0.22
	(0.10)	(0.28)	(0.10)	(0.15)
Δ Trend Canada	0.09	−0.11	0.08	0.18**
	(0.08)	(0.14)	(0.08)	(0.08)
Δ Trend Other countries	0.40***	−0.12	0.40***	0.19
	(0.12)	(0.20)	(0.12)	(0.16)
Share of non-listed hotels	−0.02**	−0.00	−0.01**	−0.07***
	(0.01)	(0.01)	(0.01)	(0.01)
Kayak hotel rating (centered)	2.20***	2.44**	2.17***	0.43
	(0.82)	(1.04)	(0.82)	(0.27)
GT city	0.02***	0.02***	0.02***	−0.04***
	(0.01)	(0.01)	(0.01)	(0.01)
GT Booking.com	0.16***	0.17***	0.16***	0.18***
	(0.01)	(0.01)	(0.01)	(0.01)
France				3.61***
				(0.63)
Italy				2.78***
				(0.66)
Sweden				4.27***
				(1.15)
Austria				7.30***
				(1.60)
Canada				5.78***
				(0.68)
Other countries				3.80***
				(1.26)
Hotel category in stars (centered)				−0.88***
				(0.21)
Number of rooms (centered)				−0.01***
				(0.00)
Constant				3.12***
				(1.19)
Weekdays	Yes	Yes	Yes	Yes
Days before travel date	Yes	Yes	Yes	Yes
Popularity other OTAs	Yes	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes	No
Observations	2,904,221	1,762,803	2,889,402	2,857,448
R^2	0.147	0.165	0.144	0.022
Adjusted R^2	0.146	0.164	0.143	0.022

Standard errors (clustered by hotel) in parentheses. (1) is the regression from the main analysis aggregated for all hotel types. (2) only contains data until (end of) July 2016. (3) excludes all hotels that exhibit no variation in the dep. variable ("strategy"). (4) includes no hotel fixed effects and controls for all observed hotel characteristics that are centered around the mean. The dep. variable is equal to 100 if Booking.com is price leader and 0 otherwise. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.24: Robustness check – Price leadership of Booking.com

	(1) Main reg.	(2) Until July	(3) Strategy	(4) No FE
Trend (Base: Germany)	0.06***	0.23***	1.50***	0.45***
	(0.02)	(0.04)	(0.54)	(0.05)
Δ Trend France	0.05	−0.16**	−0.20	−0.05
	(0.04)	(0.07)	(0.65)	(0.05)
Δ Trend Italy	−0.12***	−0.35***	−3.04***	−0.27***
	(0.03)	(0.06)	(0.71)	(0.03)
Δ Trend Sweden	−0.10	−0.33***	−2.83	−0.32***
	(0.06)	(0.09)	(1.88)	(0.08)
Δ Trend Austria	−0.02	0.66***	−0.94	−0.15*
	(0.06)	(0.16)	(0.92)	(0.09)
Δ Trend Canada	−0.08*	−0.16*	−1.77*	−0.13*
	(0.04)	(0.09)	(1.07)	(0.07)
Δ Trend Other countries	−0.01	−0.20**	−0.07	−0.13**
	(0.05)	(0.08)	(1.26)	(0.06)
Avg. share of non-listed hotels	−0.00	0.00	−0.13	−0.08***
	(0.00)	(0.01)	(0.13)	(0.02)
Avg. Kayak hotel rating (centered)	0.36	0.38	9.37	−0.20
	(0.24)	(0.30)	(7.07)	(0.23)
Avg. GT city	0.00	−0.00	0.04	0.11***
	(0.00)	(0.00)	(0.06)	(0.01)
Avg. GT Booking.com	−0.00*	−0.01**	−0.08	−0.08***
	(0.00)	(0.01)	(0.05)	(0.01)
France				13.77***
				(0.80)
Italy				1.25**
				(0.61)
Sweden				2.55
				(1.74)
Austria				4.25***
				(1.07)
Canada				19.32***
				(1.20)
Other countries				−0.07
				(1.09)
Hotel category in stars (centered)				5.16***
				(0.33)
Number of rooms (centered)				0.16***
				(0.01)
Constant				8.76***
				(2.42)
Weekdays	No	No	No	No
Days before travel date	No	No	No	No
Popularity other OTAs	Yes	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes	No
Observations	283,389	150,446	13,443	272,856
R^2	0.946	0.958	0.379	0.203
Adjusted R^2	0.940	0.949	0.319	0.203

Standard errors (clustered by hotel) in parentheses. (1) is the regression from the main analysis aggregated for all hotel types. (2) only contains data until (end of) July 2016. (3) excludes all hotels that exhibit no variation in the dep. variable ("strategy"). (4) includes no hotel fixed effects and controls for all observed hotel characteristics that are centered around the mean. The dep. variable is equal to 100 for all months in which a hotel used the direct channel at least once and 0 otherwise. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.25: Robustness check – Extensive direct channel use

	(1) Main reg.	(2) Until July	(3) Strategy	(4) No FE
Trend (Base: Germany)	1.80***	4.16***	7.20***	1.61***
	(0.06)	(0.13)	(0.16)	(0.05)
Δ Trend France	−0.92***	−1.87***	−1.74***	−0.84***
	(0.07)	(0.16)	(0.23)	(0.07)
Δ Trend Italy	−0.21***	0.13	−0.79***	−0.19***
	(0.07)	(0.17)	(0.20)	(0.07)
Δ Trend Sweden	−1.97***	−3.50***	−8.53***	−1.87***
	(0.07)	(0.13)	(0.91)	(0.07)
Δ Trend Austria	−1.08***	−1.97***	−1.83***	−0.97***
	(0.08)	(0.24)	(0.42)	(0.09)
Δ Trend Canada	−1.82***	−3.30***	−7.23***	−1.69***
	(0.06)	(0.13)	(0.52)	(0.07)
Δ Trend Other countries	−1.80***	−3.55***	−6.59***	−1.70***
	(0.06)	(0.14)	(0.46)	(0.06)
Avg. share of non-listed hotels	−0.11***	−0.26***	−0.94***	−0.07***
	(0.01)	(0.02)	(0.07)	(0.01)
Avg. Kayak hotel rating (centered)	1.57***	1.96**	4.94***	1.69***
	(0.50)	(0.81)	(1.70)	(0.15)
Avg. GT city	−0.03***	0.00	−0.03*	−0.05***
	(0.00)	(0.01)	(0.02)	(0.00)
Avg. GT Booking.com	0.14***	−0.08***	0.97***	0.18***
	(0.00)	(0.01)	(0.02)	(0.00)
France				12.39***
				(0.69)
Italy				3.26***
				(0.65)
Sweden				24.36***
				(0.78)
Austria				16.13***
				(0.86)
Canada				18.00***
				(0.69)
Other countries				21.37***
				(0.62)
Hotel category in stars (centered)				−0.24*
				(0.13)
Number of rooms (centered)				0.00
				(0.00)
Constant				60.82***
				(1.52)
Weekdays	No	No	No	No
Days before travel date	No	No	No	No
Popularity other OTAs	Yes	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes	No
Observations	283,389	150,446	51,082	272,856
R^2	0.516	0.631	0.405	0.057
Adjusted R^2	0.462	0.550	0.345	0.057

Standard errors (clustered by hotel) in parentheses. (1) is the regression from the main analysis aggregated for all hotel types. (2) only contains data until (end of) July 2016. (3) excludes all hotels that exhibit no variation in the dep. variable ("strategy"). (4) includes no hotel fixed effects and controls for all observed hotel characteristics that are centered around the mean. The dep. variable is equal to 100 for all months in which a hotel used Booking.com at least once and 0 otherwise. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.26: Robustness check – Extensive Booking.com use

	(1) Main reg.	(2) Until July	(3) Strategy	(4) No FE
Trend (Base: Germany)	0.36***	0.54***	0.36***	0.20*
	(0.10)	(0.18)	(0.10)	(0.11)
Δ Trend France	−0.59***	−2.30***	−0.59***	−0.26**
	(0.12)	(0.24)	(0.12)	(0.13)
Δ Trend Italy	−1.33***	−3.77***	−1.34***	−1.11***
	(0.20)	(0.45)	(0.20)	(0.21)
Δ Trend Sweden	−0.65***	−1.45***	−0.65***	−0.55**
	(0.24)	(0.32)	(0.24)	(0.26)
Δ Trend Austria	−0.15	0.09	−0.15	0.62*
	(0.28)	(0.72)	(0.28)	(0.38)
Δ Trend Canada	−0.32**	−1.28***	−0.32**	−0.27*
	(0.12)	(0.24)	(0.12)	(0.14)
Δ Trend Other countries	−0.92***	−2.83***	−0.92***	−1.01***
	(0.26)	(0.53)	(0.26)	(0.33)
Share of non-listed hotels	−0.31***	−0.31***	−0.32***	−0.17***
	(0.01)	(0.01)	(0.01)	(0.02)
Kayak hotel rating (centered)	−1.14	0.89	−1.13	1.69***
	(1.24)	(1.39)	(1.25)	(0.63)
GT city	−0.09***	−0.07***	−0.09***	−0.07***
	(0.01)	(0.01)	(0.01)	(0.02)
GT Booking.com	−0.06***	0.03***	−0.06***	−0.07***
	(0.01)	(0.01)	(0.01)	(0.01)
France				4.10***
				(0.89)
Italy				−0.81
				(1.22)
Sweden				2.58*
				(1.43)
Austria				−10.68***
				(3.16)
Canada				4.89***
				(0.84)
Other countries				0.91
				(1.57)
Hotel category in stars (centered)				−0.13
				(0.48)
Number of rooms (centered)				0.02***
				(0.00)
Constant				99.85***
				(2.00)
Weekdays	Yes	Yes	Yes	Yes
Days before travel date	Yes	Yes	Yes	Yes
Popularity other OTAs	Yes	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes	No
Observations	3,723,221	2,270,745	3,715,121	3,651,769
R^2	0.403	0.326	0.402	0.039
Adjusted R^2	0.402	0.325	0.402	0.039

Standard errors (clustered by hotel) in parentheses. (1) is the regression from the main analysis aggregated for all hotel types. (2) only contains data until (end of) July 2016. (3) excludes all hotels that exhibit no variation in the dep. variable ("strategy"). (4) includes no hotel fixed effects and controls for all observed hotel characteristics that are centered around the mean. The dep. variable is equal to 100 if direct channel is present at Kayak request and 0 otherwise. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.27: Robustness check – Intensive direct channel use

	(1) Main reg.	(2) Until July	(3) Strategy	(4) No FE
Trend (Base: Germany)	0.26***	0.35***	0.31***	0.11***
	(0.03)	(0.04)	(0.03)	(0.03)
Δ Trend France	−0.24***	−0.37***	−0.26***	−0.10**
	(0.04)	(0.06)	(0.04)	(0.04)
Δ Trend Italy	−0.61***	−1.22***	−0.67***	−0.51***
	(0.05)	(0.08)	(0.06)	(0.05)
Δ Trend Sweden	−0.04	−0.88***	−0.04	0.07
	(0.05)	(0.08)	(0.05)	(0.05)
Δ Trend Austria	0.26***	−0.59***	0.34***	0.30***
	(0.07)	(0.15)	(0.08)	(0.09)
Δ Trend Canada	−0.09**	−1.08***	−0.09**	0.12***
	(0.04)	(0.08)	(0.05)	(0.04)
Δ Trend Other countries	−0.03	−0.85***	−0.05	0.05
	(0.04)	(0.07)	(0.05)	(0.04)
Share of non-listed hotels	−0.28***	−0.27***	−0.33***	−0.20***
	(0.00)	(0.00)	(0.01)	(0.01)
Kayak hotel rating (centered)	0.39	1.18**	0.45	−0.33***
	(0.46)	(0.60)	(0.53)	(0.12)
GT city	−0.07***	0.00	−0.08***	−0.09***
	(0.00)	(0.00)	(0.00)	(0.00)
GT Booking.com	0.03***	0.08***	0.04***	0.04***
	(0.00)	(0.00)	(0.00)	(0.00)
France				2.94***
				(0.33)
Italy				0.17
				(0.41)
Sweden				−3.68***
				(0.41)
Austria				0.24
				(0.75)
Canada				−1.33***
				(0.35)
Other countries				0.22
				(0.36)
Hotel category in stars (centered)				0.78***
				(0.12)
Number of rooms (centered)				0.00*
				(0.00)
Constant				105.73***
				(0.58)
Weekdays	Yes	Yes	Yes	Yes
Days before travel date	Yes	Yes	Yes	Yes
Popularity other OTAs	Yes	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes	No
Observations	16,284,525	10,025,115	14,293,638	15,916,558
R^2	0.207	0.224	0.199	0.033
Adjusted R^2	0.206	0.222	0.198	0.033

Standard errors (clustered by hotel) in parentheses. (1) is the regression from the main analysis aggregated for all hotel types. (2) only contains data until (end of) July 2016. (3) excludes all hotels that exhibit no variation in the dep. variable ("strategy"). (4) includes no hotel fixed effects and controls for observed hotel characteristics that are centered around the mean. The dep. variable is equal to 100 if Booking.com is present at Kayak request and 0 otherwise. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.28: Robustness check – Intensive Booking.com use

Appendix G: Accounting for Seasonality with Two-Month Indicators

In this robustness check we run our main regressions with two-month indicators instead of a country-specific linear time trend. With this specification that pools independent and chain hotels together, we allow for country-specific seasonality that goes beyond the main specification with the linear time trend. Moreover, we can compare the realizations of the dependent variables between the reference period (January 2016 and February 2016) to the beginning of 2017, which yields a seasonality-corrected measure of our estimates. We use both January and February 2016 as reference period because we only have a limited coverage of January 2016. We compare this with January 2017 as our data set does not cover February 2017. For the countries of comparison we only report the estimation results for January 2017, which allows us to verify that the materialization of the dependent variable at the end of our observation period generally coincides with the predictions of the linear time trend. The results are in Tables 1.29 and 1.30. The comparison to the results of the main regressions (which are reported in Tables 1.5, 1.6 and 1.7) verifies that the results are robust to a more flexible specification that allows for country-specific seasonal trends. We conclude that the linear trend is an informative statistic for aggregating the development of the dependent variables in the countries of investigation.

	(1) Ext. use	(2) Int. use	(3) Price leader
March April 2016	1.16***	−0.23	1.62***
	(0.13)	(0.65)	(0.44)
May June 2016	1.12***	1.37**	5.22***
	(0.16)	(0.69)	(0.75)
July August 2016	0.99***	1.47*	4.91***
	(0.21)	(0.81)	(0.79)
September October 2016	1.18***	1.35	4.67***
	(0.22)	(0.85)	(0.78)
November December 2016	1.38***	3.53***	2.38***
	(0.25)	(0.90)	(0.90)
January 2017	0.83***	2.55***	3.83***
	(0.27)	(0.95)	(1.10)
January 2017 × France	0.80*	−8.94***	−4.37***
	(0.48)	(1.28)	(1.36)
January 2017 × Italy	−1.40***	−15.79***	−3.88**
	(0.34)	(2.06)	(1.81)
January 2017 × Sweden	−1.34*	−6.79**	−3.67*
	(0.75)	(2.74)	(2.04)
January 2017 × Austria	1.43	13.46***	−0.01
	(1.16)	(4.34)	(2.55)
January 2017 × Canada	−0.89*	−2.43**	−4.08***
	(0.50)	(1.24)	(1.28)
January 2017 × Other countries	−0.45	−8.85***	−5.20**
	(0.56)	(3.00)	(2.11)
Avg. share of non-listed hotels	−0.00		
	(0.00)		
Avg. Kayak hotel rating	0.35		
	(0.24)		
Avg. GT city	0.01**		
	(0.00)		
Avg. GT Booking.com	−0.00		
	(0.00)		
Share of non-listed hotels		−0.32***	0.04***
		(0.01)	(0.01)
Kayak hotel rating		−1.21	0.47
		(1.24)	(1.01)
GT city		−0.05***	0.03***
		(0.01)	(0.01)
GT Booking.com		−0.01	0.01*
		(0.01)	(0.01)
Weekdays	No	Yes	Yes
Days before travel date	No	Yes	Yes
Other two-month-country interactions	Yes	Yes	Yes
Popularity other OTAs	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes
Observations	283,389	3,723,221	2,968,019
R^2	0.946	0.406	0.427
Adjusted R^2	0.941	0.405	0.427

Standard errors (clustered by hotel) in parentheses. The data are aggregated for all hotel types. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.29: Two-month regressions direct channel

	(1) Ext. use	(2) Int. use	(3) Price leader
March April 2016	1.35***	−0.57***	−0.05
	(0.20)	(0.19)	(0.24)
May June 2016	16.80***	−0.16	−1.03***
	(0.53)	(0.18)	(0.27)
July August 2016	16.73***	2.05***	2.50***
	(0.57)	(0.17)	(0.37)
September October 2016	17.91***	1.65***	−0.81**
	(0.57)	(0.21)	(0.38)
November December 2016	15.50***	−1.61***	−0.24
	(0.63)	(0.49)	(0.45)
January 2017	16.38***	3.72***	−2.39***
	(0.60)	(0.26)	(0.43)
January 2017 × France	−6.84***	−5.71***	0.07
	(0.76)	(0.37)	(0.69)
January 2017 × Italy	−4.13***	−6.81***	3.20***
	(0.77)	(0.50)	(0.97)
January 2017 × Sweden	−14.94***	−1.69**	−2.16
	(0.72)	(0.67)	(1.40)
January 2017 × Austria	−11.91***	1.10	−6.09***
	(1.45)	(0.89)	(1.46)
January 2017 × Canada	−16.88***	−1.16**	−2.83***
	(0.71)	(0.46)	(0.88)
January 2017 × Other countries	−16.02***	1.85***	4.32***
	(0.64)	(0.43)	(1.62)
Avg. share of non-listed hotels	−0.02**		
	(0.01)		
Avg. Kayak hotel rating	1.57***		
	(0.50)		
Avg. GT city	−0.01***		
	(0.00)		
Avg. GT Booking.com	0.03***		
	(0.01)		
Share of non-listed hotels		−0.27***	−0.03***
		(0.00)	(0.01)
Kayak hotel rating		0.56	1.83**
		(0.46)	(0.82)
GT city		−0.05***	0.02***
		(0.00)	(0.01)
GT Booking.com		0.02***	0.07***
		(0.00)	(0.01)
Weekdays	No	Yes	Yes
Days before travel date	No	Yes	Yes
Other two-month-country interactions	Yes	Yes	Yes
Popularity other OTAs	Yes	Yes	Yes
Hotel FE	Yes	Yes	Yes
Observations	283,389	16,284,525	2,904,221
R^2	0.530	0.209	0.150
Adjusted R^2	0.478	0.208	0.149

Standard errors (clustered by hotel) in parentheses. The data are aggregated for all hotel types. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.30: Two-month regressions Booking.com

Appendix H: Evidence on Commission Rates of OTAs

We understand that major OTAs such as Booking.com and Expedia use an agency model where hotels set room prices on the OTA and pay a commission to the OTA for every realized booking via the OTA. We understand that effective commissions are determined by a standard rate plus an additional fee if hotels want to appear higher in the OTA's ranking.[56] The interventions against BPCs aimed at removing restraints of competition among OTAs in commission rates. However, the recent interventions have not obviously led to significant changes in the OTAs' commission rates so far. A recent Europe-wide survey by HOTREC finds that for more than 90% of all hotels the effective commission rates have not decreased over the past one year.[57] Our anecdotal examination (including interviews with hoteliers) in the course of 2016 indicates that the basis commission rates of the major OTAs range between 12% and 18% in Europe. While we took note of basis commissions of 15% at Expedia and HRS, Booking.com's basis commissions apparently vary across destinations (see Table 1.31 for the observations). Similarly, the Bundeskartellamt reported in the decisions regarding HRS[58] and Booking.com[59] that in 2013 and in 2015 the major OTAs' basis commission rates ranged from 10% to 15%. This also indicates that in Germany (basis) commissions have not changed in recent years.

Düsseldorf	Berlin	Termoli	Rome	Orebro	Stockholm	Toulouse	Paris
12%	15%	15%	18%	15%	15%	17%	15%

Table 1.31: Booking.com's standard commissions by destination

According to the Bundeskartellamt, effective commissions can account for up to 50% of the room price.[60] In 2015, the German hotel association estimated average commission payments to range between 20% and 25%.[61]

[56]For example via Expedia's hotel accelerator program that sells higher ranking positions by auction (see https://skift.com/2016/03/03/first-look-at-expedias-hotel-accelerator-program-for-improving-hotel-placement/; last accessed December 1, 2017) or Booking.com's preferred partner program (see http://www.booking.com/content/hotel-help.de.html; last accessed December 1, 2017).

[57]HOTREC survey on online platforms of 2016 (see http://www.hotrec.eu/newsroom/press-releases-1714/dominant-online-platforms-gaining-market-share-in-travel-trade-no-signs-of-increased-competition-between-online-travel-agents-unveils-european-hotel-distribution-study.aspx; last accessed December 1, 2017).

[58]Bundeskartellamt (2013) B9-66-10 Par. 225

[59]Bundeskartellamt (2015) B9-121-13 Par. 18.

[60]Bundeskartellamt (2015) B9-121-13 Par. 2.

[61]Statement of the German hotel association from August 31, 2015, according to Bundeskartellamt (2015) B9-121-13, Footnote 414.

Chapter 2

Managing Seller Conduct in Online Marketplaces and Platform Most-Favored Nation Clauses

2.1 Introduction

In an increasingly digitalized economy, consumers can purchase a wide range of goods and services via online platforms. Famous examples are the Amazon Marketplace and online travel agencies such as Booking.com. One crucial premise for the well-functioning of these online markets is that there is a competitive environment between the sellers and that a platform provider has an incentive to promote such an environment on its marketplace. Whereas the academic literature on this topic is relatively scarce, high-profile antitrust cases of illegal price fixing of sellers on such online platforms (discussed below) cast doubt on whether this premise is always fulfilled, and suggest that this form of collusive behavior is a concern for competition authorities more broadly.

The present article contributes to this debate with a specific focus on platform most-favored nation clauses (PMFN) by formally analyzing a platform's incentive and ability to encourage competition or collusion on its own marketplace in the presence of such clauses. A PMFN is a contractual requirement for online sellers not to offer better prices and conditions on other distribution channels. Such clauses have triggered substantial antitrust scrutiny in several jurisdictions, and the recent proposal for the Digital Markets Act of the European Commission suggests banning such clauses altogether for designated gatekeepers.[1] Moreover, PMFNs have also played a role in cases of price fixing on online marketplaces.

This paper emphasizes that a platform's preferred seller conduct can change with the introduction of a PMFN. Table 2.1 depicts the main result schematically, which distinguishes whether a platform prefers seller competition or seller collusion as conduct. At this stage, I take as given that sellers can coordinate on a cartelized outcome and then focus below on how it can be sustained through tacit collusion in an infinitely-repeated game. I analyze a stylized model building on and extending Johansen and Vergé (2017) in which online sellers have two distribution channels via which to sell to consumers. The first is a strategic platform, which employs the *agency model.* This means the platform receives a commission for every intermediated transaction, and the sellers set the retail prices on the platform. The second distribution channel is a non-strategic direct channel on which the online sellers do not incur per-transaction commission rates. I analyze both per-unit and revenue-sharing commission rates on the platform and, for the sake of tractability, focus on a linear-demand specification.

[1] European Commission (2020), Proposal for a Regulation on Digital Markets Act, Article 5 (b).

	No PMFN	With PMFN
Seller competition	✓	
Seller collusion		✓

Table 2.1: Platform's preferred seller conduct.

The table shows schematically which form of seller conduct the platform prefers for the case of revenue-sharing commission rates. For the case of per-unit commission rates, the result with PMFN relies on the qualifier that substitutability between sellers (interbrand competition) is sufficiently strong.

Absent a PMFN, a platform realizes higher profits with seller competition than with seller collusion. To understand the result that collusion cannot be optimal in the case of per-unit commission rates, note that at a given commission rate, seller collusion leads to a lower quantity sold on the platform, which *c.p.* decreases platform profits. Even at the optimal collusive rate, the platform would hence be better off inducing competition. Optimally adjusting the rate can only further increase profits. The same result is obtained in the case of revenue-sharing commissions. A seller's price strictly increases in the commission rate, and for a high enough commission rate, exceeds the collusive price. Roughly speaking, I find that a platform prefers the combination of competition and a high commission rate to that of collusion and a lower commission rate – reinforcing that absent a PMFN a platform strictly prefers seller competition also with revenue-sharing commissions.

This result, however, changes if the platform introduces a PMFN. I show that the platform can charge higher commission rates from colluding sellers than it can from competing ones. Importantly, this increase in the commission rate can render seller collusion more profitable for the platform. The result is driven by the fact that a PMFN induces sellers to charge uniform prices if they sell via the platform and the direct channel. If sellers compete and the platform charges high commission rates, it is tempting for a seller to delist from the platform and to charge optimal prices on the direct channel alone. This incentive to delist from the platform restricts the platform's commission rate (Johansen and Vergé, 2017). As delisting and competing aggressively on the direct channel alone is not a concern for the sellers if they can coordinate their behavior, the platform can charge higher commission rates from colluding sellers.

A PMFN therefore undermines a platform's incentive to ensure competition between sellers. Prior models instead (discussed in more detail in Section 2.2) emphasize that a PMFN has the potential to increase a platform's commission rate for a given degree of seller competition (Boik and Corts, 2016; Johnson, 2017). My findings provide a novel and complimentary theory of harm to treat PMFNs with scrutiny. Importantly, my findings suggest that a PMFN can be harmful even if commission rates do not adjust after the introduction or removal of a PMFN, as a platform still can have the incentive to restrict competition between the sellers.

I continue to analyze the stability of collusion between online sellers in an infinitely-repeated game. This analysis is directly related to high-profile antitrust cases involving colluding sellers on digital platforms. A leading case is the famous e-book case that involved a PMFN, and in which five major publishers of e-books as well as the platform provider (Apple) were found guilty of engaging in illegal fixing of retail e-book prices.[2] Moreover, online sellers of posters and frames, Trod Limited and GB eye Limited, colluded on retail prices between 2011 and 2015 on the Amazon UK website by means of price-matching algorithms.[3] Arguably, Amazon should be able to identify the use of such algorithms (Chen et al., 2016), and prevent their application if doing so is in its interest (e.g., by threatening seller suspension).[4] Note that Amazon also had a platform most-favored nation clause in place at the time that the collusive agreement was implemented between Trod Limited and GB eye Limited in the UK and the US.[5]

I determine to which extent the introduction of a PMFN allows a platform to affect the stability of tacit seller collusion. Sellers sustain collusion with grim-trigger strategies and coordinate their behavior in order to maximize their discounted stream of joint profits. In line with the finding that a platform can benefit from seller collusion with a PMFN, I identify a range of commission rates that the platform can choose in order to profitably stabilize collusion between sellers compared to the case without a PMFN. With a PMFN, the commission rate affects the sellers' distribution channel choices and thereby influences punishment and deviation behavior.

The remainder of the article is structured as follows: Section 2.2 discusses the related literature. In Section 2.3, I analyze the case of per-unit commission rates in a static model in order to highlight that a PMFN can alter a platform's incentives regarding seller conduct. Section 2.4 focuses on the stability of seller collusion in an infinitely-repeated game. In Section 2.5, I show that the results are robust to the case of revenue-sharing commission rates. Section 2.6 concludes. All missing proofs can be found in Appendix A.

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[2] See Baker (2013) and Klein (2017) for comprehensive overviews of the antitrust case in the US, and Gaudin and White (2014) on the antitrust economics of this case. In 2011, the European Commission also opened an antitrust case against Apple and the e-book publishers with similar anticompetitive concerns (Case COMP/AT.39847-E-BOOKS). In the year after the adoption, e-book prices for e.g., *New York Times* bestsellers increased by 40 percent as a result of this price fixing conspiracy (De los Santos and Wildenbeest, 2017).

[3] CMA, Decision of 12.08.16, Case 50223. There was also an investigation in the US and the founder of Trod Limited was also found guilty of the same conduct of price fixing lasting from 2013 to 2014 (United States v. Trod Limited, No. CR 15-0419 WHO).

[4] See, for instance, the blog post What to Do If Your Amazon Account Gets Suspended on www.repricerexpress.com indicating that Amazon uses suspension as disciplinary measures against sellers that do not comply with Amazon policies (last access, April 29, 2021).

[5] See, for instance, for the US the blog post "Amazon's Pricing Policy Caused Consumers to Overpay by $55B to $172B, Class Action Claims" indicating that until 2019 Amazon imposed PMFNs in the Amazon Services Business Solutions Agreement with the online sellers (last access, April 29, 2021).

2.2 Related Literature

The present article contributes to three strands of the literature. First, it contributes to a nascent literature that links platform behavior to the interaction between sellers (e.g., their competitiveness) on the platform. Second, it fits into the analysis of collusion in vertically-related markets. This research analyzes how vertical relations and vertical restraints affect the stability of collusion at different stages of the vertical chain. Third, the present article relates to articles analyzing the competitive effects of the comparably new vertical restraint of platform most-favored nation clauses.

Platform Behavior and Seller Interaction. Given the platforms' importance as private rule-makers for the marketplaces that they have created, there is a surprisingly small related literature that relates strategic platform behavior to the interaction (e.g., competitiveness) between sellers on a platform. None of the existing literature investigates the impact of PMFN clauses on the incentives to limit competition between sellers. Teh (2019) studies governance designs of a monopoly platform in order to affect on-platform competition. In particular, he studies governance decisions including seller entry, minimum quality standards, and on-platform search frictions. Karle et al. (2020) focus on the agglomeration and segmentation of sellers on different platforms and find that the competitive conditions between sellers shape the platform market structure. Relatedly, for a given market structure, Belleflamme and Peitz (2019) address the interaction of seller competition (i.e., negative within-group externalities on the platform) with platform pricing and product variety. Pavlov and Berman (2019) and Lefez (2020) study price recommendations that a platform sends to sellers which are active on the marketplace. Johnson et al. (2020) investigate a platform's ability to promote competition between sellers that use pricing algorithms with rules that reward firms with exposure to additional consumers if they cut prices.

Collusion in Vertically-Related Markets. The second strand of the literature studies the effects of vertical restraints on the stability of collusion. Closely related to the present analysis is Hino et al. (2019) who compare the stability of upstream collusion in the presence of either the traditional wholesale model (in which the retailer sets final consumer prices) or the agency model (in which sellers set these prices on the platform). I also focus on the agency model. Their main contribution is to analyze whether the distribution via wholesale contracts or agency contracts affects the stability of collusion between upstream sellers differently. They do not, however, analyze the use of platform most-favored nation clauses, which are common in markets that are operated via the agency model and have played an important role in multiple antitrust cases.

More broadly, the literature analyzes other forms of vertical restraints and their impact on collusion. The seminal articles by Nocke and White (2007) and Normann (2009) find that vertical integration can increase the stability of collusion between upstream firms. Relatedly, Biancini and Ettinger (2017) show that vertical integration generally also favors downstream collusion. The impact of resale price maintenance (RPM) on collusion on different levels at the vertical chain is analyzed by Jullien and Rey (2007), Overvest (2012), and Hunold and Muthers (2020). These articles demonstrate that the use of RPM can facilitate upstream collusion. Relatedly, I characterize the conditions under which a PMFN stabilizes seller collusion.

Further articles that study the effects of different contractual arrangements on collusion in vertically-related markets include Piccolo and Miklós-Thal (2012) and Gilo and Yehezkel (2020). They establish that contracts featuring slotting allowances and high wholesale prices during collusive periods can increase the stability of collusion between firms, as such a contract makes a deviation less profitable. Reisinger and Thomes (2017) study implications of the channel structure on seller collusion and find that seller collusion is easier to sustain if the sellers have independent retailers compared to the case in which they have a common retailer.

In non-vertical settings, contractual provisions have also been found to affect the stability of collusion between firms. Schnitzer (1994) analyzes the collusive potential of two forms of best-price clauses that guarantee consumers rebates on the purchase price if they find a better price for the purchased product. She finds that, in particular, contract clauses that promise consumers to meet price cuts from competing sellers have anticompetitive potential.

In the present paper, I emphasize that with a PMFN the platform's commission rate can affect punishment and deviation behavior differently and thereby stabilize seller collusion. Importantly, I demonstrate that the introduction of a PMFN can alter a platform's incentives to prevent collusion between online sellers. If a platform stabilizes seller collusion, a PMFN can therefore have a competition-weakening effect on the level of the sellers.

Competitive Effects of Platform Most-Favored Nation Clauses. The competitive effect of platform most-favored nation clauses have mostly been analyzed in static settings.[6] Recent articles such as Boik and Corts (2016), Johnson (2017), and Foros et al. (2017) support that such contract clauses have the potential to increase commission rates and final consumer prices. In the presence of a PMFN, online sellers react less sensitively to changes in a platform's commission rate, which allows them to sustain higher

[6]See Baker and Scott Morton (2017) and Fletcher and Hviid (2016) for comprehensive overviews of the competitive effects of PMFNs. They also informally discuss the effect of PMFN on the stability of upstream collusion but neither the impact on the sellers' listing decisions nor the desirability of collusion for the platforms are considered in this discussion.

rates in equilibrium than absent a PMFN. Moreover, these clauses may curtail entry in the platform market, as a new entrant in the platform market cannot win consumers by achieving lower retail prices on its own platform, and lead to excessive adoption of the platform's services as well as overinvestment in benefits to consumers (Edelman and Wright, 2015). In contrast, Johansen and Vergé (2017) show that accounting for the sellers' participation constraint can alleviate the anticompetitive price effects of a PMFN and can even lead to an increase in welfare if sellers have a direct channel through which to reach final consumers. Wang and Wright (2020) and Ronayne and Taylor (2020) analyze a setting in which a platform uses a PMFN in order to prevent sellers from engaging in *showrooming,* in which case consumers can search for products on the platform and buy on another channel in order to take advantage of lower prices. Both articles highlight that even in the presence of this efficiency defense for PMFNs, such clauses have the potential to harm consumers.

These papers abstract from any effect of a PMFN on the competition between sellers on the platform and focus instead on the competition between the platform and other distribution channels. The present paper contributes to this literature by focusing on the competitive effects of PMFNs at the seller level, and their impact on the stability of seller collusion. This analysis offers a novel theory of harm regarding PMFNs that applies even in settings in which a platform does not adjust its commission rate after the introduction of a PMFN. My findings add to existing concerns regarding such PMFNs as those mentioned above.

2.3 Static Model

2.3.1 Players and Environment

Consider an environment with two competing sellers $i \in \{1, 2\}$ producing differentiated products at constant symmetric marginal costs $c \geq 0$. Each seller offers a quantity q_{ij} of products to consumers through two distribution channels $j \in \{M, D\}$. The first distribution channel is a platform that provides a marketplace M and the second one is a direct channel D that sellers can use to reach consumers. For every intermediated transaction, the platform charges a commission from the sellers. Suppose that the marginal costs for an additional intermediated transaction between sellers and consumers on each distribution channel $j \in \{M, D\}$ is constant and normalized to zero.

2.3.2 Contracts and Timing

The platform uses the *agency model*, which implies that the sellers set retail prices on each distribution channel $j \in \{M, D\}$. Denote by p_{ij} the price that seller i sets on distribution channel j, and with $p_i = (p_{iM}, p_{iD})$ the vector of retail prices that seller i

charges on both distribution channels. The vector $p = (p_1, p_2)$ is the vector of all retail prices. I analyze two forms of contracts between the platform and the sellers. For the main part of the analysis, I will focus on the case in which the platform receives a per-unit commission rate w_M from the sellers for every transaction that is intermediated on the platform.[7] The focus on simple per-unit commission rates facilitates the analysis and allows for closed-form solutions.[8] Contract offers are observable.[9]

In the unregulated case, the platform can impose a platform most-favored nation clause (PMFN) in the contracts with the sellers. A PMFN requires each seller to offer on the platform at least as favorable prices as on the direct channel, $p_{iM} \leq p_{iD}$. I compare the case with a PMFN on the platform to the case in which PMFNs are prohibited.

The timing of the game is as follows: First, the platform sets the commission rate. Second, sellers simultaneously decide whether to accept the platform's contract, and they set retail price p_{iB} on the direct channel as well as the retail price p_{iM} on the platform in case they accept the offer. I solve for subgame perfect equilibria in pure strategies with symmetric listing decisions. If there is more than one equilibrium, I assume that firms coordinate on the payoff-dominant equilibrium. Below, I say that a seller is active on a distribution channel if it has accepted the contract offer (in the case of the platform), and sells a positive quantity to consumers via this channel.

2.3.3 Consumer Behavior

The consumers have preferences for the seller and the distribution channel. Hence, consumers have demand for four differentiated seller-channel configurations. Building on Dobson and Waterson (1996), I assume that the demand function is linear and depends on the prices of the sellers $i, h \in \{1, 2\}$ on each distribution channel $j, k \in \{M, D\}$

$$q_{ij}(p) = \frac{1}{(1-\alpha^2)(1-\beta^2)} \left(1 - \beta - p_{ij} + \beta p_{ik} - \alpha \left(1 - \beta - p_{hj} + \beta p_{hk}\right)\right). \quad (2.1)$$

The parameter $\alpha \in (0, 1)$ captures the degree of interbrand competition and $\beta \in (0, 1)$ the degree of intrabrand competition.[10] The demand function captures that a seller can reach more consumers if it is present on both distribution channels than if it is present only on one channel. Cazaubiel et al. (2020) document empirically that a hotel chain's direct

[7] I obtain the same results when allowing for seller-specific commission rates. In order to simplify the exposition, I impose symmetric commission rates.

[8] In Section 2.5, I explain intuitively why the same economic forces are present when commissions are based on sellers' revenue, but formally the case is much less tractable. In line with the economic intuition, I numerically verify that the main economic results carry over to the case of revenue-sharing commission rates.

[9] See Johansen and Vergé (2017) for a related analysis with unobservable contract offers.

[10] Such a linear demand specification has been widely employed to study collusion in vertically-related markets (Reisinger and Thomes, 2017; Hino et al., 2019) and PMFNs in the agency model (Johansen and Vergé, 2017; Boik and Corts, 2016). The demand function is derived from the utility maximization of a representative consumer with quadratic utility (see also Singh and Vives, 1984).

channel is a credible alternative to an online travel agent such as Expedia. Similarly, estimates by Duch-Brown et al. (2017) show that there is considerable sales diversion between online and offline distribution channels for consumer electronics.

2.3.4 Analysis of the Static Model

In this section, I analyze how the introduction of a PMFN affects the profitability of seller competition for the platform. In order to do so, I characterize the static competitive market outcome and compare it to the outcome in which sellers can coordinate on the joint profit-maximizing behavior (e.g., through seller collusion). Throughout this section, I abstract from the exact mechanism supporting this monopolistic outcome in order to highlight the platform's incentive to restrict seller competition. In the following section, I analyze an infinitely-repeated game in order to study the stability of such collusive market outcomes when the platform can affect the stability of seller collusion by means of its commission rate.

Without loss of generality, normalize the seller's marginal costs to zero in this section and write the profit function of seller i that is present on both distribution channels as

$$\pi_i(p) \quad = \quad (p_{iM} - w_M)\, q_{iM}(p) + p_{iD} q_{iD}(p)\,. \tag{2.2}$$

The platform's profit is

$$\Pi_M(w_M) = w_M \sum_{i \in \{1,2\}} q_{iM}(p)\,, \tag{2.3}$$

No Platform Most-Favored Nation Clause. Absent a PMFN, the presence of a positive commission rate w_M that sellers must pay to the platform leads to an incentive for the seller to charge different prices on each distribution channel. Given demand symmetry and the higher distribution costs on the platform, each seller charges lower prices on the direct channel if not restricted by a PMFN. Sellers' conduct leads either to competitive retail prices denoted by $\tilde{p}$ or collusive ones denoted by $\bar{p}$. The following lemma summarizes the seller behavior for both forms of conduct absent a PMFN.

Lemma 2.1. *For $w_M \in [0, 1-\beta]$ the sellers list on both distribution channels. Absent a PMFN (NP), seller i sets the retail prices*

$$\tilde{p}_{iM}^{NP}(w_M) = \frac{1-\alpha+w_M}{2-\alpha}, \;\; \textit{and} \;\; \tilde{p}_{iD}^{NP}(w_M) = \frac{1-\alpha}{2-\alpha}, \tag{2.4}$$

on distribution channel $j \in \{M, D\}$ if sellers compete, and

$$\bar{p}_{iM}^{NP}(w_M) = \frac{1+w_M}{2}, \;\; \textit{and} \;\; \bar{p}_{iD}^{NP}(w_M) = \frac{1}{2}, \tag{2.5}$$

in the monopolistic case.

The restriction on the commission rate $w_M \in [0, 1-\beta]$ ensures that—independent of their conduct—sellers prefer to be active on both distribution channels instead of listing on the direct channel only. As I verify below, the platform does not indeed find it profitable to charge higher commission rates than $1-\beta$ because then sellers are not willing to list on the platform. The result of Lemma 2.1 shows that with collusion the sellers successfully eliminate the interbrand competition (as measured in α) on both distribution channels. This implies that retail prices are higher with collusion than they are with seller competition. Moreover, retail prices on distribution channel j are independent of the costs of distribution on the other channel $k \neq j$.

Based on the seller behavior described in Lemma 2.1, the proposition below shows that the commission rate that maximizes the platform's profit is independent of the seller conduct in the setting with linear demand. An immediate corollary being that the platform prefers seller competition to seller collusion, as lower prices increase the transaction on the platform. More generally, fixing the commission rate, the platform prefers competition over collusion whenever delisting is not a concern and lower competitive prices on both channels lead to an increase in the amount of sales on the platform. The latter seems to be a weak condition that holds in the linear demand specification. Given that a platform benefits at any such fixed commission rate from seller competition, it also does so for the optimal commission rate. The following proposition summarizes the optimal platform behavior absent a PMFN and the resulting profits.

Proposition 2.1. *Without a PMFN, the optimal commission rate is*

$$w_M^{NP} = \frac{1-\beta}{2}, \tag{2.6}$$

which is independent of the seller conduct. The resulting platform profits depending on seller conduct are

$$\tilde{\Pi}_M^{NP}\left(w_M^{NP}\right) = \frac{1-\beta}{2(2-\alpha)(1+\alpha)(1+\beta)}, \tag{2.7}$$

$$\bar{\Pi}_M^{NP}\left(w_M^{NP}\right) = \frac{1-\beta}{4(1+\alpha)(1+\beta)}, \tag{2.8}$$

with $\tilde{\Pi}_M(w_M) > \bar{\Pi}_M(w_M)$ *for all* $w_M \in [0, 1-\beta]$.

Note that $w_M^{NP} < 1-\beta$, so that both sellers are active on both distribution channels. Importantly, since the platform's profit is greater when sellers compete than if they collude, a platform prefers to induce a competitive environment absent a PMFN.

Platform Most-Favored Nation Clause. Next, I turn to the analysis of the profitability of seller competition for the platform with a PMFN. Such a contract restriction leads to an important change in the contracting between the platform and the online sellers. With PMFN, it is important to take into account the sellers' listing decision on the platform as highlighted in Johansen and Vergé (2017). Due to the contractual restrictions of the PMFN, a seller is induced to charge higher than optimal prices on its direct channel if it is active on both distribution channels. It may therefore be more profitable for a seller to delist from the platform in order to charge more profitable prices on its direct channel and save the commission payments that accrue for every transaction via the platform. Hunold et al. (2018) and Cazaubiel et al. (2020) provide empirical evidence that listing decisions are economically important dimensions of adjustments in the hotel sector if online travel agents impose a PMFN. In the following, I characterize how a PMFN affects seller behavior in the case of competitive and monopolistic seller conduct.

Competitive Case. If present on both distribution channels, competing sellers maximize the profit function in Equation (2.2) subject to the constraint that $p_{iM} \leq p_{iD}$. If active on both channels, denote the resulting uniform retail price that seller i charges on both distribution channels by $\tilde{p}_i^P$. To show that these retail prices constitute an equilibrium, it is necessary to verify that no seller has an incentive to delist from the platform (explained below). In particular, taking as given that the rival seller h is active on both distribution channels and is anticipated to charge $\tilde{p}_h^P$, seller i can realize a profit of

$$\max_{p_{iD}} \ \pi_i \left(p_{iD}, \infty, \tilde{p}_h^P\right) = p_{iD} q_{iD} \left(p_{iD}, \infty, \tilde{p}_h^P\right), \tag{2.9}$$

from delisting from the platform, where ∞ indicates that seller i is not active on the platform. By delisting, a seller can avoid the contractual restrictions of a PMFN and charge more profitable prices on the direct channel.

If the profit on the direct channel alone (Equation (2.9)) exceeds the profit from being active on both channels, it cannot be an equilibrium in which both sellers are active on both distribution channels. In the following lemma, I verify that this is the case if the platform's commission rate is too high and that there exists an equilibrium in which both sellers are only present on the direct channel and offer no products via the platform in this case. Denote with $\tilde{\pi}_{i(D)}^P = \pi_i \left(\tilde{p}_D^P, \infty\right)$ seller i's equilibrium profit in case both sellers are only present on the direct channel. The following lemma summarizes the listing decision and prices of competing sellers as a function of the commission rate w_M if sellers compete.

Lemma 2.2. *Suppose that the platform imposes a PMFN* (P)*. Competing sellers are active on both distribution channels if*

$$w_M \ \leq \ \tilde{w}_{max} = \frac{4\,(1-\alpha)\,(2-\sigma\,(\beta))}{4-\alpha\,(4-\sigma\,(\beta))}, \tag{2.10}$$

with $\sigma(\beta) = \sqrt{2(1+\beta)}$, *and set the same retail price on both channels*

$$\tilde{p}_i^P(w_M) = (2 - 2\alpha + w_M) / (4 - 2\alpha). \tag{2.11}$$

Otherwise, both sellers are only active on the direct channel and set direct channel prices of $\tilde{p}_{iD}^P = (1-\alpha)/(2-\alpha)$ *as specified in Equation (2.4) in Lemma 2.1.*

The result of Lemma 2.2 provides a threshold value $\tilde{w}_{max}$ for the maximal commission rate on the platform for which sellers are active on both distribution channels (Johansen and Vergé, 2017). If sellers are active on the platform, they optimally set the same retail prices on both distribution channels (as they are contractually forced not to offer lower prices on the direct channel). In contrast to the case without a PMFN, the equilibrium retail price on distribution channel $j \in \{M, D\}$ therefore depends on the costs of distribution on both channels. In particular, the retail price on the direct channel is affected by the commission rate w_M that the platform charges for every intermediated transaction. A comparison of the equilibrium retail prices with and without a PMFN reported in Lemma 2.1 and Lemma 2.2 shows that the pass-through rate of the commission rate w_M on the retail price on the platform p_M is lower with a PMFN than without. Intuitively, a seller that wants to raise the retail price on the platform also needs to suboptimally increase it on the direct channel, which renders such adjustments less responsive than without a PMFN. This property is at the core of the analyses that relate PMFNs to reduced competition on the platform level (see, for instance, Boik and Corts, 2016).

For commission rates above the threshold $\tilde{w}_{max}$, it cannot be an equilibrium that both competing sellers are present on both channels as it is unilaterally profitable for a seller to delist from the platform if $w_M > \tilde{w}_{max}$. By delisting, a seller can charge more profitable prices on the direct channel and additionally benefits from the fact that the competing seller, which is anticipated to be present on both channels, is contractually induced to charge higher-than-optimal prices on the direct channel. Lemma 2.2 establishes that in this case both sellers are only active on the direct channel and optimally set the same retail prices as in the case without contractual restrictions specified in Lemma 2.1.

Joint Profit-Maximizing (Monopolistic) Case. The unilateral incentive to delist is not a concern for sellers if they can coordinate their listing decisions and retail prices in order to maximize their joint profits $\pi_{12} = \pi_1 + \pi_2$ because sellers internalize that delisting and competing aggressively on the direct channel alone cannibalizes the profits of the second seller. If present on both channels, the collusive maximization problem stipulates

$$\max_{p} \ \pi_{12}(p) = \sum_{i\in\{1,2\}} (p_{iM} - w_M) q_{iM}(p) + p_{iD} q_{iB}(p), \qquad (2.12)$$
$$s.t. \ \ p_{iM} \leq p_{iD}.$$

As in the case with seller competition, the constraint on the retail prices is binding in equilibrium. Denote the resulting collusive retail price on both distribution channels as $\bar{p}_i^P$. Sellers delist from the platform if the commission rate is such that their joint profits are larger on the direct channel alone than on both distribution channels. If only active on the direct channel, the sellers maximize

$$\max_{p_D} \ \pi_{12}(p_D, \infty) = \sum_{i\in\{1,2\}} p_{iD} q_{iD}(p_D, \infty), \qquad (2.13)$$

where ∞ denotes that sellers are not active on the platform. Denote the monopolistic seller profit on the direct channel alone as $\bar{\pi}_{i(D)}^P$. In the following lemma, I characterize the behavior of colluding sellers.

Lemma 2.3. *Suppose that the platform imposes a PMFN* (P)*. Monopolistic sellers are active on both distribution channels if*

$$w_M \leq \bar{w}_{max} = 2 - \sqrt{2(1+\beta)} = 2 - \sigma(\beta), \qquad (2.14)$$

with $\bar{w}_{max} > \tilde{w}_{max}$*, and set retail prices of*

$$\bar{p}_i^P(w_M) = (2 + w_M)/4. \qquad (2.15)$$

Otherwise, sellers coordinate to be present on the direct channel only and set $\bar{p}_{iD}^P = 1/2$.

The threshold value $\bar{w}_{max} > \tilde{w}_{max}$ below which colluding sellers are willing to list on both distribution channels is larger than the threshold value $\tilde{w}_{max}$ for the competing sellers due to the fact that collusion allows sellers to overcome the unilateral incentive to delist from the platform. This implies that colluding sellers may be active on both distribution channels while such listing decisions cannot be sustained in equilibrium in the case of seller competition. Moreover, this result shows that a profit-maximizing platform, which imposes a PMFN, will never charge commission rates above $w_M > \bar{w}_{max}$ as neither competing nor colluding sellers are willing to list on the platform and accept the contractual restrictions from a PMFN for such high commission rates.

Platform Profits. As derived in Lemmas 2.2 and 2.3, the sellers' participation constraints restricts the platform's commission rate. In fact, the commission rates that maximize the platform's profit are the same as the threshold values that make competing and colluding sellers indifferent to their outside option of being active on the direct channel only. Recall from the comparison of seller competition and seller collusion that this threshold value is smaller in the case of seller competition ($\bar{w}_{max} > \tilde{w}_{max}$). As a result, a platform can enforce a higher commission rate from colluding sellers than it can from competing sellers. This effect makes a platform more lenient toward seller collusion and can lead to the platform obtaining higher profits with seller collusion than with seller competition.

Proposition 2.2. *If seller conduct is competitive, the commission rate that maximizes the platform's profit with a PMFN is equal to the threshold value $\tilde{w}_M^P = \tilde{w}_{max}$ (Equation (2.10)). In the monopolistic case, this commission rate is equal to the threshold value $\bar{w}_M^P = \bar{w}_{max}$ ((2.14)). The resulting platform profits depending on seller conduct are*

$$\tilde{\Pi}_M^P\left(\tilde{w}_M^P\right) = \frac{8\left(1-\alpha\right)\left(2-\sigma\left(\beta\right)\right)\sigma\left(\beta\right)}{\left(1+\alpha\right)\left(1+\beta\right)\left(4-\alpha\left(4-\sigma\left(\beta\right)\right)\right)^2}, \tag{2.16}$$

$$\bar{\Pi}_M^P\left(\bar{w}_M^P\right) = \frac{\left(2-\sigma\left(\beta\right)\right)\sigma\left(\beta\right)}{2\left(1+\alpha\right)\left(1+\beta\right)}, \tag{2.17}$$

with $\sigma\left(\beta\right) = \sqrt{2\left(1+\beta\right)}$. The platform's profit with seller collusion is larger than with seller competition if interbrand substitutability α is sufficiently large. That is, $\bar{\Pi}_M\left(\bar{w}^P\right) > \tilde{\Pi}_M^P\left(\tilde{w}^P\right)$ if $\alpha > \bar{\alpha} = \left(16-8\sigma\left(\beta\right)\right)/\left(16-8\sigma\left(\beta\right)+\sigma\left(\beta\right)^2\right)$.

The result of Proposition 2.2 captures that monopolistic seller behavior has two diverging effects on the platform profits. First, joint profit-maximizing behavior of the sellers allows the platform to charge higher commission rates without violating the sellers' participation constraint. This effect increases platform profits. Second, seller collusion leads sellers to charge higher retail prices at given commission rates. This reduces demand and thereby decreases platform profits. The first effect dominates the second one if the degree of interbrand substitutability α is sufficiently large. If substitutability is large, the threat of a rival delisting and stealing market share is so severe that the platform has no incentive to discourage seller collusion ($\alpha > \bar{\alpha}$).

In Section 2.5, I analyze the case of revenue-sharing commission rates. Importantly, the results reveal that the platform prefers monopolistic seller behavior for all degrees of interbrand substitutability α, and hence with this contract form a platform is even more prone to limit seller competition than with per-unit commission rates.

Profitability of Platform Most-Favored Nation Clauses. In various digital markets, platform providers have revealed a strong interest in imposing a PMFN.[11] Comparing the platform's profit levels reported in Proposition 2.1 (for the case without a

[11] See, for instance, the blog post Amazon Gets Bulk of Complaint in AAP Filing With US Trade Commission on www.publishingperspectives.com or Bundeskartellamt calls Booking.com's best-price clauses anticompetitive on www.triptease.com (last access, April 29, 2021).

PMFN) and Proposition 2.2 (with a PMFN) allows to study the profitability of a PMFN for the platform.[12] With seller competition (comparing the profits in Equations (2.7) and (2.16)), the comparison yields that a platform benefits from a PMFN only if the interbrand competition between the online sellers is not too strong, because otherwise the commission rate with a PMFN is too small to make a PMFN profitable.[13] In contrast, this case distinction on the intensity of the interbrand competition regarding the profitability of a PMFN does not apply in the case of colluding sellers. If sellers collude (comparing the profits in Equations (2.8) and (2.17)), the platform unambiguously prefers a PMFN. A PMFN is therefore particularly profitable for a platform in the monopolistic case.

Online sellers typically complain about the use of PMFNs, suggesting that seller profits are higher absent a PMFN. For competing sellers this result is supported in the theoretical studies establishing the main theory of harm discussed in Section 2.2 (e.g., Foros et al., 2017).[14] Related to this result, I also find that monopolistic sellers realize lower profits with a PMFN than absent a clause if the platform charges the optimal commission rates $\bar{w}_M^{NP}$ and $\bar{w}_M^{P}$ characterized in Propositions 2.1 and 2.2. Also, comparing across different forms of seller conduct yields that sellers dislike a PMFN. Seller competition absent a PMFN yields a higher profit than seller collusion with such a clause. Moreover, both with and without a PMFN, the relative gain of colluding compared to competing $((\bar{\pi}_i - \tilde{\pi}_i)/\tilde{\pi}_i)$ is the same for the online sellers in the analyzed setting.

2.4 Dynamic Model

2.4.1 Infinitely-Repeated Game

In this section, I analyze the industry structure introduced above in an infinitely-repeated game in discrete time $t = 0, ..., \infty$. So far, I have imposed that sellers can coordinate on the joint profit-maximizing behavior without focusing on the exact stabilizing mechanism. The framework of the infinitely-repeated game allows to study a possible mechanism with which such seller behavior can be sustained. Moreover, this approach is motivated by antitrust cases such as the e-book case discussed in the Introduction.

[12]Another reason that makes a PMFN desirable for the platform that is outside of this model is the avoidance of *showrooming*, which means that consumers search on the platform for an online seller and purchase the product on the distribution channel that offers the product at the lowest price (see Wang and Wright (2020); Ronayne and Taylor (2020)).

[13]In particular, $\tilde{\Pi}_M^P\left(w_M^{NP}\right) > \tilde{\Pi}_M^{NP}\left(w_M^{NP}\right)$ if $\alpha < (8 - 2\sigma(\beta))/(7-\beta)$. See Johansen and Vergé (2017) for a similar condition.

[14]In contrast, Johansen and Vergé (2017) find that PMFNs can benefit all the actors (platforms, sellers, and consumers) in an industry. The result that profits of non-cooperative sellers can increase due to a PMFN is also supported in the present analysis for the case of large intrabrand substitution β (profits are reported in Appendix A). In this case, distribution channels are easily substitutable for the online seller, and the seller's participation constraint to be active on the platform commands a low commission rate.

My focus is on the stability of collusion between the sellers under contracts with and without a PMFN. Sellers have a common discount factor $\delta \in (0,1)$, and aim to maximize present-discounted stream of profits

$$\sum_{t=0}^{\infty} \delta^t \pi_i \left(p_t\right), \tag{2.18}$$

where p_t is the vector of retail prices in period t, and π_i retailer i's stage profit at these retail prices.

The platform does not take part in the collusive agreement and sets a constant and symmetric commission rate at the beginning of the first period that does not change in future periods.[15] In fact, this pricing behavior appears to be in line with actual platform behavior. For instance, in the online hotel booking sector, a recent report by EU competition authorities indicates that there were little to no changes in the base and effective commission rates paid by hotels to online travel agencies during the period 2014 to 2016.[16] Similarly, the commission rate that Apple negotiated with the major e-book publishers was set at 30 percent and did not change during and after the collusive period (Foros et al., 2017).

I solve for a subgame-perfect Nash equilibrium of the infinitely-repeated game between the sellers based on this constant commission rate. On the path of play, the sellers coordinate to achieve in each period the joint profit maximum (i.e., the most collusive outcome) by coordinating their listing decisions and setting the collusive price $\bar{p}_{ij}$ on each active distribution channel j. For brevity, it is convenient to suppress that the retail prices depend on the constant commission rate.

I analyze the stability of collusion in an equilibrium sustained through grim-trigger strategies (Friedman, 1971). If a seller deviates from the collusive scheme, it makes its listing decision and sets $\hat{p}_{ij}$ such that its deviation profit is maximized.[17] After a deviation, all sellers revert to playing their static Nash equilibrium listing decision and prices $\tilde{p}_{ij}$ for all future periods. In Appendix B, I numerically analyze the case in which incentive-compatibility prevents sellers from coordinating on profit-maximizing prices and sellers instead coordinate on the highest feasible (i.e., incentive-compatible) prices. The results are qualitatively comparable, and reinforce the finding that the platform can benefit from seller collusion if it imposes a PMFN.

[15]By offering asymmetric commission rates, the platform would induce sellers with asymmetric costs of distribution, which affects collusive stability if sellers continue to collude on the joint profit-maximizing retail prices. The sellers are, however, able to offset this effect on their critical discount factor by agreeing on a different distribution of profits or side payments. Both strategies render the effect of asymmetric costs of distribution on the stability of collusion negligibly small.

[16]See the Report on the Monitoring Exercise Carried out in the Online Hotel Booking Sector by EU Competition Authorities in 2016 (last access, April 29, 2021).

[17]Note that the deviation can involve another listing decision than that of the seller who sticks to the collusive agreement.

Formally, in any period $t = 0, 1, ..., \infty$ in which sellers coordinate on collusion, seller i sets the collusive prices $\bar{p}_{ijt}$ on both distribution channels $j \in \{M, D\}$. For any future period t, it holds that

$$p_{ijt} = \begin{cases} \bar{p}_{ij} & \text{if } p_{hj\tau} = \bar{p}_{hj} \; \forall \; \tau < t, \; h \in \{1, 2\}, \; j \in \{M, D\}, \\ \tilde{p}_{ij} & \text{if otherwise.} \end{cases} \tag{2.19}$$

Denote the corresponding stage-game profits that are associated with the prices defined above by $\bar{\pi}_i$, $\tilde{\pi}_i$, and $\hat{\pi}_i$. The condition that there is no unilateral incentive to deviate from the collusive scheme is

$$\sum_{t=0}^{\infty} \delta^t \bar{\pi}_i \geq \hat{\pi}_i + \sum_{t=1}^{\infty} \delta^t \tilde{\pi}_i. \tag{2.20}$$

The discounted stream of profits from sticking to the collusive scheme needs to exceed the profit that an upstream firm can obtain from cheating and reverting afterwards to the static Nash equilibrium for all future periods. Rearranging yields that the common discount factor needs to exceed

$$\delta \geq \underline{\delta} = \frac{\hat{\pi}_i - \bar{\pi}_i}{\hat{\pi}_i - \tilde{\pi}_i} \in [0, 1], \tag{2.21}$$

where $\underline{\delta}$ denotes the seller's critical discount factor for collusion to be sustainable.

In order to ensure that both sellers are active and sell positive quantities in all periods of the infinitely-repeated game, I assume that the degree of interbrand substitutability is not too large:

Assumption 2.1. $\alpha < \sqrt{3} - 1$.

In particular, this assumption ensures that a seller that charges collusive prices sells a positive quantity to the consumers even if the other seller deviates from the collusive scheme and charges lower prices in order to maximize the current-period profits (see also Ross, 1992).[18]

Discussion of the model framework applied to collusion in digital markets. In this section, I analyze the stability of collusion in online markets, taking the canonical approach of comparing the long-term benefits from collusion with the temptation of a one-time deviation from the collusive agreement. As already discussed in the Introduction, there are high-profile collusion cases on platform markets that motivate this analysis, and raise—among others—question about the stability of collusive agreements in online

[18]Recall that the profitability of seller collusion with PMFN (Proposition 2.2) depends on $\alpha > \bar{\alpha} = (16 - 8\sigma(\beta)) / \left(16 - 8\sigma(\beta) + \sigma(\beta)^2\right)$. Note that it holds that $\sqrt{3} - 1 > \bar{\alpha}$, $\forall \beta \in (0, 1)$ such that this result is not excluded by Assumption 2.1. Moreover, for the case of revenue-sharing commission rates there is no restriction on the degree of interbrand substitutability α such that Assumption 2.1 is innocuous in this setting.

markets and, importantly, whether the stability changes with the introduction of a PMFN. Moreover, there are recent empirical studies from other industries lending support to the hypothesis that the incentive compatibility of collusive agreements is an economically relevant dimension to help understand the behavior of cartels (Igami and Sugaya, 2019; Miller et al., 2019).

A potential concern, however, may involve how, in principle, online markets can allow for timely responses to deviations. At an extreme of immediate reactions, this would render any deviation from collusion unprofitable and allow for stable collusion with any common discount factor (Ivaldi et al., 2003). I nevertheless take the view that this approach can offer fruitful insights for the study of collusion in online markets for the following reasons.

First, as derived below, the analysis links the stability of collusion to the listing decisions of the sellers on different distribution channels. Arguably, the channel choice is less flexible than an adjustment in the posted prices and takes more time to react to in case of a change in the market environment. Recent empirical studies such as Hunold et al. (2018) and Cazaubiel et al. (2020) provide evidence that the listing decision is an important dimension of adjustment in the hotel sector, particularly in the presence of a PMFN.

Second, there may be a fraction of online sellers that can react quickly to changes in the posted prices of other sellers, for instance, by using pricing algorithms in order to automate pricing decisions. In a recent paper, Chen et al. (2016) detect that 2.4 percent of online sellers use such algorithmic pricing on the Amazon Marketplace. For a large fraction of sellers, it is therefore still necessary to detect and react to a deviation without the help of algorithms, which may make them more comparable to other industries to which the approach is usually applied. Relatedly, deviations on other distribution channels than on the platform itself may be more difficult to monitor and also take more time to react to for the other sellers.

As a modeling choice, I abstract from information frictions. Arguably, a PMFN may improve the observability of secret price cuts and thereby stabilize collusion (see informal discussions of this effect in Fletcher and Hviid, 2016; Baker and Scott Morton, 2017). According to Stigler (1964), avoiding the threat of secret price cuts is the major obstacle for stable collusion, and this argument is reminiscent of the analysis by Jullien and Rey (2007) for the case with a resale price maintenance. This reasoning reinforces my findings that a PMFN stabilizes seller collusion. Importantly, however, when holding commission rates fixed, prior arguments fail to establish that platforms that earn commissions from sales benefit from such collusion.

2.4.2 Analysis of the Dynamic Model

The aim of this section is to characterize how the introduction of a PMFN changes the stability of seller collusion by altering punishment and deviation behavior compared to the case without a PMFN.

No Platform Most-favored Nation Clause. Given Lemma 2.1 specifies the static competitive and collusive profits, I next derive a seller's optimal deviation profits. The following lemma summarizes this for the case without a PMFN.

Lemma 2.4. *Absent a PMFN (NP), a deviating seller i is active on both distribution channels and optimally sets*

$$\hat{p}_{iM}^{NP}(w_M) = \frac{2-\alpha+(2+\alpha)\,w_M}{4}, \quad \text{and} \quad \hat{p}_{iD}^{NP}(w_M) = \frac{2-\alpha}{4}, \tag{2.22}$$

for all $w_M \in [0, 1-\beta]$.

If a seller deviates from the collusive agreement, it finds it profitable to be active on both distribution channels. The deviation prices that maximize the current-period profits of a seller in Equation (2.22) are below the collusive prices (Equation (2.5)) and above the competitive prices (Equation (2.4)). Independent of the conduct, the sellers prefer to set lower prices on the direct channel than on the platform as the costs of distribution on the direct channel are lower.

Based on the results in Lemmas 2.1 and 2.4 that characterize seller behavior in competitive, collusive, and deviation periods, the following proposition states the critical discount factor above which collusion is supported by a subgame-perfect equilibrium for the sellers.

Proposition 2.3. *Without a PMFN (NP), the critical discount factor is*

$$\underline{\delta}^{NP} = \frac{(2-\alpha)^2}{8-8\alpha+\alpha^2}, \tag{2.23}$$

for both sellers $i \in \{1,2\}$. It increases in the degree of interbrand competition α, and is independent of the degree of intrabrand competition β and the commission rate w_M.

The result of Proposition 2.3 shows that the critical discount factor absent a PMFN is independent of the seller's cost level. This implies that a platform's per-unit commission rate does not affect the seller's incentive constraint for collusion to be stable in this setting. Relatedly, the degree of intrabrand substitutability between the distribution channels (as measured by β), which indirectly affects the per-unit commission rates that the platform can impose, does not affect the sellers' critical discount factor either. Moreover, with per-unit commission rates, the critical discount factor $\underline{\delta}^{NP}$ depends on the degree of interbrand competition and increases in α, which shows that a higher degree of substitutability between the sellers decreases the stability of collusion.

Platform Most-Favored Nation Clause. Next, I turn to the analysis of the stability of collusion with a PMFN. Due to the contractual restrictions of the PMFN, a seller is induced to charge higher than optimal prices on its direct channel if it is active on both distribution channels. This can affect a seller's listing decision (Johansen and Vergé, 2017): with a PMFN, a seller may prefer to delist and charge the optimal price on the direct channel. This allows the seller to divert sales from the high-commission platform channel to the commission-free direct channel.[19]

In the following, I characterize how a PMFN affects the behavior of a deviating seller. As colluding and competing sellers, a deviating seller also needs to decide whether to be active on both channels or only on the direct channel. First, consider a deviating seller i that decides to be active on both channels and takes as given that the second seller h is also present on both channels and sets collusive prices $\bar{p}_h^P(w_M) = (2 + w_M)/4$ (derived in Lemma 2.3). The deviating seller then sets retail prices p_i in order to maximize

$$\max_{p_i} \ \pi_i\left(p_i, \bar{p}_h^P\right) = (p_{iM} - w_M)\, q_{iM}\left(p_i, \bar{p}_h^P(w_M)\right) + p_{iD} q_{iD}\left(p_i, \bar{p}_h^P(w_M)\right), \tag{2.24}$$

subject to the constraint that $p_{iM} \leq p_{iD}$. Alternatively, the deviating seller may decide to delist from the platform, and to offer products only via the direct channel. In this case, such a seller sets the retail price p_{iD} in order to

$$\max_{p_{iD}} \ \pi_i\left(p_{iD}, \infty, \bar{p}_h^P(w_M)\right) = p_{iD} q_{iD}\left(p_{iD}, \infty, \bar{p}_h^P(w_M)\right). \tag{2.25}$$

Denote the profit of a deviating seller that is present on the direct channel only as $\hat{\pi}_{i(D)}^P(w_M)$. The next lemma summarizes the optimal deviation behavior.

Lemma 2.5. *Suppose the platform imposes a PMFN (P). If seller i deviates from collusion, it is active on both distribution channels if*

$$w_M \ < \ \hat{w}_{max} = \frac{2(2-\alpha)(2-\sigma(\beta))}{4-\alpha(2-\sigma(\beta))}, \tag{2.26}$$

and sets $\hat{p}_i^P(w_M) = (4 - 2\alpha + (2+\alpha) w_M)/8$. Otherwise, a deviating seller is only active on the direct channel and charges $\hat{p}_{iB}^P(w_M) = (4 - \alpha(2 - w_M))/8$ while the non-deviating seller stays active on both channels. One has

$$\tilde{w}_{max} < \hat{w}_{max} < \bar{w}_{max}.$$

[19] If sellers do not delist and stay active on both distribution channels, the presence of a PMFN effectively undermines a seller's ability to price discriminate between distribution channels. For instance, Helfrich and Herweg (2016) show that the firms' ability to engage in preference-based price discrimination can destabilize collusion. As I derive below, the model based on per-unit commission rates and the linear demand specification implies that the latter mechanism does not affect the stability of seller collusion. The analysis, therefore, highlights effects of altered punishment and deviation behavior due to a PMFN.

The result of Lemma 2.5 shows that a deviating seller may be active on both distribution channels or on the direct channel only, depending on the commission rate on the platform. More specifically, if competing sellers are present on the platform $w_M < \tilde{w}_{max}$, it is also profitable for a deviating seller to do so. In contrast, at the other extreme, if the commission rate is very high such that colluding sellers are close to indifferent between listing on both distribution channels or only the direct channel, a deviating seller prefers to delist from the platform and to sell only via the direct channel. In this case collusive prices are high due to the high costs of distribution on the platform and a deviating seller benefits strongly from avoiding contractual restrictions from a PMFN by delisting from the platform.

Based on the results in Lemma 2.2, 2.3, and 2.5, the following proposition characterizes the stability of collusion in the presence of a PMFN.

Proposition 2.4. *Suppose the platform imposes a PMFN (P). If $w_M \leq \tilde{w}_{max}$, the critical discount factor is*

$$\underline{\delta}^P = \underline{\delta}^{NP} = \frac{(2-\alpha)^2}{8 - 8\alpha + \alpha^2}, \tag{2.27}$$

as in the case without a PMFN (NP). At $w_M = \tilde{w}_{max}$, there is a discrete decrease in the critical discount factor such that $\underline{\delta}^P(\tilde{w}_{max}) < \underline{\delta}^{NP}$. Above this commission rate, the critical discount factor $\underline{\delta}^P(w_M)$ increases in $w_M \in (\tilde{w}_{max}, \bar{w}_{max})$, with a kink at $w_M = \hat{w}_{max}$. For a sufficiently large w_M in this range, it holds that $\underline{\delta}^P > \underline{\delta}^{NP}$.

The exact terms for the critical discount factor $\underline{\delta}^P$ for $w_M > \tilde{w}_{max}$ are provided in Equations (2.63) and (2.64) in Appendix A.

For small commission rates $w_M \leq \tilde{w}_{max}$ the critical discount factor is equal to the case without a PMFN and independent of w_M. By conventional interpretation, it follows that the cartel stability between sellers is not affected by the introduction of a PMFN in this range of commission rates. Moreover, this result emphasizes that the ability to engage in price discrimination between distribution channels itself, which is restricted due to a PMFN, does not affect the stability of collusion in this setting as long as the sellers list on both channels.

For higher commission rates, Proposition 2.4 highlights that a PMFN has an effect on the stability of seller collusion due to the fact that it changes the sellers' listing decisions. In particular, at the threshold $w_M = \tilde{w}_{max}$, there is a discrete decrease in the critical discount factor due to the fact that competing sellers do not list on the platform. This effect renders punishment more severe in this range of commission rates and stabilizes seller collusion. Importantly, sellers would realize higher profits if they were present on both distribution channels also for commission rates $w_M > \tilde{w}_{max}$. But, as described above, in this range of commission rates, each seller has a unilateral incentive to delist from the platform and to compete aggressively on the direct channel alone. The sellers therefore suffer from a Prisoner's Dilemma in their listing decisions and realize discretely lower competitive profits.

For commission rates above $\tilde{w}_{max}$, the critical discount factor increases in w_M with a kink at $w_M = \hat{w}_{max}$ due to the fact that at this point the optimal deviation behavior (i.e., the listing decision) changes. This has the effect that $\underline{\delta}^P$ increases more strongly above this threshold because after delisting a deviating seller benefits if the second seller faces a higher commission rate. For the highest admissible commission rate of $w_M = \bar{w}_{max}$, the critical discount factor $\underline{\delta}^P$ is above the critical discount factor without a PMFN, $\underline{\delta}^{NP}$, indicating that collusion is harder to sustain at high commission rates close to $\bar{w}_{max}$. Note that the platform is generally able choose a commission rate such that (i) seller collusion is more profitable than seller competition, and (ii) the critical discount factor $\underline{\delta}^P$ is below the benchmark $\underline{\delta}^{NP}$ absent a PMFN.[20]

Figure 2.1 plots the critical discount factor $\underline{\delta}^P$ depending on the commission rate w_M on the platform as characterized in Proposition 2.4.

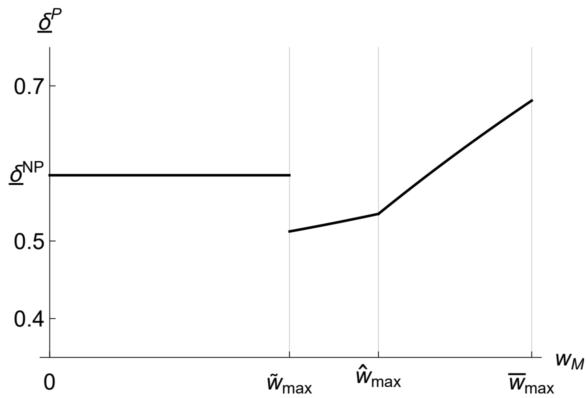

Figure 2.1: Critical discount factor with per-unit commission rates.

The figure shows the critical discount $\underline{\delta}^P$ depending on the exogenous commission rate w_M for $\alpha = 7/10$ and $\beta = 1/2$.

Novel Theory of Harm. The results presented in Sections 2.3 and 2.4 provide a novel theory of harm: A PMFN undermines a platform's incentive to ensure intense competition on its marketplace. Moreover, a PMFN gives the platform the ability to profitably stabilize seller collusion.

These results complement existing concerns regarding PMFNs. As described in Section 2.2, the main established theory of harm predicts that a PMFN leads to higher commission rates and therefore higher consumer prices. As argued above (see, for instance, fn. 16),

[20]For instance, for $\alpha = 7/10$ and $\beta = 1/2$, the optimal commission rate with seller competition is $\tilde{w}_M^P = 0.133$ and yields a profit for the platform of $\tilde{\Pi}_M^P\left(\tilde{w}_M^P\right) = 0.075$. With seller collusion, the commission rate at which the critical discount factor $\underline{\delta}^P\left(w_M\right) = \underline{\delta}^{NP}$ is $\bar{w}_M = 0.268$ and yields a platform profit of $\bar{\Pi}_M^P\left(\bar{w}_M\right) = 0.091$. This implies that the platform can choose a commission rate $w_M < 0.268$ that jointly increases the stability of seller collusion and increases its profit compared to the case of seller competition.

evidence from several markets, however, shows that there is little variation in commission rates when platforms impose or waive a PMFN. Moreover, a platform may not want to increase its commission rate above a certain level in the shadow of regulation. An important aspect of my results is therefore that they do not necessarily require the platform to change its commission in such an event. In particular, suppose that, absent a PMFN, the platform charges a commission rate that violates the participation constraint of competing sellers if it introduces such a clause. Absent adjustments in its commission rates, the platform obviously has a strong incentive to alleviate the competitive pressure between the sellers in order to induce them to continue to sell via the platform. Moreover, the introduction of a PMFN can also stabilize seller collusion without making it necessary for the platform to adapt its commission rate.

2.5 Robustness: Revenue-Sharing Commission

In this section, I verify that the main effects of a PMFN on the stability of seller collusion derived for the case of per-unit commission rates also extend to the case with revenue-sharing commission rates. I show that even small sellers' marginal costs are economically important in my setting and therefore allow for $c \geq 0$ in this section.

In contrast to existing contributions analyzing the agency model with revenue-sharing commission rates such as Foros et al. (2017) or Hino et al. (2019), I allow for asymmetric distribution channels (one platform and one direct channel instead of two symmetric platforms), and online sellers facing (weakly) positive marginal costs $c \geq 0$. Both aspects prevent to fully analyze the model in closed-form solutions and hence I provide the results by means of numerical simulations.

I first provide results for the optimal symmetric revenue-sharing commission rate ϕ_M as a function of seller conduct and whether a PMFN is in place. Second, I establish that with this form of commission rate the platform prefers seller competition absent a PMFN and seller collusion with a PMFN. Third, I analyze the stability of seller collusion.

Commission Rates. If both sellers are active on the platform, the platform's profit is

$$\Pi_A(\phi_M) \quad = \quad \phi_M \sum_{i \in \{1,2\}} p_{iM} q_{iM}(p), \tag{2.28}$$

potentially subject to the constraint $p_{iM} \leq p_{iD}$ if the platform imposes a PMFN.

Depending on the seller conduct, Figure 2.2 plots the numerical results for the optimal revenue-sharing commission rates that the platform sets for a representative parametrization. The left panel shows the case absent a PMFN and the right panel the one with a PMFN. If sellers compete, the optimal commission rate is depicted by the solid line, and if they collude by the dashed line.

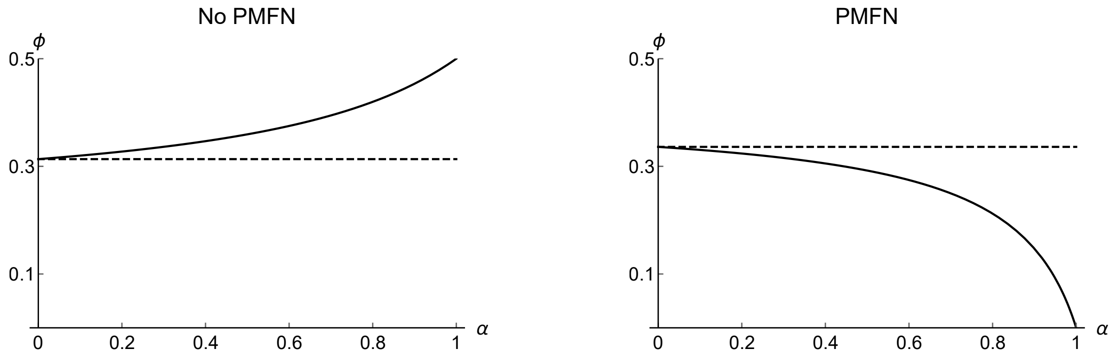

Figure 2.2: Revenue-sharing commission rates.

The figure shows revenue-sharing commission rates for $\beta = 1/2$ and $c = 1/5$ depending on the degree of interbrand competition $\alpha \in (0, 1)$ for the case of seller competition (solid line) and seller collusion (dashed line). The left panel shows the case without a PMFN, the right panel the case with a PMFN.

Absent a PMFN, the optimal commission rate positively depends on the degree of interbrand competition α if the sellers compete. This finding is in contrast to the optimal per-unit commission rate w_M^{NP}, which is independent of α (see Proposition 2.1). The lowest commission rate that online sellers can obtain is at $\alpha \to 0$, which is exactly the commission rate that online sellers obtain if they collude (dashed line).

With a PMFN, this comparative static result is reversed (right panel of Figure 2.2). As in the case with per-unit commission rates, the platform can charge higher commission rates from colluding sellers than it can from competing ones. Again, the reason for this result is that competing sellers may have a unilateral incentive to delist from the platform, which also restricts revenue-sharing commission rates on a low level.[21]

Preferred Seller Conduct. Next, I turn to the platform's preferred seller conduct. Absent a PMFN, the platform benefits from seller competition as in the case with per-unit commission rates.[22] I illustrate this result numerically in the first panel of Figure 2.3.

[21] These comparative static results underline the robustness of the results of Johansen and Vergé (2017). Abstracting from the possibility of seller collusion, they derive qualitatively similar results on the basis of per-unit commission rates and the assumption that contract offers are unobservable, but do not analyze its impact on seller collusion.

[22] With non-zero marginal costs $c > 0$ of the sellers and substitutability between two distribution channels, it is not a concern for the platform that competitive prices and realized revenue on the platform are too low. Each feature implies that the prices on the platform depend positively on the commission rate such that it can ensure a high revenue on the platform. If otherwise marginal costs $c = 0$ and no substitutable channel exists, this effect is not present and the platform would realize low profits if there is strong competition between the sellers. In this case, a platform may prefer weaker seller competition even absent a PMFN.

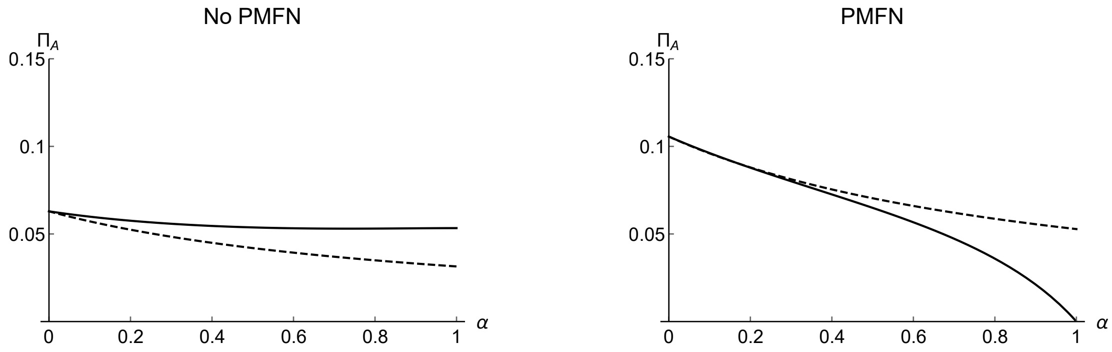

Figure 2.3: Platform profits with revenue-sharing commissions

The figure shows platform profits with optimal revenue-sharing commission rates for $\beta = 1/2$ and $c = 1/5$ depending on the degree of interbrand competition $\alpha \in (0, 1)$ for the case of seller competition (solid line) and seller collusion (dashed line). The left panel shows the case without a PMFN, the right panel the case with a PMFN.

This result is in contrast to Hino et al. (2019). They analyze the case without a PMFN and focus on two symmetric platforms as distribution channels in an extension. They conclude that for fixed commission rates, platforms typically benefit from seller collusion. My analysis shows that if the platform charges optimal commission rates based on seller conduct, it always benefits from seller competition absent a PMFN. Even for fixed commission rates, I find that only for small degrees of intrabrand substitutability β and close to zero sellers' marginal costs c (as analyzed in Hino et al. (2019)) does it hold that the platform prefers seller collusion.[23] This finding shows that it is important to incorporate the seller's marginal costs in the analysis despite the fact that this makes the model less tractable to analyze.

The right panel of Figure 2.3 verifies that the preferred seller conduct changes if the platform can impose a PMFN. As described above, the platform optimally charges higher commission rates from monopolistic sellers and this increase is sufficient to render seller collusion more profitable than seller competition. Importantly, I find that a platform prefers seller collusion for the whole parameter range $\alpha \in (0, 1)$. Hence, the anticompetitive potential of PMFNs is more pronounced in the model with revenue-sharing commission rates than with per-unit commission rates.

Stability of Seller Collusion. Recall that I restrict the range of interbrand competition to $\alpha \in \left(0, \sqrt{3} - 1\right)$ for the analysis of tacit collusion. With revenue-sharing commission rates, I additionally restrict the commission rate to be lower than the threshold value $\hat{\phi}_{max}^{NP}$ (defined in Equation (2.82)) in order to ensure that a seller that charges collusive prices while the other seller deviates from the collusive agreement sells positive

[23]For instance, for $\phi_A = 3/10$ and $\beta = 2/10$, I find that seller collusion is not profitable for the platform for all $\alpha \in (0, 1)$ if $c \gtrsim 1/10$. For smaller degrees of marginal costs (e.g., $c = 3/100$) seller collusion is more profitable for the platform than seller competition for $\alpha \gtrsim 1/2$.

quantities on the platform. The following proposition summarizes the effect of PMFNs on the critical discount factor in the case in which the platform charges time-constant and symmetric revenue-sharing commission rate ϕ_M from the sellers.

Proposition 2.5. *Suppose that* $\alpha \in \left(0, \sqrt{3}-1\right)$ *and the commission rate is* ϕ_M *with* $\phi_M \in \left(0, \hat{\phi}_{max}^{NP}\right)$. *Without a PMFN, the critical discount factor is*

$$\underline{\delta}^{NP}(\phi_M) = \frac{(1-\phi_M)(2-\alpha)^2(1-\beta^2)-(1-\alpha)\beta^2\phi_M^2}{(1-\phi_M)(8-8\alpha+\alpha^2)(1-\beta^2)-2(1-\alpha)\beta^2\phi_M^2}, \tag{2.29}$$

for both sellers $i \in \{1,2\}$. *The critical discount factor increases in* ϕ_M *in the relevant parameter range.*

The result of Proposition 2.5 characterizes the critical discount factor if the platform charges revenue-sharing commission rates and does not impose a PMFN. Clearly, the case of $\phi_M = 0$ is formally equivalent to the case of a per-unit commission rate of zero, and, accordingly, the critical discount factor is the equal to $(2-\alpha)^2/(8-8\alpha+\alpha^2)$ as in Proposition 2.3. In contrast to the case with per-unit commission rates, for $\phi_M > 0$, the critical discount factor positively depends on the revenue-sharing commission rates. This implies that a higher ϕ_M leads to less stable seller collusion. Quantifying the magnitude of the stabilizing effect of revenue-sharing commission rates, however, reveals that there is only a minimal change in the critical discount factor if ϕ_M increases.[24]

For the case with a PMFN, the dependence of the critical discount factor on the commission rate ϕ_M is qualitatively the same as with per-unit commission rates in Proposition 2.4. In particular, I also find threshold values on the commission rate for which competing $\left(\tilde{\phi}_{max}^P\right)$, deviating $\left(\hat{\phi}_{max}^P\right)$, and colluding sellers $\left(\bar{\phi}_{max}^P\right)$ prefer to be active on both distribution channels, and these threshold values exhibit the same ordering as for the case with per-unit commission rates. The following proposition summarizes the result.

Proposition 2.6. *Suppose the platform imposes a PMFN* (P). *If sellers face a commission rate* $\phi_M \leq \tilde{\phi}_{max}^P$, *the critical discount factor is*

$$\underline{\delta}^{P}(\phi_M) = \frac{(2-\alpha)^2}{8-8\alpha+\alpha^2}. \tag{2.30}$$

At $\phi_M = \tilde{\phi}_{max}^P$, *there is a discrete decrease in the critical discount factor. Above this commission rate, the critical discount factor* $\underline{\delta}^P(\phi_M)$ *increases in* $\phi_M \in \left(\tilde{\phi}_{max}^P, \bar{\phi}_{max}^P\right)$, *with a kink at* $\phi_M = \hat{\phi}_{max}^P$. *For a sufficiently large* ϕ_M *in this range, it holds that* $\underline{\delta}^P(\phi_M) > \frac{(2-\alpha)^2}{8-8\alpha+\alpha^2}$. *Over the complete parameter range, it holds that* $\tilde{\phi}_{max}^P < \hat{\phi}_{max}^P < \bar{\phi}_{max}^P$.

[24] For the specification $\alpha = \beta = 1/2$ and $c = 0$, Figure 2.4 in Appendix A illustrates that the critical discount factor $\underline{\delta}^{NP}(\phi_M)$ maximally increases by 0.4%.

The result of Proposition 2.6 is illustrated in Figure 2.5 in Appendix A. It highlights that the same pattern as with per-unit commission rates emerges for the case with revenue-sharing commission rates.

2.6 Conclusion

This paper links the presence of a PMFN to reduced platform incentives to ensure seller competition on the platform. Absent contractual restrictions, a platform benefits from seller competition as it leads to more transactions on the platform and generally (weakly) higher commission rates for the platform. In contrast, a PMFN can align the interests of sellers and platforms regarding seller collusion and, therefore, undermines a platform's incentive to organize a competitive marketplace. Intuitively, a reduction of competition between the sellers on both the platform and the direct channel enables a platform to collect higher commission rates. Through this increase in the commission rate, the platform can benefit from seller collusion.

Moreover, in line with the incentive to reduce seller competition, the analysis highlights that a platform can profitably stabilize seller collusion if it imposes a PMFN. Recent antitrust cases (discussed in the Introduction) suggest that the conduct of price-fixing agreements between sellers is a concern for competition authorities more broadly. This concern can be especially pressing if platform providers have little interest in encouraging seller competition on their own marketplace, and my analysis reveals under which conditions this is the case in the presence of a PMFN.

In summary, my results offer a novel theory of harm, linking such clauses to potentially reduced competition at the seller level, and add to the vivid debate as regards their anticompetitive potential. Established concerns regarding PMFNs rely on the prediction that a PMFN leads to higher commission rates (see e.g., Boik and Corts 2016). In several real-world cases (online hotel bookings, e-books, etc.) this prediction, however, appears not to hold. Importantly, the results presented in this paper on a platform's incentive and ability to encourage seller competition also apply if a platform does not adjust its commission rate with the introduction of a PMFN. In particular, the result that collusive sellers are more likely to list on the platform for higher commission rates than competing ones implies that a platform may lose its incentive to fight seller collusion with the introduction of a PMFN even if it does not adjust its commission rate.

Future research should continue to analyze a platform's incentive and ability to affect the competitive interaction between sellers in different environments. Given that platforms are *private rule-makers* for the marketplace that they have created, it is important to identify situations in which a platform has little interest in ensuring a competitive environment between sellers, and to ensure that consumers can reap the full benefits of purchasing goods and services in the digital economy.

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Appendix

Appendix A: Proofs

Proof of Lemma 2.1. Absent a PMFN and if sellers set prices non-cooperatively, each seller maximizes its profit function in Equation (2.2). Solving the corresponding first-order conditions yields the retail prices $\tilde{p}^{NP}$ reported in the lemma. It is straightforward to verify that the second-order conditions are fulfilled. Inserting these retail prices in the demand function in Equation 2.1, yields that the quantity that seller i sells via the platform is

$$q_{iM}\left(\tilde{p}^{NP}\right) = \frac{1-\beta-w_M}{(2-\alpha)(1+\alpha)(1-\beta^2)}, \tag{2.31}$$

which is non-negative if and only if $w_M \leq 1-\beta$.

In the monopolistic case, sellers set retail prices in order to maximize their joint profit

$$\pi_{12}(p) = \pi_1(p) + \pi_2(p) = \sum_{i\in\{1,2\}} (p_{iM}-w_M)\, q_{iM}(p) + p_{iD}q_{iD}(p). \tag{2.32}$$

The resulting retail prices $\bar{p}^{NP}$ are reported in the lemma, and the second-order conditions hold. The quantity that each seller i sells on the platform is

$$q_{iM}\left(\bar{p}^{NP}\right) = \frac{1-\beta-w_M}{2(1+\alpha)(1-\beta^2)}, \tag{2.33}$$

which is non-negative if and only if $w_M \leq 1-\beta$. This establishes the result. For future reference, note that a seller's profit with competition is

$$\tilde{\pi}_i^{NP}(w_M) = \frac{(1-\alpha)\left(2-2\beta+w_M^2-2(1-\beta)w_M\right)}{(2-\alpha)^2(1+\alpha)(1-\beta^2)}, \tag{2.34}$$

where $\tilde{\pi}_i^{NP}(w_M) = \tilde{\pi}_i^{NP}\left(\tilde{p}^{NP}(w_M)\right)$. The resulting monopolistic seller profit is

$$\bar{\pi}_i^{NP}(w_M) = \frac{2-2\beta+w_M^2-2(1-\beta)w_M}{4(1+\alpha)(1-\beta^2)}, \tag{2.35}$$

where $\bar{\pi}_i^{NP}(w_M) = \bar{\pi}_i^{NP}\left(\bar{p}^{NP}(w_M)\right)$Note that $\tilde{\pi}_i^{NP}(w_M)$ and $\bar{\pi}_i^{NP}(w_M)$ decrease in $w_M \in [0, 1-\beta]$.

□

Proof of Proposition 2.1. Based on the seller behavior in the second stage of the static game (Lemma 2.1), the platform maximizes its profit in Equation (2.3) with respect to the per-unit commission rate w_M. The corresponding first-order condition $\partial\Pi_M/\partial w_M = 0$ can be written as

$$q_1(p(w_M)) + q_2(p(w_M)) + w_M\left(\frac{\partial q_1(p(w_M))}{\partial w_M} + \frac{\partial q_2(p(w_M))}{\partial w_M}\right) = 0.$$

Solving the first-order condition yields the optimal commission rate w_M^{NP} reported in the proposition at which the second-order conditions hold. Note that $w_M^{NP}{=}(1-\beta)/2 < 1{-}\beta$, which implies that sellers are willing to accept the platform's contract at this commission rate (Lemma 2.1). Based on w_M^{NP} , the platform realizes a profit of

$$\tilde{\Pi}_M^{NP}\left(w_M^{NP}\right) = \frac{1-\beta}{2(2-\alpha)(1+\alpha)(1+\beta)}, \tag{2.36}$$

if sellers compete, and it realizes

$$\bar{\Pi}_M^{NP}\left(w_M^{NP}\right) = \frac{1-\beta}{4(1+\alpha)(1+\beta)}, \tag{2.37}$$

in the monopolistic case. Calculations reveal that $\tilde{\Pi}_M(w_M) > \bar{\Pi}_M(w_M)$ for $w_M \in [0, 1-\beta]$. □

Proof of Lemma 2.2. Suppose that the platform imposes a PMFN, which requires $p_{iM} \leq p_{iD}$. This proof characterizes the sellers' competitive price setting and listing behavior depending on the platform's commission rate.

Suppose that both list on both distribution channels. In the competitive case, each seller faces the maximization problem

$$\begin{aligned} \max_{p_{iM}, p_{iD}} \pi_i(p_i, p_h) &= (p_{iM} - w_M)\, q_M(p) + p_{iD} q_{iD}(p) \\ &\quad s.t. \;\; p_{iM} \leq p_{iD}. \end{aligned} \tag{2.38}$$

Based on the results of Lemma 2.1, the constraint is binding. Thus, sellers charge the same retail price on both distribution channels if active on the platform. Solving the corresponding first-order condition leads to the retail prices reported in the lemma leading to seller profits of

$$\tilde{\pi}_i^P(w_M) = \frac{(1-\alpha)(2-w_M)^2}{2(2-\alpha)^2(1+\alpha)(1+\beta)}. \tag{2.39}$$

Alternatively, a seller can deviate and list only on the direct channel and maximize the following profit function

$$\pi_i\left(p_{iD}, \infty, \tilde{p}_h^P\right) = p_{iD} q_{iD}\left(p_{iD}, \infty, \tilde{p}_h^P\right), \tag{2.40}$$

where ∞ indicates that seller i is not active on the platform while the rival seller h is present on both distribution channels and is expected to set $\tilde{p}_h^P$ on both distribution channels. Taking as given that seller h charges the competitive retail prices, seller i maximizes its profit by setting

$$\tilde{p}_{iD}^P\left(w_M\right) = \frac{4-\alpha\left(4-w_M\right)}{8-4\alpha}, \tag{2.41}$$

resulting in a profit of

$$\tilde{\pi}_i^P\left(\tilde{p}_{iD}^P\left(w_M\right), \infty, \tilde{p}_h^P\right) = \frac{\left(4-\alpha\left(4-w_M\right)\right)^2}{16\left(\alpha-2\right)^2\left(1-\alpha^2\right)}. \tag{2.42}$$

In order to derive the threshold value $\tilde{w}_{max}$ reported in Lemma 2.2, equate the profit from being active on both channels in Equation (2.39) with the profit from being active on the direct channel in Equation (2.42), which yields

$$\begin{aligned} & \tilde{\pi}_i^P\left(w_M\right) && = \pi_i\left(\tilde{p}_{iD}^P\left(w_M\right), \infty, \tilde{p}_i^P\left(w_M\right)\right) \\ \Longleftrightarrow\quad & \tfrac{4(1-\alpha)(2-w_M)}{2(2-\alpha)^2(1+\alpha)(1+\beta)} && = \frac{\left(4-\alpha\left(4-w_M\right)\right)^2}{16\left(\alpha-2\right)^2\left(1-\alpha^2\right)} \\ \Longleftrightarrow\quad & \tfrac{(1-\alpha)(2-w_M)^2}{4-\alpha(4-w_M)} && = \sqrt{2\left(1+\beta\right)} \end{aligned} \tag{2.43}$$

The resulting threshold value is

$$\tilde{w}_{max} = \frac{4\left(1-\alpha\right)\left(2-\sigma\left(\beta\right)\right)}{4-\alpha\left(4-\sigma\left(\beta\right)\right)}, \tag{2.44}$$

with $\sigma\left(\beta\right) = \sqrt{2\left(1+\beta\right)}$.

For commission rates $w_M > \tilde{w}_{max}$, suppose that both sellers are active on the direct channel only. In this case each seller maximizes $\pi_i\left(p_D, \infty\right) = p_{iD} q_{iD}\left(p_D, \infty\right)$. The resulting retail prices are $\tilde{p}_{iD}^P\left(w\right) = \left(1-\alpha\right)/\left(2-\alpha\right)$ as specified in Equation (2.4) in Lemma 2.1. The resulting profit is

$$\begin{aligned} \tilde{\pi}_{i(D)}^P\left(w_M\right) &= \pi_i\left(\tilde{p}_{iD}^P\left(w_M\right), \infty\right) \\ &= \frac{1-\alpha}{\left(2-\alpha\right)^2\left(1+\alpha\right)}. \end{aligned} \tag{2.45}$$

Note that for $w_M > \tilde{w}_{max}$, no seller finds it profitable to deviate from this equilibrium and list on both distribution channels. The profit from being active on both channels $\tilde{\pi}_i^P(w_M)$ in Equation (2.39) is larger than the profit on the direct channel only $\tilde{\pi}_{i(D)}^P(w_M)$ in Equation (2.45) for $w_M \in (0, 2-\sigma(\beta))$, with $\tilde{w}_{max} < 2-\sigma(\beta)$. Equilibrium selection based on payoff-dominance hence implies that both sellers list on the platform for $w_M \leq \tilde{w}_{max}$ and on the direct channel only for $w_M > \tilde{w}_{max}$. This establishes the result. □

Proof of Lemma 2.3. In the monopolistic case and if sellers are active on both distribution channels, the joint profit maximization of $\pi_{12} = \pi_1 + \pi_2$ is

$$\max_p \ \pi_{12}(p) = \sum_{i\in\{1,2\}} (p_{iM} - w_M) q_{iM}(p) + p_{iD} q_{iD}(p) \qquad (2.46)$$
$$s.t. \quad p_{iM} \leq p_{iD}.$$

Solving the corresponding first-order conditions leads to the retail prices reported in the lemma, and the monopolistic profit of

$$\bar{\pi}_i^P(w_M) = \frac{(2-w_M)^2}{8(1+\alpha)(1+\beta)}. \qquad (2.47)$$

Monopolistic sellers can also decide to only list on the direct channel in order to avoid the contractual restrictions of a PMFN. In this case, they set retail prices in order to maximize their profits on the direct channel

$$\max_{p_D} \ \pi_{12}(p_D, \infty) = \sum_{i\in\{1,2\}} p_{iD} q_{iD}(p_{1D}, \infty, p_{2D}, \infty). \qquad (2.48)$$

The resulting retail prices are the same as the monopolistic direct channel prices for the case without a PMFN as reported in Lemma 2.1, $\bar{p}_{iD}^P = 1/2$, and the profit in this case for each seller i is

$$\bar{\pi}_i^P\left(\bar{p}_D^P, \infty\right) = \frac{1}{4+4\alpha}. \qquad (2.49)$$

Monopolistic sellers prefer to be active on both distributions channels if the profit in Equation (2.47) exceeds the profit in Equation (2.49), which is equivalent to the commission rate w_M being sufficiently small:

$$w_M \leq \bar{w}_{max} = 2 - \sqrt{2(1+\beta)} = 2 - \sigma(\beta). \qquad (2.50)$$

This establishes the result. □

Proof of Proposition 2.2. With both seller competition and monopolistic seller behavior, the unrestricted solution to the platform's maximization yields an optimal commission rate of $w_M = 1$, which exceeds both threshold values $\tilde{w}_{max}$ and $\bar{w}_{max}$ derived in Lemma 2.2 and Lemma 2.3. The platform's profit increases in the per-unit commission rate up to $w_M = 1$ given that both sellers are willing to list on the platform, and hence the sellers' participation constraint binds at the optimal commission rate.

Based on the optimal commission rate $\tilde{w}_M^P = \tilde{w}_{max}$ (Equation (2.10)), the platform realizes a profit of

$$\tilde{\Pi}_M^P \left(\tilde{w}_M^P\right) = \frac{8\left(1-\alpha\right)\left(2-\sigma\left(\beta\right)\right)\sigma\left(\beta\right)}{\left(1+\alpha\right)\left(1+\beta\right)\left(4-\alpha\left(4-\sigma\left(\beta\right)\right)\right)^2}, \tag{2.51}$$

with seller competition, and based on the commission rate $\bar{w}_M^P = \bar{w}_{max}$ (Equation (2.14)), the platform realizes a period profit of

$$\bar{\Pi}_M^P \left(\bar{w}_M^P\right) = \frac{\left(2-\sigma\left(\beta\right)\right)\sigma\left(\beta\right)}{2\left(1+\alpha\right)\left(1+\beta\right)}, \tag{2.52}$$

with seller collusion. Calculations show that $\bar{\Pi}_M\left(\bar{w}^P\right) > \tilde{\Pi}_M^P\left(\tilde{w}^P\right)$ if
$\alpha > \bar{\alpha} = \left(16 - 8\sigma\left(\beta\right)\right) / \left(16 - 8\sigma\left(\beta\right) + \sigma\left(\beta\right)^2\right)$. □

Proof of Lemma 2.4. If a seller i deviates from the collusive agreement, it decides (i) whether it prefers to be active on both distribution channels or only the direct channel, and (ii) on retail prices on each active channel that maximize the seller's profits in the current period given the commission rate w_M, and given that the other seller h charges collusive retail prices $\bar{p}_h^{NP} = \left(\bar{p}_{hM}^{NP}, \bar{p}_{hD}^{NP}\right)$ as in Equation (2.5). If the deviating seller decides to be active on both distribution channels, this implies $\hat{p}_i^{NP} = \left(\hat{p}_{iM}^{NP}, \hat{p}_{iD}^{NP}\right) \in \arg\max_{p_i} \pi_i\left(p_i; \bar{p}_h^{NP}\right)$. The resulting retail prices of the deviating seller are

$$\begin{aligned} \hat{p}_{iM}^{NP}\left(w_M\right) &= \frac{2-\alpha}{4} + \frac{\left(2+\alpha\right)w_M}{4}, \\ \hat{p}_{iD}^{NP}\left(w_M\right) &= \frac{2-\alpha}{4}, \end{aligned} \tag{2.53}$$

where the hat symbol indicates that seller i deviated from the collusive agreement. The deviating seller i receives a profit of

$$\hat{\pi}_i^{NP}\left(w_M\right) = \frac{\left(\alpha-2\right)^2\left(2-2\beta+w_M^2-2\left(1-\beta\right)w_M\right)}{16\left(1-\alpha^2\right)\left(1-\beta^2\right)}. \tag{2.54}$$

Denote the seller's profits in the case of being active only on the direct channel with $\pi_i\left(p_{iD}, \infty; \bar{p}_h^{NP}\right)$, where ∞ indicates that seller i is inactive on the platform. Note that the same direct channel price $\hat{p}_{iD}^{NP}$ as reported in Equation (2.53) maximizes the profit of the deviating seller in this case. The resulting profit in this case is $\hat{\pi}_i^{NP} = (2 -$

$\alpha)^2/(16(1-\alpha^2))$, which is strictly smaller than the profit from being active on both distribution channels reported in Equation (2.54) for all $w_M \in [0, 1-\beta]$.

Lastly, it is necessary to verify that the non-deviating seller h sells a positive quantity via the platform. That is, for w_M in the relevant range it has to hold that

$$\begin{aligned} \check{q}_{hM} = q_{hM}\left(\bar{p}_h^{NP}, \hat{p}_i^{NP}\right) &= \frac{(\alpha^2 + 2\alpha - 2)(1-\beta-w_M)}{4(1-\alpha^2)(1-\beta^2)} > 0 \\ \iff \quad \alpha &< \sqrt{3} - 1, \end{aligned} \tag{2.55}$$

where $\check{q}_{hM} = q_{hM}(\bar{p}_h, \hat{p}_i)$ indicates the quantity of the non-deviating seller h on the platform. The same inequality holds for the direct channel. This establishes the result. □

Proof of Proposition 2.3. Given that upstream firms sustain collusion by means of grim trigger strategies, and inserting Equations (2.34), (2.35), and (2.54) into the formula for the critical discount factor in Equation 2.21 yields

$$\underline{\delta}^{NP} = \frac{(2-\alpha)^2}{8 - 8\alpha + \alpha^2}. \tag{2.56}$$

As reported in Proposition 2.3, the critical discount factor is independent of the degree of intrabrand competition β and the exact level of the symmetric commission rate w_M. Moreover, the critical discount factor $\underline{\delta}^{NP}$ is an increasing function of α in the relevant range $\alpha \in \left(0, \sqrt{3} - 1\right)$. □

Proof of Lemma 2.5. If a seller decides to deviate from the collusive agreement characterized in Lemma 2.3, it has to decide whether to be active on both distribution channels or on the direct channel only. Consider that the commission rate is sufficiently small that $w_M \leq \bar{w}_{max}$ such that colluding sellers are active on the platform. First, consider that the seller is active on both channels. Restricted by the PMFN, the deviating seller maximizes

$$\begin{aligned} \max_{p_i} \; \pi_i\left(p_i, \bar{p}_h^P(w_M)\right) \quad &= \quad (p_{iM} - w_M)\, q_{iM}\left(p_i, \bar{p}_h^P(w_M)\right) + p_{iD} q_{iD}\left(p_i, \bar{p}_h^P(w_M)\right) \\ &s.t. \quad p_{iM} \leq p_{iD}, \end{aligned} \tag{2.57}$$

where the rival seller h sticks to the collusive agreement and charges $\bar{p}_h^P(w)$ as specified in Equation (2.15) on both distribution channels. The seller optimally charges

$$\hat{p}_i^P \quad = \quad \frac{1}{8}\left(4 - 2\alpha + (2+\alpha)\, w_M\right), \tag{2.58}$$

which results in a profit of

$$\hat{\pi}_i^P(w) = \frac{(2-\alpha)^2 (2 - w_M)^2}{32(1-\alpha^2)(1+\beta)}. \tag{2.59}$$

Instead, the deviating seller can delist from the platform in order to maximize the profit function $\pi_i\left(p_{iD}, \infty; \bar{p}_h^P(w_M)\right)$, where ∞ indicates that the seller is not active on the platform. The seller is not restricted by the PMFN in this case and optimally charges $\hat{p}_{iD}(w) = \frac{1}{8}(4-(2-w_M)\alpha)$. This price depends positively on the commission rate on the platform w_M due to the fact that it induces the collusive price of the other seller to be higher on both channels. The resulting profit is

$$\hat{\pi}_{i(D)}^P(w) = \hat{\pi}_i^P\left(\hat{p}_{iD}(w), \infty; \bar{p}_h^P(w)\right) = \frac{(4-\alpha(2-w_M))^2}{64(1-\alpha^2)}, \tag{2.60}$$

which is smaller than the profit from being active on both channels in Equation (2.59) only if the platform's commission rate is sufficiently small. By the same steps as above, the threshold value is

$$w_M \leq \hat{w}_{max} = \frac{2(2-\alpha)(2-\sigma(\beta))}{4-\alpha(2-\sigma(\beta))}, \tag{2.61}$$

with $\sigma(\beta) = \sqrt{2(1+\beta)}$. Otherwise, a deviating seller prefers to be present only on the direct channel $\left(\hat{\pi}_{i(D)}^P(w) > \hat{\pi}_i^{NP}(w),\ \forall w_M > \hat{w}_{max}\right)$, as the benefit from charging a more profitable direct channel price outweighs the forgone profit from the lost sales on the platform at high commission rates. Comparing the threshold values given in Equations (2.44), (2.50), and (2.61) yields that $\tilde{w}_{max} \leq \hat{w}_{max} \leq \bar{w}_{max}$ over the complete parameter range. This establishes the result. □

Proof of Proposition 2.4. For the derivation of the critical discount factor with PMFN, I distinguish three cases: First, I consider the case for which the commission rate is sufficiently small such that sellers are active on the platform in all periods. In particular, this condition is fulfilled for $w_M \leq \tilde{w}_{max}$. In this case, I can insert the equilibrium profits of the stage games in which sellers are active on both channels (Equations (2.39), (2.47), and 2.59) in the formula for the critical discount factor derived in Equation (2.21). The resulting critical discount factor is

$$\underline{\delta}^P = \frac{\hat{\pi}_i^P - \bar{\pi}_i^P}{\hat{\pi}_i^P - \tilde{\pi}_i^P} = \frac{(2-\alpha)^2}{8-8\alpha+\alpha^2}, \tag{2.62}$$

as in the case without PMFN (see Equation (2.23) in Proposition 2.3).

Second, as derived in Lemma 2.2, for commission rates $w_M > \tilde{w}_{max}$, competing sellers are only present on the direct channel and realize profits of $\tilde{\pi}_{i(D)}^P(w)$ derived in Equation (2.45) instead of $\tilde{\pi}_i^P(w)$. Due to the fact that, at $w_M = \tilde{w}_{max}$, $\tilde{\pi}_{i(D)}^P(\tilde{w}_{max})$ is strictly smaller than $\tilde{\pi}_i^P(\tilde{w}_{max})$ in Equation (2.39), and as the critical discount factor decreases in the punishment profit, there is a discrete decrease in $\underline{\delta}^P$ at $w_M = \tilde{w}_{max}$.

For the range $w_M \in (\tilde{w}_{max}, \hat{w}_{max}]$, the critical discount factor $\underline{\delta}^P$ is

$$\frac{(2-\alpha)^2 \alpha^2 (2-w_M)^2}{4\left(\alpha\left(\alpha\left((2-\alpha)^4-8\beta\right)-16(1-\beta)\right)-8\beta+8\right)+(2-\alpha)^4 w_A^2-4(2-\alpha)^4 w_M}, \quad (2.63)$$

which increases in $w_M \in (\tilde{w}_{max}, \hat{w}_{max}]$ for the complete parameter range.

Third, as derived in Lemma 2.5, a deviating seller is only present on the direct channel for $w_M > \hat{w}_{max}$. Compared to the critical discount factor for low commission rates in Equation (2.62), the deviation profit is therefore $\hat{\pi}^P_{i(D)}(w)$ in Equation (2.60) instead of $\hat{\pi}^P_i(w)$ in Equation (2.59). As $\hat{\pi}^P_{i(D)}(\hat{w}_{max}) = \hat{\pi}^P_i(\hat{w}_{max})$ and as in the range $w_M \in (\hat{w}_{max}, \bar{w}_{max}]$, $\hat{\pi}^P_{i(D)}(w)$ increases more strongly in w_M, there is a kink in the critical discount factor $\underline{\delta}^P$ at $w_M = \hat{w}_{max}$. For the range $w_M \in (\hat{w}_{max}, \bar{w}_{max}]$, the critical discount factor $\underline{\delta}^P$ is

$$\frac{(2-\alpha)^2\left((4-\alpha(2-w_M))^2-\frac{8(1-\alpha)(2-w_M)^2}{1+\beta}\right)}{\alpha\left(4\alpha(8-(8-\alpha)\alpha)+\alpha(2-\alpha)^2 w_M^2+4(2-\alpha)^3 w_M\right)}, \quad (2.64)$$

which increases in w_M. At $w_M = \bar{w}_{max}$, it holds that the critical discount factor $\underline{\delta}^P$ is strictly larger than $\underline{\delta}^{NP}$. This establishes the result. □

Proof of Proposition 2.5. As in the case with per-unit commission rates, I first analyze the case of no PMFN and afterwards analyze the case with a PMFN. Consider that the platform sets a symmetric commission rate ϕ_M. I restrict the platform's commission rate to

$$\phi_M \in \left[0, \frac{(\alpha(2+\alpha)-2)(1-\beta)(1-c)}{\alpha^2+2\alpha+(1-\alpha^2-\alpha)\beta(1-c)-2}\right], \quad (2.65)$$

in order to ensure that a seller that charges collusive prices remains active on the platform if the second sellers deviates from the collusive agreement. If a seller is present on both distribution channels, its profit is

$$\pi_i(p) = ((1-\phi_M)p_{iM}-c)\, q_{iM}(p) + (p_{iD}-c)\, q_{iD}(p). \quad (2.66)$$

Absent a PMFN, and with seller competition,each seller i maximizes the profit in Equation (2.66) taking as given the commission rates and the rival seller's behavior. I verify below that a seller has no incentive to be active on the direct channel only. The resulting retail prices are

$$\begin{aligned} \tilde{p}^{NP}_{iM}(\phi_M) &= \frac{(2-\alpha)\left(1-\beta^2\right)(1-\alpha+c)+(1-\alpha)(1-\beta)\phi_M(\alpha-\beta(1-\alpha+c)-2)}{(2-\alpha)^2(1-\beta^2)-(1-\alpha)\beta^2\phi_M^2-(2-\alpha)^2(1-\beta^2)\phi_M}, \\ \tilde{p}^{NP}_{iD}(\phi_M) &= \frac{(\beta-1)((1-\alpha)(1-\phi_M)(\beta\phi_M-(2-\alpha)(1+\beta))+c\phi_M(2-\alpha+\beta)-(2-\alpha)(1+\beta)c)}{(2-\alpha)^2(1-\beta^2)-(1-\alpha)\beta^2\phi_M^2-(2-\alpha)^2(1-\beta^2)\phi_M}. \end{aligned} \quad (2.67)$$

Each seller $i \in \{1, 2\}$ sets the same retail price on distribution channel $j \in \{M, D\}$ but the retail prices are strictly lower on the direct channel for $\phi_M > 0$. The price on the platform $\tilde{p}_{iM}^{NP}(\phi_M)$ positively depends on the commission rate ϕ_M for $c \geq 0$ and $\alpha, \beta \in (0, 1)$ in the relevant range. The resulting seller profit is

$$\tilde{\pi}_i^{NP}(\phi_M) = \frac{(1-\alpha)\left(\phi_M{}^2(1-\beta+\beta c) - (1-\beta)(3-c)(1-c)\phi_M + 2(1-\beta)(1-c)^2\right)}{(1+\alpha)(2-\alpha)^2(1-\beta^2) - (1-\alpha^2)\beta^2\phi_M{}^2 - (1+\alpha)(2-\alpha)^2(1-\beta^2)\phi_M}. \tag{2.68}$$

Suppose seller i does not accept the platform's contract offer, while the competing seller h is active on both distribution channels and charges retail prices as specified in Equation (2.67). In this case, seller i maximizes

$$\max_{p_{iD}} \ \pi_i\left(p_{iD}, \infty, \tilde{p}_h^{NP}(\phi_M)\right) = (p_{iD} - c)\, q_{iD}\left(p_{iD}, \infty, \tilde{p}_h^{NP}(\phi)\right). \tag{2.69}$$

The resulting retail price is

$$\begin{aligned} \tilde{p}_{i(D)}^{NP}(\phi_M) &= \frac{1}{2}(1-\alpha+c) \\ &+ \frac{\alpha(\beta-1)\left((1-\alpha)(1-\phi_M)(\beta\phi_M - (2-\alpha)(1+\beta)) + c\phi_M(2-\alpha+\beta) + (\alpha-2)(1+\beta)c\right)}{2\left((\alpha-1)\beta^2\phi_M{}^2 + (2-\alpha)^2(\beta^2-1)\phi_M + (2-\alpha)^2(1-\beta^2)\right)}, \end{aligned} \tag{2.70}$$

where $\tilde{p}_{i(D)}^{NP}$ indicates that i is only active on the direct channel. The resulting profit for seller i is

$$\tilde{\pi}_{i(D)}^{NP}(\phi_M) = \frac{(1-\alpha)\left(2(2-\alpha)\left(1-\beta^2\right)(1-c) + \beta\phi_M{}^2(\alpha - \beta(1-c)) + (1-\beta)(1-c)\phi_M(\alpha(2+\beta) - 4(1+\beta))\right)^2}{4(1+\alpha)\left((2-\alpha)^2(1-\beta^2)(1-\phi_M) - (1-\alpha)\beta^2\phi_M{}^2\right)^2}, \tag{2.71}$$

where $\tilde{\pi}_{i(D)}(\phi_M) = \tilde{\pi}_i^{NP}\left(\tilde{p}_{i(D)}^{NP}(\phi_M), \infty, \tilde{p}_h(\phi_M)\right)$. This deviation is not profitable if the profit in Equation (2.68) exceeds the profit in Equation (2.71), which is the case if

$$\phi_M \leq \tilde{\phi}_{max}^{NP} = \frac{(2-\alpha)(1-\beta)(1-c)}{2-\alpha-\beta(1-c)}. \tag{2.72}$$

Note that this restriction on the commission rate is weaker than the one imposed in Equation (2.65). Hence, competing sellers always prefer to be active on both distribution channels.

With collusion, sellers maximize joint profits $\pi_{12} = \pi_1 + \pi_2$ and optimally set retail prices of

$$\begin{aligned} \bar{p}_{iM}^{NP}(\phi_M) &= \frac{(1-\beta)\phi_M(2+\beta+\beta c) - 2\left(1-\beta^2\right)(1+c)}{\beta^2(2-\phi_M)^2 - 4(1-\phi_M)}, \\ \bar{p}_{iD}^{NP}(\phi_M) &= \frac{(1-\beta)\left(\phi_M(2+3\beta+(2+\beta)c) - \beta\phi_M^2 - 2(1+\beta)(1+c)\right)}{\beta^2(2-\phi_M)^2 - 4(1-\phi_M)}, \end{aligned} \tag{2.73}$$

with collusive profits of

$$\bar{\pi}_i^{NP}(\phi_M) = \frac{(1-\beta)(3-c)(1-c)\phi_M - \phi_A^2(1-\beta(1-c)) - 2(1-\beta)(1-c)^2}{(1+\alpha)\left(\beta^2(\phi_M-2)^2 + 4(\phi_A-1)\right)}. \tag{2.74}$$

Alternatively, colluding sellers may decide to list on the direct channel only. In this case they maximize

$$\max_{p_D} \; \pi_{12}(p_D, \infty) = \sum_{i\in\{1,2\}} (p_{iD} - c)\, q_{iD}(p_D, \infty), \tag{2.75}$$

with resulting retail prices of $\bar{p}_{i(D)}^{NP} = (1+c)/2$ and a realized profit of $\bar{\pi}_{i(D)}^{NP} = (1-c)^2/(4(1+\alpha))$. Colluding sellers prefer to be present on both distribution channels if

$$\phi_M \leq \bar{\phi}_{max}^{NP} = 2 - \frac{2(1+c)}{2-\beta(1-c)}. \tag{2.76}$$

This restriction on the commission rate is weaker than the one imposed in Equation (2.65), and colluding sellers are active on both distribution channels.

Consider that seller i deviates from the collusive agreement, while seller h is present on both distribution channels and charges collusive prices specified in Equation (2.73). The deviating seller sets retail prices p_i in order to maximize

$$\pi_i\left(p_i, \bar{p}_h^{NP}(\phi_M)\right) = ((1-\phi_M)p_{iM} - c)\, q_{iM}\left(p_i, \bar{p}_h^{NP}(\phi_M)\right) + (p_{iD} - c)\, q_{iD}\left(p_i, \bar{p}_h^{NP}(\phi_M)\right). \tag{2.77}$$

The resulting retail prices are

$$\hat{p}_{iM}^{NP}(\phi_M) = \frac{\left(1-\beta^2\right)(2-\alpha+(2+\alpha)c) + (1-\beta)\phi_M(2-\alpha+\beta(1-\alpha+c))}{4(1-\phi_M) - \beta^2(2-\phi_M)^2}, \tag{2.78}$$

$$\hat{p}_{iD}^{NP}(\phi_M) = \frac{(1-\beta)(1-\phi_M)((2-\alpha)(1+\beta)+\beta\phi_M) + (2+\alpha)\left(1-\beta^2\right)c - (1-\beta)c\phi_M(2+\alpha\beta+\alpha+\beta)}{4(1-\phi_M) - \beta^2(2-\phi_M)^2}, \tag{2.79}$$

yielding a deviation profit of

$$\hat{\pi}_i^{NP}(\phi_M) = \frac{\left((2-\alpha)^2\left(1-\beta^2\right) - (1-\alpha)\beta^2\phi_M^2 - (2-\alpha)^2\left(1-\beta^2\right)\phi_M\right)}{\left(1-\alpha^2\right)\left(\beta^2(2-\phi_M)^2 - 4(1-\phi_M)\right)^2} \\ \frac{\left(\phi_M^2(1-\beta(1-c)) - (1-\beta)(3-c)(1-c)\phi_M + 2(1-\beta)(1-c)^2\right)}{\left(1-\alpha^2\right)\left(\beta^2(2-\phi_M)^2 - 4(1-\phi_M)\right)^2} \tag{2.80}$$

The non-deviating seller h that sticks to the collusive agreement sells on the platform the quantity of

$$\begin{aligned} & q_{hM}\left(\bar{p}_h^{NP}\left(\phi_M\right), \hat{p}_i^{NP}\left(\phi_M\right)\right) \\ = \quad & \frac{\phi_M\left(\alpha^2+2\alpha+\left(1-\alpha^2-\alpha\right)\beta\left(1-c\right)-2\right)-\left(\alpha\left(2+\alpha\right)-2\right)\left(1-\beta\right)\left(1-c\right)}{\left(1-\alpha^2\right)\left(4\left(1-\phi_M\right)-\beta^2\left(2-\phi_M\right)^2\right)}, \end{aligned} \tag{2.81}$$

which is larger than zero if Assumption 2.1 is fulfilled $\left(\alpha<\sqrt{3}-1\right)$ and the commission rate ϕ_M is sufficiently small

$$\phi_M \quad \leq \quad \hat{\phi}_{max}^{NP}=\frac{\left(\alpha\left(2+\alpha\right)-2\right)\left(1-\beta\right)\left(1-c\right)}{\alpha^2+2\alpha+\left(1-\alpha^2-\alpha\right)\beta\left(1-c\right)-2}, \tag{2.82}$$

which is the restriction on the commission rate imposed in Equation (2.65). The critical discount factor is

$$\underline{\delta}^{NP}\left(\phi_M\right)=\frac{\left(1-\phi_M\right)\left(2-\alpha\right)^2\left(1-\beta^2\right)-\left(1-\alpha\right)\beta^2\phi_M^2}{\left(1-\phi_M\right)\left(8-8\alpha+\alpha^2\right)\left(1-\beta^2\right)-2\left(1-\alpha\right)\beta^2\phi_M^2}. \tag{2.83}$$

Note that the critical discount factor simplifies to $\underline{\delta}^{NP}\left(0\right)=\left(\left(2-\alpha\right)^2\right)/\left(8-8\alpha+\alpha^2\right)$ for $\phi_M=0$, which is equal to the critical discount factor for the case without a PMFN and per-unit commission rates reported in Equation (2.23) in Proposition 2.3. Moreover, the critical discount factor in Equation (2.83) increases in ϕ_M over the relevant range. This establishes the result. □

The following figure illustrates that the increase in $\underline{\delta}^{NP}\left(\phi_M\right)$ is small in the present setting. Note that the scaling of the y-axis ranges only from 0.529 to 0.532, and that the critical discount factor only increases by approximately 0.002 which translates to a relative increase from 0.4% over the admissible range of revenue-commission rates ϕ_M.

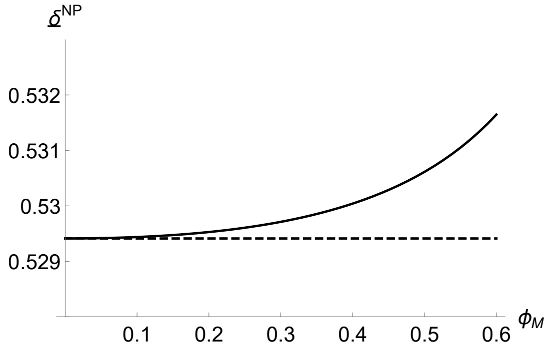


Figure 2.4: Critical discount factor with revenue-sharing commission rates and without PMFN.

The figure shows the critical discount $\underline{\delta}^{NP}(\phi_M)$ (solid line) and the critical discount factor for the case with per-unit commission rates and without a PMFN (dashed line) depending on the exogenous commission rate ϕ_M for $\alpha = 1/2$, $\beta = 1/2$, and $c = 0$. As specified in Equation (2.65), the highest admissible commission rate for this specification is $\hat{\phi}^{NP}_{max} = 6/10$. For reference, the profit-maximizing commission rate that the platform charges from colluding sellers in this specification is $\bar{\phi}^{NP}_M \approx 0.465$.

Proof of Proposition 2.6. With a PMFN, competing sellers maximize their profit function in Equation (2.66) subject to the constraint that $p_{iM} \leq p_{iD}$. This constraint is binding for $\phi_M > 0$ and the retail price on both distribution channels is

$$\tilde{p}^P_i(\phi_M) = \frac{(1-\alpha)(2-\phi_M)+2c}{(2-\alpha)(2-\phi_M)}. \tag{2.84}$$

The resulting profit for each seller is

$$\tilde{\pi}^P_i(\phi_M) = \frac{(1-\alpha)(2c+\phi_M-2)^2}{(2-\alpha)^2(1+\alpha)(1+\beta)(2-\phi_M)}. \tag{2.85}$$

Alternatively, each seller can deviate and list on the direct channel only. As in the case without a PMFN in Equation (2.69), seller i maximizes in this case

$$\max_{p_{iD}} \ \pi_i\left(p_{iD}, \infty, \tilde{p}^P_h(\phi_M)\right) = (p_{iD}-c)\, q_{iD}\left(p_{iD}, \infty, \tilde{p}^P_h(\phi_M)\right), \tag{2.86}$$

with a resulting retail price on the direct channel of

$$\tilde{p}^P_{i(D)}(\phi_M) = \frac{2(1-\alpha)(2-\phi_M)+c(4-(2-\alpha)\phi_M)}{2(2-\alpha)(2-\phi_M)}, \tag{2.87}$$

and profits of

$$\tilde{\pi}^P_{i(D)}\left(\tilde{p}^P_{i(D)}(\phi_M), \infty, \tilde{p}^P_h(\phi_M)\right) = \frac{\left(c(4-\alpha(4-\phi_M)-2\phi_M)+2(1-\alpha)(2-\phi_M)\right)^2}{4(2-\alpha)^2(1-\alpha^2)(2-\phi_M)^2}. \tag{2.88}$$

The two sellers are active on both distribution channels if the profit in Equation (2.85) exceeds the profit in Equation (2.88). Define the threshold commission rate $\tilde{\phi}^P_{max}$ at which sellers are indifferent between being active on both channels and listing on the direct channel only. That is, $\tilde{\pi}^P_i\left(\tilde{\phi}^P_{max}\right) = \tilde{\pi}^P_{i(D)}\left(\tilde{\phi}^P_{max}\right)$. There is no closed-form solution for $\tilde{\phi}^P_{max}$ but it is possible to solve numerically for it. If the commission rate ϕ_M exceeds this threshold value, there is an equilibrium of the stage game in which both sellers are active on the direct channel. In this case they set $\tilde{p}^P_{iD} = (1-\alpha+c)/(2-\alpha)$ and realize an equilibrium profit of

$$\tilde{\pi}^P_{i(D)}\left(\tilde{p}^P_D, \infty\right) = \frac{(1-\alpha)(1-c)^2}{(2-\alpha)^2(1+\alpha)}. \tag{2.89}$$

Colluding sellers that are present on both distribution channels set optimal retail prices of

$$\bar{p}^P_i(\phi) = \frac{2+2c-\phi_M}{4-2\phi_M}, \tag{2.90}$$

and realize profits of

$$\bar{\pi}^P_i(\phi_M) = \frac{(2-2c-\phi_M)^2}{4(1+\alpha)(1+\beta)(2-\phi_M)}. \tag{2.91}$$

If sellers jointly decide to delist from the platform, face the same maximization problem as in Equation (2.75) and set the same retail prices of $\bar{p}^{NP}_{i(D)} = (1+c)/2$ in order to realize a profit of $\bar{\pi}^{NP}_{i(D)}(\phi_M) = (1-c)^2/(4(1+\alpha))$. Colluding sellers prefer to be present on both distribution channels if

$$\phi_M \leq \bar{\phi}^P_{max} = \frac{1}{2}(1-c)\left(3-\beta+(1+\beta)c-\sqrt{(1+\beta)(\beta+c(6-\beta(2-c)+c)+1)}\right). \tag{2.92}$$

Computations reveal that $\bar{\phi}^P_{max} > \tilde{\phi}^P_{max}$ over the complete parameter range. This implies that colluding sellers are willing to list on both distribution channels for higher commission rates ϕ_M than competing sellers.

Consider that seller i deviates from the collusive agreement. If it is active on both distribution channels, it optimally charges

$$\hat{p}^P_i(\phi_M) = \frac{1}{4}\left(2-\alpha-\frac{2(2+\alpha)c}{\phi_M-2}\right), \tag{2.93}$$

and realizes a profit of

$$\hat{\pi}^P_i(\phi_M) = \frac{(2-\alpha)^2(2c+\phi_M-2)^2}{16(1-\alpha^2)(1+\beta)(2-\phi_M)}. \tag{2.94}$$

Alternatively, the deviating seller can decide to delist from the platform and only sell via the direct channel. In this case it optimally charges

$$\hat{p}_{i(D)}^{P} = \frac{1}{4}\left(2-\alpha+c\left(2+\frac{2\alpha}{2-\phi_M}\right)\right), \tag{2.95}$$

And realizes a profit of

$$\hat{\pi}_{i(D)}^{P}\left(\phi_M\right) = \frac{\left(\left(2-\alpha\right)\left(2-\phi_M\right)-2c\left(2-\alpha-\phi_M\right)\right)^2}{16\left(1-\alpha^2\right)\left(2-\phi_M\right)^2}. \tag{2.96}$$

Again, there exists a threshold commission rate $\hat{\phi}_{max}^{P}$ above which a deviating seller prefers to be active on the direct channel only. As in the case with seller competition, there is no closed-form solution for $\hat{\phi}_{max}^{P}$ but it can be characterized numerically. Simulations over the whole parameter range reveal that the same ordering of threshold values holds as in the case with per-unit commission rates. That is, $\bar{\phi}_{max}^{P} > \hat{\phi}_{max}^{P} > \tilde{\phi}_{max}^{P}$.

Based on the threshold values and the seller profits for the different stage games, the critical discount factor is characterized for three intervals of commission rates: The first interval is $\phi_M \in \left[0, \tilde{\phi}_{max}^{P}\right]$, the second one is $\phi_M \in \left(\tilde{\phi}_{max}^{P}, \hat{\phi}_{max}^{P}\right]$, and the third interval is $\phi_M \in \left(\hat{\phi}_{max}^{P}, \bar{\phi}_{max}^{P}\right]$.

In the first case, sellers are present on both distribution channels independent of seller conduct, and the critical discount factor is

$$\underline{\delta}^{P}\left(\phi\right) = \frac{\left(2-\alpha\right)^2}{\alpha^2-8\alpha+8},\ \phi_M \in \left[0, \tilde{\phi}_{max}^{P}\right]. \tag{2.97}$$

For the second interval, competing sellers prefer to be active on the direct channel only and realize the profit of $\tilde{\pi}_{i(D)}^{P}$ in Equation (2.89) instead of $\tilde{\pi}_{i}^{P}\left(\phi\right)$ in Equation (2.85), and the critical discount factor is characterized by

$$\begin{aligned} \underline{\delta}^{P}\left(\phi_M\right) &= \frac{\alpha^2\left(2c+\phi_M-2\right)^2}{16\left(1-\alpha\right)\left(1+\alpha\right)\left(1+\beta\right)\left(2-\phi_A\right)} \\ &\cdot \frac{1}{\frac{\left(2-\alpha\right)^2\left(2-2c-\phi_M\right)^2}{16\left(1-\alpha^2\right)\left(1+\beta\right)\left(2-\phi_M\right)}-\frac{\left(1-\alpha\right)\left(1-c\right)^2}{\left(2-\alpha\right)^2\left(1+\alpha\right)}},\ \phi_M \in \left(\tilde{\phi}_{max}^{P}, \hat{\phi}_{max}^{P}\right] \end{aligned} \tag{2.98}$$

Due to the fact that $\tilde{\pi}_{i(D)}^{P}\left(\tilde{\phi}_{max}^{P}\right) < \tilde{\pi}_{i}^{P}\left(\tilde{\phi}_{max}^{P}\right)$ at the threshold value $\tilde{\phi}_{max}^{P}$, and that the critical discount factor increases in the punishment profit $\tilde{\pi}_i$, there is a discrete decrease in $\underline{\delta}^{P}\left(\phi_M\right)$ at $\tilde{\phi}_{max}^{P}$. The critical discount factor $\underline{\delta}^{P}\left(\phi_M\right)$ increases in ϕ_M in the range $\left(\tilde{\phi}_{max}^{P}, \hat{\phi}_{max}^{P}\right]$.

In the third interval, not only competing sellers but also a deviating seller decides to be active on the direct channel only. Taking this listing decision into account, the critical discount factor in this range is

$$\underline{\delta}^P(\phi_M) = \frac{\frac{4(\phi_M-2)(2c+\phi_M-2)^2}{(1+\alpha)(1+\beta)} - \frac{((\alpha-2)(\phi_M-2)+2c(\alpha+\phi_M-2))^2}{\alpha^2-1}}{16(\phi_M-2)^2\left(\frac{(\alpha-1)(c-1)^2}{(\alpha-2)^2(\alpha+1)} - \frac{((\alpha-2)(\phi_M-2)+2c(\alpha+\phi_M-2))^2}{16(\alpha^2-1)(\phi_M-2)^2}\right)},\ \phi_M \in \left(\hat{\phi}^P_{max}, \bar{\phi}^P_{max}\right], \tag{2.99}$$

which also increases in ϕ_M. This establishes the result. □

In the following figure, I illustrate that the effect of revenue-sharing commission rates on the critical discount factor is qualitatively the same as with the per-unit commission rates derived in Proposition 2.4 and depicted in Figure 2.1.

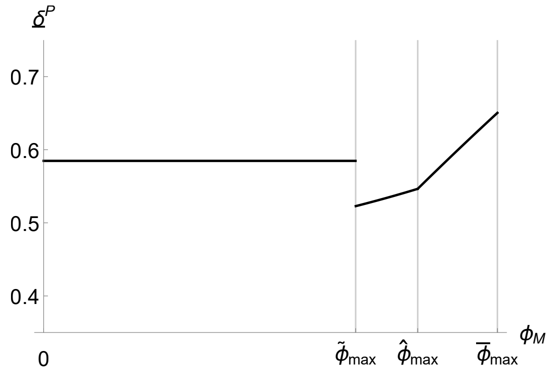


Figure 2.5: Critical discount factor with revenue-sharing commission rates and PMFN.

The figure shows the critical discount $\underline{\delta}^P(\phi_M)$ depending on the exogenous commission rate ϕ_M for $\alpha = 7/10$, $\beta = 4/10$, and $c = 3/10$.

Appendix B: Constrained Collusion

The main analysis in Section 2.4 focuses on the sustainability of full collusion on the joint profit-maximizing retail prices. If the sellers' common discount factor is too small to sustain full collusion, the analysis assumes that sellers cannot coordinate at all and play competition in every period of the infinitely-repeated game.

It is possible, however, that sellers still coordinate on smaller than fully-collusive prices if this increases their joint profits (compared to the competitive level) and fulfills the incentive-compatibility constraint. I refer to this form of collusion as *constrained collusion.* Importantly, if sellers collude in this form, I show that high commission rates (which make a deviation more tempting in the model analyzed in Section 2.4), can lead to a decrease in the constrained collusive retail price that is necessary to keep the incentive-compatibility constraint binding. This reinforces the result that a platform may prefer seller collusion over seller competition with a PMFN, as this leads to higher commission rates and potentially lower retail prices, and both aspects increase a platform's profit.

Again, I suppose that sellers sustain constrained collusion by means of grim trigger strategies. Denote punishment prices as $\tilde{p}$ and suppose that sellers cannot coordinate on fully-collusive prices $\bar{p}$. I consider instead that sellers coordinate on the highest feasible retail prices such that the incentive-compatibility constraint to be willing to stick to the collusive agreement is binding. Denote the constrained-collusive prices as $\bar{p}^{PC}$ and the deviation prices, which depends on the constrained-collusive prices, as $\hat{p}\left(\bar{p}^{PC}\right)$. The joint maximization problem is as follows:

$$\begin{aligned} \max_{p\in[\tilde{p},\bar{p}]} \pi_{12}(p) &= \sum_{i\in\{1,2\}} (p_{iM} - w_M)\, q_{iM}(p) + p_{iD} q_{iD}(p) \\ s.t.\ & \bar{\pi}_i(p) - (1-\delta)\,\hat{\pi}_i(\hat{p}(p)) - \delta\tilde{\pi}_i(\tilde{p}) \geq 0,\ \forall i, \end{aligned} \tag{2.100}$$

where the constraint in the second line ensures that the incentive-compatibility constraint in Equation (2.20) is fulfilled. With constrained collusion the sellers' common discount factor is sufficiently small such that the constraint needs to be binding with equality as otherwise sellers can coordinate on a higher constrained-collusive prices and realize higher joint profits on the equilibrium path. If the constraint is not binding at the fully-collusive price $\bar{p}$, sellers can sustain full collusion (the case analyzed in Section 2.4).

For the sake of exposition, I report a representative numerical result of the constrained-collusive prices. The findings are qualitatively the same for other parameter constellations for which coordination on constrained-collusive prices is the relevant case. The results for the retail prices absent and with a PMFN are depicted in Figure 2.6. The first panel shows the sellers' retail prices on the platform depending on the commission rate $w_M \in [0, 1-\beta]$ for three cases.[25] The dotted line is the competitive price $\tilde{p}_M$, the solid line is the fully-collusive price $\bar{p}_M$, and the dashed line shows the constrained-collusive price $\bar{p}_M^{CC}$. For $\delta = 3/10$, the incentive constraint is violated at the fully-collusive prices, but sellers can coordinate on constrained-collusive prices above the competitive level $\tilde{p}_M$. As the common discount factor δ increases, sellers are able to sustain higher constrained-collusive retail prices that approach the level of full collusion as δ approaches the critical discount factor reported in Equation (2.23) in Proposition 2.3.

[25] Recall that sellers are willing to list on the platform for commission rates up to $1-\beta$.

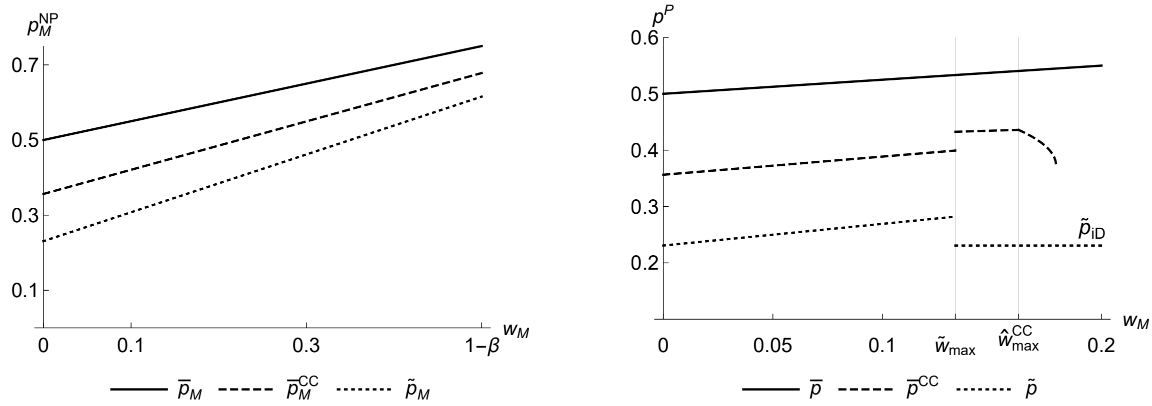


Figure 2.6: Retail prices with constrained collusion

The figure shows the highest feasible collusive retail price (i.e., constrained collusion) for a case in which full collusion is not feasible depending on the constant commission rate w_M for $\alpha = 7/10$, $\beta = 1/2$, and $\delta = 3/10$. The left panel shows the retail prices on the platform without a PMFN (NP) for the cases of competition (dotted), full collusion (solid) and constrained collusion (dashed). The right panel shows the same retail prices for the case with a PMFN (P).

The second panel in Figure 2.6 depicts the case with a PMFN. The plot consists of three regions that are the analog to the three regions as in Figure 2.1 for the critical discount factor $\underline{\delta}^P$ necessary for full collusion to be stable. For a small $w_M \leq \tilde{w}_{max}$ (which is the same threshold value as in Proposition 2.4), sellers prefer to list on the platform for any conduct, and the plot exhibits the same features as the plot in the left panel: the constrained-collusive price lies between the competitive price level and the fully-collusive one and increases in the commission rate w_M.

For $w_M > \tilde{w}_{max}$, competing sellers are not willing to list on the platform, which has two consequences: First, the sellers are only active on the direct channel and optimally set the retail price $\tilde{p}_{iD}^P = (1-\alpha)\,/\,(2-\alpha)$ as derived in Lemma 2.2, and realize lower punishment profits compared to being present on both distribution channels. Second, this form of harsher punishment allows sellers to sustain higher constrained-collusive prices, which is apparent from the discrete increase in $\bar{p}^{CC}$ at $w_M = \tilde{w}_{max}$. This is the same mechanism that leads to the discrete decrease in the critical discount factor $\underline{\delta}^P$ characterized in Proposition 2.4 and depicted in Figure 2.1.

The third region in the plot is for commission rates $w_M > \hat{w}_{max}^{CC}$, above which a seller that deviates from the constrained-collusive prices to be present on the direct channel only. In contrast to $\tilde{w}_{max}$, the threshold value $\hat{w}_{max}^{CC}$ is not the same as in the fully-collusive case ($\hat{w}_{max}$) and generally depends on the exact constrained-collusive price level. Again, above this level, deviation becomes more tempting for the sellers, which translates to lower constrained-collusive prices that can be sustained in equilibrium. Interestingly, in this range, an increase in the platform's commission rate leads to a decrease in the constrained-collusive price.

This result reinforces the finding that, with a PMFN, a platform may prefer seller coordination in contrast to seller competition on the platform: if sellers coordinate on constrained collusion, the platform can increase its commission rate above $\tilde{w}_{max}$, which is not profitable with seller competition as sellers would delist at higher commission rates. Moreover, a commission rate above $\hat{w}_{max}^{CC}$ can lead to lower retail prices, and hence, the platform benefits from a higher commission payment than with seller competition, and, additionally, from the fact that sellers charge a low constrained-collusive retail price, which increases the quantity sold on the platform.

Chapter 3

Supply Contracts under Partial Forward Ownership

with Matthias Hunold

3.1 Introduction

Recent econometric and survey-based studies provide evidence that minority shareholders influence the target firms' strategies in an anticompetitive way. Azar et al. (2016) show that common ownership of large institutional investors and cross-ownership between competing US banks are positively associated with higher prices in the banking market. Nain and Wang (2018) report for a cross-section of US manufacturing industries that partial ownership between competitors is associated with higher prices and profits. Whereas the main effects of ownership links between competitors (horizontal ownership) appear to be well understood, the effects of ownership between firms in a supply relationship (vertical ownership) are arguably less clear. Vertical ownership is, however, prevalent in various industries. Examples include cable operators and broadcasters, banks and payment providers, financial exchanges and clearing houses, as well as automobile producers and their suppliers.[1]

We contribute to the developing theoretical research on partial vertical ownership. Our focus is how forward ownership shares (that induce a supplier to internalize a share of the downstream profits) affect the supply contracts in a vertically-related industry.[2] In order to study this question, we set up a model that allows for competition in both market segments. There are two upstream firms that produce a homogeneous input good and have different marginal production costs. Upstream competition is effective if the marginal costs of the less-efficient upstream are sufficiently small such that it can be relevant supply alternative for the downstream firms. We allow the efficient supplier to hold passive forward ownership shares of two competing downstream firms. Such passive ownership shares involve cash flow rights but do not confer control over the target firm's decision.

For a successive Cournot oligopoly, Flath (1989) shows that—compared to vertical separation—forward ownership induces an upstream firm to expand its output in order to increase the profit of the downstream firms. Such an expansion is beneficial for the supplier as it internalizes a share of the increased downstream profit. In other words, by participating in the downstream margin, the upstream firm has incentives to reduce double marginalization in the vertical chain.

We first show that this intuitive and procompetitive effect of forward ownership also arises when an upstream firm sets linear input prices instead of quantities as its strategic variable (Section 3.3.1). Crucially, in our setting, this result is limited to the case of upstream monopoly. If upstream competition is effective, the procompetitive effect of

[1]See the 2013 Annex 2 to the Commission Staff Working Document "Towards more effective EU merger control" for an overview of partial ownership acquisitions in the EU and some of its member states. Moreover, Brito et al. (2016), Greenlee and Raskovich (2006), Hunold (2020), and Hunold and Shekhar (2018) provide additional details for specific cases.

[2]Backward ownership refers to the case in which a downstream firm holds a share of its competitor.

forward ownership does not materialize as input prices are already too low from the perspective of the supplier. In Section 3.4.1, we demonstrate that this result holds not only with observable but also with unobservable linear supply contracts.

Second, and more importantly, we demonstrate that the procompetitive result for forward ownership arrangements crucially depends on the supply contracts being linear. In stark contrast, we identify novel anticompetitive effects of forward ownership when firms use two-part tariffs. These effects occur in cases where the assumption of linear tariffs or successive Cournot oligopolies suggest procompetitive or no effects at all. Contrary to prior arguments, forward ownership can therefore yield strong anticompetitive results. They materialize both if the two-part contracts are observable as well as if they are unobservable, albeit for different economic reasons.

If the supplier's contract offers are observable and competing downstream firms have a relevant supply alternative, the supplier can extract more profits from them by selling at marginal prices below the level that maximizes industry profits in order to extract high fixed fees (Caprice, 2006). As forward ownership reduces the supplier's incentive to extract rents from the downstream firms, we show that it allows the supplier to attach a higher weight on increasing the overall industry profit. This leads to marginal input prices that are closer to industry profit-maximizing level and thereby to higher output prices downstream.

With unobservable tariffs, we show that partial forward ownership is anticompetitive even in the presence of a monopolist supplier (Section 3.4.2). For vertical separation, it is well known that secret contracting prevents a supplier from committing to charge profit-maximizing marginal wholesale prices. The reason is that there is an incentive to secretly renegotiate a better contract with at least one downstream firm. Hart and Tirole (1990) show that a full vertical merger can solve the supplier's commitment problem. This theory, however, relies on the premise that vertical integration shifts the residual control rights and that full integration removes all conflicts regarding prices and trading policies between the merging up- and downstream firm.

In contrast to this view, we consider partial forward ownership arrangements that do not have these features. In particular, ownership only confers profit but no control rights over the target firm. Additionally, we show that the downstream firms make zero profit in equilibrium because the supplier can extract all profits through the fixed fees. This occurs irrespective of whether the supplier holds a forward ownership share or not. It is therefore perhaps surprising that partial ownership has any effect in the case of secret contracting as the realized profit share that the supplier internalizes is equal to zero in either case. Nevertheless, we demonstrate that forward ownership allows the supplier to commit to higher input prices. This result holds for the belief refinements of passive and wary beliefs. The reason why higher marginal input prices are sustainable in equilibrium is that the supplier internalizes that its opportunistic (off-equilibrium) behavior would harm the downstream firms.

If vertically-related firms establish a partial ownership arrangement, it might be that this makes contract offers observable such that the supplier can overcome the commitment problem described above. In Section 3.5, we therefore discuss the case in which partial ownership not only affects the contract terms but also the information structure of the contracting game. Especially for the case of downstream price competition, the *observability effect* affects prices in the same direction as the *internalization effect*: with linear contracts prices tend to decrease and with two-part tariffs they tend to increase. In the case of downstream quantity competition, the two effects may run in different directions such that the overall price effect depends on the relative strength of both effects.

In summary, we contribute to the developing theoretical literature studying the competitive effects of partial vertical ownership. We mainly build on the strand of the literature which shows that partial vertical ownership can affect prices in different directions. A central insight of the literature so far is that forward ownership is rather procompetitive by reducing downstream prices compared to vertical separation (Flath, 1989; Fiocco, 2016). In contrast, backward ownership does not have this feature (Greenlee and Raskovich, 2006), but can instead increase prices (Hunold and Stahl, 2016). By demonstrating that the competitive effects of forward ownership crucially depend on the nature of the supply contracts, we show that this differential interpretation is not justified and that also forward ownership raises competition policy concerns.

We extend our analysis in several directions. First, we show in Section 3.6.1 that the firms cannot achieve the same effects of forward ownership by means of a profit-sharing supply contract. In Section 3.6.2, we extend the analysis to asymmetric shareholdings. This analysis confirms that the overall effect of asymmetric ownership on the price level and consumer surplus tends to go in the same direction as that of symmetric ownership. The section also relates to another strand of the literature on partial vertical ownership which points out that foreclosure may arise if a partial owner has full control and only limited profit rights of a vertically-related firm (Baumol and Ordover, 1994; Spiegel, 2013; Levy et al., 2018). In our analysis, asymmetric ownership generally induces the supplier to offer more favorable contract terms to a partially-integrated downstream firm than to its non-integrated competitor. In Section 3.6.3, we discuss when partial vertical ownership links are profitable for the industry as a whole and for the firms involved in a partial ownership acquisition.

Our analysis shows that it is crucial to take into account the pricing schemes of the vertically-related firms to correctly assess the price effects. We conclude in Section 3.7 with a more detailed discussion of how our results can improve the economic analyses of partial vertical ownership and implications of our analysis for competition policy.

3.2 Industry and Ownership Structure

To study the competitive effects of forward ownership, we set up a model that allows for both upstream and downstream competition. The production of one unit of downstream output requires one unit of a homogeneous input. There are two upstream firms producing the input goods. The efficient upstream firm U produces the input at marginal costs normalized to zero. In addition, there is a less efficient competitive fringe, denoted by V, which can also produce the input, but at higher marginal costs of $c > 0$.

The cost difference between the efficient supplier and the fringe, c, is a measure for the intensity of upstream competition. If c is large, the competitive fringe is not a relevant competitor and the efficient supplier is de facto a monopolist. For sufficiently small cost differences, the fringe is a relevant supply alternative and its presence constrains the price setting of the efficient supplier. This improves the downstream firms' position *vis-à-vis* the efficient supplier U.

The efficient upstream firm offers two symmetric downstream firms indexed with $i \in \{A, B\}$ a contract that has a linear (marginal) price w_i and (possibly) a non-linear upfront fee f_i that the downstream firm pays upon contract acceptance. For $f_i = 0$, the tariff is linear. The two downstream firms purchase the input in order to produce substitutable products on a one-to-one basis. We analyze the cases in which the supplier's contract offers are observable in Section 3.3 and unobservable in Section 3.4.

The efficient supplier U holds a partial ownership share $\sigma_i \in [0, 1]$ of downstream firm $i \in \{A, B\}$ (forward ownership). We consider passive ownership that does not confer control over the target firm's strategy, such that the partial ownership essentially is a claim on the corresponding share of the downstream firm's profit. This assumption is employed in several articles of the established literature, such as Flath (1989), Greenlee and Raskovich (2006), and Hunold and Stahl (2016). Focusing on the polar case of non-controlling ownership allows us to illustrate novel anticompetitive effects that arise if the supplier internalizes a share of the downstream firms' profits. In a companion paper Hunold and Schlütter (2021), we relax this assumption and also allow an acquiring firm to exercise influence over the target's strategy.[3]

We derive our main results for a general model that allows for price and quantity competition in the downstream market under standard assumptions on demand and profits. Additionally, we illustrate some of our results with closed-form solutions based on the quadratic utility (consumer surplus) of a representative consumer (Singh and Vives, 1984; Häckner, 2000):

$$CS\left(q_A, q_B, I\right) = q_A + q_B - \frac{1}{2}\left(q_A^2 + q_B^2 + 2\gamma q_A q_B\right) + I. \tag{3.1}$$

[3] In particular, building on O'Brien and Salop (2000), we point out that a forward profit right can have the same effects as a backward control right in terms of strategic incentives (such as pricing).

The consumer obtains utility from consuming the products from downstream firms A and B and a numeraire good I. The parameter $\gamma \in (0, 1]$ captures the degree of product substitutability. The budget-constrained consumer's maximization problem yields the inverse linear demand function

$$p_i(q_i, q_{-i}) = 1 - q_i - \gamma q_{-i}. \tag{3.2}$$

For $\gamma \to 0$, the product markets are separated and for $\gamma = 1$, the products are perfect substitutes.

3.3 Observable Contracts

In this section, we derive our results for the case of observable contract offers. We first show that symmetric forward ownership $\sigma_A = \sigma_B = \sigma$ can lead to *lower* upstream and downstream prices when upstream tariffs are linear and upstream competition is weak (c is sufficiently large), in line with the insights of Flath (1989).[4] Crawford et al. (2018) provide empirical support of this theoretical result by showing that partial profit internalization indeed reduces double marginalization in the US television market where—as they argue—input prices are predominantly linear.

We then show that this ownership structure can instead lead to *higher* marginal input prices when the supplier uses observable two-part tariffs. Forward ownership can therefore be anticompetitive under non-linear tariffs, while it might be procompetitive under linear tariffs. This is arguably an important new insight that should find consideration in the assessment of partial forward ownership acquisitions.

The profit of downstream firm i net of fixed fees is $\pi_i = (p_i - w_i)\, q_i$. We conduct the analysis in this section using reduced-form downstream flow profit that depend on both firms' input prices $\pi_i(a, b)$, where a denotes the marginal costs of downstream firm i and b denotes the marginal costs of its competitor $-i$. This reduced-form formulation is consistent with both quantity and price competition downstream.

We assume that there exists a unique and stable equilibrium in the downstream market, and that the profits have the following standard properties.[5]

Assumption 3.1. *The flow profit $\pi_i(a, b)$ of downstream firm i*

(i) decreases in the own input costs: $\partial\pi_i(a, b)/\partial a < 0$,

(ii) increases in the competitor's input costs: $\partial\pi_i(a, b)/\partial b > 0$ (in the range where both firms make positive sales), and

[4] We study asymmetric ownership structures in Section 3.6.2.

[5] See, for instance, Farrell and Shapiro (2008) and Levy et al. (2018) for similar assumptions on reduced form profits.

(iii) decreases when all input costs increase : $\partial \pi_i (a, b) / \partial a + \partial \pi_i (a, b) / \partial b < 0$.

(iv) Moreover, $\partial^2 \pi_i (a, b) / \partial^2 b$ *is not too negative.*

We verified that the linear demand function introduced above fulfills the assumptions that we impose on the reduced form objective functions and the industry profit in this section. The assumption implies that an increase of the input costs of both firms leads to a lower total output and higher downstream prices (both if the downstream firms' strategic variables are prices or quantities).

The profit of downstream firm i is

$$\pi_i (w_i, w_{-i}) - f_i, \tag{3.3}$$

when purchasing inputs from the efficient supplier U while the downstream firm $-i$ has marginal costs of w_{-i}

If the upstream firm U supplies both downstream firms, its objective function consists of its own flow profit and the downstream firms' profits, weighted by the ownership shares σ_i:

$$\Omega^U (w_A, w_B, f_A, f_B) = \underbrace{\pi^U (w_A, w_B) + f_A + f_B}_{\text{upstream profit}} + \underbrace{\sum_{i \in \{A,B\}} \sigma_i (\pi_i (w_i, w_{-i}) - f_i)}_{\text{internalized downstream profits}}, \tag{3.4}$$

with $\pi^U = \sum_{i \in \{A,B\}} w_i q_i$. In order to ensure that the supplier's maximization problem has a unique interior solution, we impose

Assumption 3.2. $\pi^U (w_A, w_B) + \sum_{i \in \{A,B\}} \sigma_i \pi_i (w_i, w_{-i})$ *is strictly concave in* w_A *and* w_B *for all* $\sigma_i \in [0, 1]$.

This assumption implies that there exists a unique interior solution to the supplier's unconstrained maximization problem. In the analyses, we compare the equilibrium input prices with the input prices that emerge under vertical separation and with the input prices that maximize the industry profit $\pi^I = \sum_{i \in \{A,B\}} p_i q_i$. We assume that the industry profit is strictly concave in the marginal input prices such that there exists a unique pair of input prices that maximize the industry profit, that is, $\left(w_A^I, w_B^I\right) = \arg\max_{w_i} \sum_{i \in \{A,B\}} p_i q_i$. These input prices do not depend on the degree of forward ownership. The sum of all firms' profits (industry profit) increases if the input price approaches w_i^I (either from above or below).

For a given ownership structure, we analyze the following non-cooperative game where each firm maximizes its objective function taking into account that the supplier internalizes a share of the downstream firms' profits.

1. Supplier U offers each downstream firm an input contract with tariff $t_i = (w_i, f_i)$, $i \in \{A, B\}$. The fringe V offers the input at its unit cost of c.

2. Downstream firms A and B observe the contract offers by U and simultaneously accept or reject the offer.

3. Each downstream firm sources inputs (from U if it accepted its contract, otherwise from the fringe V), produces, and sells its products.

We solve for the subgame-perfect Nash equilibrium in which both downstream firm purchase from the efficient supplier by backward induction.

3.3.1 Linear Tariffs

We now fix $f_i = 0$, which implies that supply contracts are linear. Under vertical separation, linear tariffs result in double marginalization (Cournot, 1838). For an upstream monopoly (as with $c = \infty$), this means that the linear input prices (and the resulting downstream prices) are above the level that maximizes the industry profit. Partial forward internalization can alleviate this problem by reducing the upstream prices. The problem of supplier U is to

$$\max_{w_A, w_B} \Omega^U (w_A, w_B) = \pi^U (w_A, w_B) + \sigma (\pi_A (w_A, w_B) + \pi_B (w_B, w_A)), \tag{3.5}$$

subject to the constraint $w_i \leq c$, which ensures that both downstream firms source from U. The corresponding first-order condition is

$$\frac{\partial \Omega^U}{\partial w_i} = \frac{\partial \pi^U (w_i, w_{-i})}{\partial w_i} + \sigma \left(\frac{\partial \pi_i (w_i, w_{-i})}{\partial w_i} + \frac{\partial \pi_{-i} (w_{-i}, w_i)}{\partial w_i} \right) = 0, \; i, -i \in \{A, B\}. \tag{3.6}$$

Denote with $w_A^l (\sigma) = w_B^l (\sigma) = w^l (\sigma)$ the symmetric linear input price that solves the above conditions. As the supplier internalizes a share of each downstream firm's profit, there is an incentive to decrease the symmetric linear input price: $\partial w^l (\sigma) / \partial \sigma < 0$. This internalization effect yields input and downstream prices below the level of vertical separation and is therefore procompetitive.

If upstream competition is fierce, the input price w^l may be above the marginal cost of the competitive fringe. In this case, the internalization effect derived above does not materialize and upstream firm U sets the input price to the highest possible level of c. Hence, the equilibrium input price is $w = \min \left\{ w^l (\sigma), c \right\}$. We summarize in

Proposition 3.1. *Let the efficient supplier U charge observable linear input prices ($f_i =$ 0) and internalize a share $\sigma > 0$ of each downstream firm's profit. This leads to lower input prices and downstream prices than full separation if upstream competition is weak or non-existent (c sufficiently large). If upstream price competition is strong enough, forward ownership does not affect prices.*

Proof. See Appendix A1. □

This proposition replicates the result of Flath (1989) for the case in which the supplier sets a linear input price instead of a production quantity. We obtain qualitatively the same result only for the case of upstream monopoly. With competition from a sufficiently efficient supply alternative, there is no reduction in the linear input price due to partial forward ownership.

Parametric Example. With linear demand as defined in Equation (3.2) and quantity competition in homogeneous products ($\gamma = 1$), the optimal unconstrained input price is $w^l(\sigma) = (3 - 2\sigma)/(6 - 2\sigma)$, which equals 1/2 for $\sigma = 0$ and decreases in σ. This implies that any marginal increase in σ reduces prices if $c > 1/2$. In this case and given the parametric specification, a 15% forward ownership share decreases final consumer prices by 2.6%. For $c < 1/2$, forward ownership is competitively neutral in an interval of σ starting at $\sigma = 0$ but it can affect prices once σ is large enough (such that $w^l(\sigma) < c$). For instance, at a share $\sigma = 0.25$, we obtain $w^l(0.25) = 0.45$, which implies that forward ownership above 25% only decreases prices if $c > 0.45$.

3.3.2 Two-Part Tariffs

We now show that forward ownership can lead to higher marginal input prices and thus industry profits, compared to the case of vertical separation if the supplier uses two-part tariffs. Again, let supplier U internalize a symmetric share $\sigma_A = \sigma_B = \sigma$ of each downstream firm's profit. The maximization problem of supplier U is

$$\max_{w_i, f_i,\ i \in \{A,B\}} \Omega^U = \pi^U(w_A, w_B) + f_A + f_B + \sigma \sum_{i \in \{A,B\}} (\pi_i(w_i, w_{-i}) - f_i) \quad (3.7)$$
$$s.t. \quad \pi_i(w_i, w_{-i}) - f_i \geq \pi_i(c, w_{-i}),\ i, -i \in \{A, B\}.$$

The participation constraints mean that each downstream firm i must weakly prefer sourcing from U to sourcing from the competitive fringe at linear costs of c, which yields the outside option of $\pi_i(c, w_{-i})$. The competitive fringe is a *relevant supply alternative* if a downstream firm can obtain positive profits when sourcing from the competitive fringe. Otherwise, for a sufficiently large c, a downstream firm's outside option has a value of zero and does not depend on the rival's input costs.

In equilibrium, supplier U sets the fixed fees such that each downstream firm is indifferent between the contract offer and its outside option such that each firm sources from U. Hence, the reduced maximization problem is

$$\max_{w_A, w_B} \Omega^U = \pi^I(w_A, w_B) - (1 - \sigma)(\pi_A(c, w_B) + \pi_B(c, w_A)), \quad (3.8)$$

where $\pi^I = \pi^U + \sum_{i \in \{A,B\}} \pi_i$ denotes the industry profit. The implied system of first-order conditions is

$$\frac{\partial \Omega^U}{\partial w_i} = \frac{\partial \pi^I (w_i, w_{-i})}{\partial w_i} - (1-\sigma) \frac{\partial \pi_{-i} (c, w_i)}{\partial w_i} = 0, \ i, -i \in \{A, B\}. \tag{3.9}$$

Denote the symmetric optimal marginal input price $w_A^{tp}(\sigma) = w_B^{tp}(\sigma) = w^{tp}(\sigma)$. For $\sigma = 1$, Equation (3.9) is the optimality condition as in the case of vertical integration and the optimal marginal prices maximize the industry profit. The same holds true if $\partial \pi_{-i}(c, w_i) / \partial w_i = 0$, which occurs for instance if the competitive fringe is no supply alternative (i.e., c sufficiently large). In this case, the upstream firm can extract all downstream profits through the fixed fees and simply maximize the industry profit by setting the marginal input price equal to w^I.

The situation is different, however, if $\sigma < 1$ and if the downstream firms obtain positive profits in case they source from the competitive fringe. With such a relevant supply alternative, the outside option profit of a downstream firm decreases if its competitor faces lower marginal input costs: $\partial \pi_{-i}(c, w_i) / \partial w_i > 0$. The supplier thus faces a trade-off between a high industry profit π^I and less valuable outside options $\pi_i(c, w_{-i})$ for the downstream firms. As a result, the supplier charges input prices below the industry profit-maximizing level. Reducing the marginal input price allows the supplier to extract higher profits via the fixed fee.[6]

The supplier's marginal profit from lowering a downstream firm's outside option shrinks in the internalization share σ (Equation (3.9)). Intuitively, partial internalization of the downstream profits makes decreasing these outside option profits less attractive and the supplier puts more emphasis on maximizing the industry profit. We summarize in

Proposition 3.2. *Let supplier U charge observable two-part tariffs. With upstream competition (c sufficiently small), forward internalization $\sigma > 0$ leads to higher marginal input prices and downstream prices, compared to full separation. Without upstream competition, supplier U sets the input price w^I such that downstream prices maximize the industry profit for all $\sigma \in [0, 1]$.*

Proof. See Appendix A. □

The result that, with two-part tariffs, forward internalization leads to higher marginal input prices is in stark contrast to the result of price reductions with linear tariffs (Proposition 3.1). If the supplier can charge two-part tariffs, double marginalization is not a concern for the firms. In contrast, with up- and downstream competition, input prices and profits are too low from an industry perspective in the case of vertical separation.

[6]For the case of vertical separation, this strategic effect of reducing the downstream firms' outside options by means of low marginal input prices also finds consideration in, for instance, Marx and Shaffer (1999) and Caprice (2006).

This makes an *increase* of the input prices profitable and we show that forward ownership makes it feasible and unilaterally profitable for a supplier to do so.

Parametric Example. Under homogeneous quantity competition with linear demand as defined in Equation (3.2), the competitive fringe is a relevant supply alternative for the downstream firms if $c < 0.625$. For smaller marginal costs of the competitive fringe, the optimal input price is $w^{tp}(\sigma) = (4c(1-\sigma) + 2\sigma - 1)/2(3-\sigma)$, which increases in $\sigma \in [0,1]$. If the competitive fringe has larger marginal costs in this example, the downstream firms' outside option is to stay inactive instead of sourcing from the fringe if they refuse U's offer, and partial forward ownership does not affect the marginal input prices. For $c = 3/10$, a forward ownership share of 15% increases final consumer prices by 4.3% in this specification. This increase in input prices is considerably larger than the 2.6%-decrease of prices in the linear-tariffs case for the same ownership share of 15%.

3.4 Secret Contracts

In this section, we analyze contracting in the vertical chain if the supplier's contract offers are unobservable. In particular, we adjust the information structure to the case in which a downstream firm cannot observe the contract terms and acceptance decision of the rival downstream firm before making its own sourcing and sales decisions.[7] We find that the direction of the main competitive effects derived for observable contracts—both with linear and two-part tariffs—prevails. With two-part tariffs, they apply even more broadly also to the case of upstream monopoly.

It is well known that the construction of the equilibrium with unobservable contracts depends on whether downstream firms compete in prices or quantities (Rey and Vergé, 2004). We therefore focus the case of on quantity competition downstream. In Appendix B, we provide the analysis with two-part tariffs also for the case of price competition where we obtain qualitatively the same detrimental price effects.

We solve for a symmetric perfect Bayesian-Nash equilibrium as contract unobservability leads to an incomplete information game. Each downstream firm needs to form a belief about the other downstream firm's contract offer. We assume that the downstream firms hold passive beliefs about their rival's contract offer (see, e.g., Hart and Tirole, 1990; McAfee and Schwartz, 1994; Rey and Vergé, 2004). This implies that a downstream firm does not update its belief about the other contract if it receives an out-of-equilibrium offer.[8] In the perfect Bayesian-Nash equilibrium the beliefs are correct. Denote a downstream firm's belief about the competitor's rival in capital letters as $T_{-i} = (W_{-i}, F_{-i})$.

[7] This is the case of interim unobservability in the terms of Rey and Vergé (2004).

[8] For the case of two-part tariffs, we analyze the belief refinement of wary beliefs in Appendix C.

Based on this belief, a downstream firm expects that its rival sets the quantity Q_{-i} on the market.

We assume that the inverse demand for each downstream firm, $p_i(q_i, q_{-i})$, $i \in \{A, B\}$, is symmetric and satisfies $\frac{\partial p_i}{\partial q_i} < \frac{\partial p_i}{\partial q_{-i}} < 0$. We further impose for any q_i, $i \in \{A, B\}$

Assumption 3.3. $2\frac{\partial p_i(q_i,q_{-i})}{\partial q_i} - \frac{\partial p_{-i}(q_i,q_{-i})}{\partial q_i} + \frac{\partial^2 p_i(q_i,q_{-i})}{\partial^2 q_i} q_i < 0$,

which ensures that downstream firms' profit functions are strictly concave and that downstream profits decrease for a uniform increase in the marginal input price. It is therefore the analog to Assumption 3.1 in the section on observable contract offers. Finally, we assume that the downstream firm's second-order conditions are fulfilled in the relevant range in order to guarantee a unique and stable symmetric equilibrium in the downstream market.[9]

The profit function of downstream firm i is

$$\pi_i = (p_i(q_i, Q_{-i}) - w_i) q_i - f_i, \tag{3.10}$$

where it expects to sell at a price $p_i(q_i, Q_{-i})$ that depends on its own quantity choice q_i and its beliefs about the quantity Q_{-i} that its competitor will produce. Denote the optimal strategic decision of a downstream firm as a function of its input price as

$$q_i(w_i) = \arg\max_{q_i} (p_i(q_i, Q_{-i}) - w_i) q_i - f_i. \tag{3.11}$$

Importantly, due to contract unobservability, the optimal strategic choice of downstream firm i cannot adjust if the rival's input price w_{-i} changes. It therefore only depends on the downstream firm's marginal input price w_i and its belief about the rival's quantity choice Q_{-i}. Note that the strategic decision $q_i(w_i)$ is independent of the fixed fee f_i and therefore the same with linear and two-part tariffs under secret contracting.

3.4.1 Linear Tariffs

We first analyze the case of unobservable linear tariffs with $f_i = 0$. This section builds on Gaudin (2019) who shows that under vertical separation double marginalization arises also under secret contracting.[10] There is thus scope for forward ownership to reduce double marginalization, as in the case of observable linear tariffs.

Given the downstream firms' beliefs about each others' contract offers and corresponding quantity choices, the supplier's objective function is

$$\Omega^U = \sum_{i,-i \in \{A,B\}} w_i q_i(w_i) + \sigma \left[(p_i(q_i(w_i), q_{-i}(w_{-i})) - w_i) q_i(w_i) \right]. \tag{3.12}$$

[9]This assumption holds if $\partial^2 \pi_i / \partial^2 q_i + \left| \partial^2 \pi_i / \partial q_i \partial q_{-i} \right| < 0$.

[10]His results are robust to both the belief refinements of passive and wary beliefs. We therefore expect that our results in this section that are based on passive beliefs also extend to wary beliefs.

Similar to Assumption 3.2 for the case of observable contracts, we impose

Assumption 3.4. *The supplier's objective function in Equation (3.12) is strictly concave in w_A and w_B for all $\sigma_i \in [0,1]$.*

Note that whereas the downstream firms expect to sell at the price $p_i\left(q_i\left(w_i\right), Q_{-i}\right)$, the supplier knows both contract offers as well as the beliefs, and anticipates a downstream price of $p_i\left(q_i\left(w_i\right), q_{-i}\left(w_{-i}\right)\right)$. The difference to the case with observable contract offers is that a change in w_i only affects the quantity choice of downstream firm i. When changing w_i, the other downstream firm $-i$ is only affected through the effect of i's quantity choice on the aggregate price. Taking this strategic behavior into account, the supplier's first-order condition, $\partial\Omega^U/\partial w_i = 0 \; i \in \{A, B\}$, is

$$
\begin{aligned}
& q_i\left(w_i\right) + w_i \frac{\partial q_i\left(w_i\right)}{\partial w_i} \\
+ \quad & \sigma \left[\underbrace{-q_i\left(w_i\right) + q_{-i}\left(w_{-i}\right) \frac{\partial p_{-i}\left(q_{-i}\left(w_{-i}\right), q_i\left(w_i\right)\right)}{\partial q_i} \frac{\partial q_i\left(w_i\right)}{\partial w_i}}_{<0} \right] = 0,
\end{aligned} \tag{3.13}
$$

Denote the symmetric input price that solves the system of first-order conditions with $w_A^{lu}(\sigma) = w_B^{lu}(\sigma) = w^{lu}(\sigma)$, where $w^{lu}(\sigma) = W_i, \; i \in \{A, B\}$. The super-script lu stands for linear and unobservable contracts. If the marginal costs of the competitive fringe are sufficiently large this is the equilibrium input price. We show in the proof to the next proposition that the term in brackets is negative, and, hence, by the same reasoning as in the proof of Proposition 3.1, we therefore obtain that a larger degree of partial forward internalization leads to lower input prices.

If the competitive fringe has marginal costs $c < w^{lu}(\sigma)$, the supplier charges an input price as high as the fringe's marginal costs, that is, $w^{lu}(\sigma) = c$. In this case, partial forward ownership does not affect the linear input price. We summarize in

Proposition 3.3. *Let the efficient supplier U charge unobservable linear input prices ($f_i = 0$) and internalize a share $\sigma > 0$ of each downstream firm's profit. With quantity competition and passive beliefs, this leads to lower input prices and downstream prices than full separation if upstream competition is weak or non-existent (c sufficiently large). Otherwise, forward ownership does not affect prices.*

Proof. See Appendix A. □

3.4.2 Two-Part Tariffs

With secret two-part tariffs and under vertical separation, the supplier suffers from the well-known commitment problem (Hart and Tirole, 1990; O'Brien and Shaffer, 1992;

McAfee and Schwartz, 1994).[11] It can secretly offer each downstream firm a contract with a low linear price as this maximizes the bilateral profit, which it can extract through the fixed fee. Under vertical separation, this can lead to marginal prices equal to the supplier's marginal costs, and in turn low downstream prices and industry profits.

In this section, we assume that supplier U does not face competition from the competitive fringe ($c = \infty$). This is without loss of generality for the price effects of partial ownership. With unobservable two-part tariffs, the competitive fringe does not affect the marginal prices of the efficient supplier but only how firms split the joint surplus from trade through the fixed fee (Hart and Tirole, 1990). This also means that the anticompetitive effects of partial forward ownership with unobservable two-part tariffs occur independent of whether there is a relevant supply alternative or not.

In equilibrium, the supplier offers a contract such that the downstream firms are indifferent between accepting the contract and their outside option. We denote the outside option profit that a downstream firm expects to realize if it sources from the competitive fringe at an input price of c as $\pi_i(c, W_{-i})$; Equation (3.29) contains the formal definition. If the marginal costs of the competitive fringe are too large, supplier U is a monopolist and the downstream firm's outside option profit is equal to zero. From a downstream firm's profit in Equation (3.10), it follows that the fixed fee is equal to

$$f_i = \left(p_i\left(q_i\left(w_i\right), Q_{-i}\right) - w_i\right) q_i\left(w_i\right) - \pi_i\left(c, W_{-i}\right). \tag{3.14}$$

The determination of the fixed fee is conceptually the same as with observable two-part tariffs: it extracts the downstream firm's profit on the equilibrium path up to the outside option $\pi_i(c, W_{-i})$. The only difference is that the fee now depends on a downstream firm's expectation about its rival marginal input price W_{-i} and the corresponding quantity choice Q_{-i}.

The supplier, who internalizes a share σ of each downstream firm's profit, has the following objective function for given beliefs' of the downstream firms about each others' output decisions:

$$\begin{aligned} \Omega^U\left(w_A, w_B, f_A, f_B\right) \quad = \quad & \sum_{i\in\{A,B\}} \left(w_i q_i\left(w_i\right) + f_i\right. \\ & + \sigma\left(\left(p_i\left(q_i\left(w_i\right), q_{-i}\left(w_{-i}\right)\right) - w_i\right) q_i\left(w_i\right) - f_i\right)). \end{aligned} \tag{3.15}$$

Whereas f_i depends only on the contract offered to downstream firm i (and its belief Q_{-i}), the profit that the supplier internalizes depends on the contract offers to both downstream firms. Intuitively, if the supplier changes the contract with one downstream firm, this has

[11] Fiocco (2016) studies secret contracting and partial backward ownership, but excludes that an upstream firm supplies two competing downstream firms. Hence, there is no commitment problem à la Hart and Tirole (1990).

no effect on the fixed fee that it can extract from the second downstream firm simply because the latter firm cannot observe this change. In contrast, changing the contract for one firm has an effect on the eventually realized profits and the supplier internalizes this effect with a weight of σ.

Our starting point is that the well-known equilibrium with marginal cost pricing does not exist with partial forward ownership.

Lemma 3.1. *Let supplier U charge unobservable two-part tariffs. The downstream firms compete in quantities and hold passive beliefs. With forward ownership, there always exists a unique symmetric perfect Bayesian-Nash equilibrium with passive beliefs. In equilibrium, the marginal input prices are not equal to the supplier's marginal costs.*

Proof. See Appendix A. □

In order to establish a perfect Bayesian-Nash equilibrium under partial forward ownership with secret two-part tariffs, it is generally not sufficient that the first-order conditions hold. It is also necessary to verify that the supplier has no incentive to change both contracts simultaneously (a multilateral deviation). For vertical separation, Rey and Vergé (2004) show that an equilibrium exists if there is downstream quantity competition or price competition that is not too intense. The lemma above extends the existence result for quantity competition to the case of partial forward ownership.

In the following proposition, we establish that partial forward ownership leads to an increase of the prices also with secret two-part tariffs.

Proposition 3.4. *Under the conditions in Lemma 3.1, the symmetric marginal input prices (and thus downstream prices) increase in the degree of forward internalization σ.*

Proof. See Appendix A. □

Proposition 3.4 shows that partial forward ownership reduces the supplier's commitment problem that secret contracting causes under vertical separation. The reason is that the supplier internalizes a share of the loss of one downstream firm if it secretly offers a lower input price to the downstream rival. Hence, such an ownership structure is an effective commitment to higher input (and thus downstream) prices.

In contrast, we show in Hunold and Schlütter (2019) that passive backward ownership does not confer additional commitment power to the supplier and the equilibrium input costs remain at the same level as under vertical separation. This is an important difference to the case of full vertical integration as analyzed by Hart and Tirole (1990) in which the direction of the acquisition does not matter for the competitive effects.

Moreover, Lemma 3.1 establishes that an equilibrium in passive beliefs exists if downstream firms compete in quantities. The contracts, however, do not affect the supplier's maximization problem in a separable way, as it is the case under vertical separation. This implies that the main justification to employ passive beliefs does not hold if the supplier internalizes a share of the downstream profits. In Appendix C, we therefore additionally analyze the belief refinement of *wary beliefs* whereby—in case of an out-of-equilibrium offer—a downstream firm anticipates that the supplier might also have an incentive to change the contract offer to the downstream rival. As with passive beliefs, we find that forward internalization yields higher input prices than vertical separation and therefore reduces the commitment problem.

3.5 Discussion of the Competitive Effects with Observable and Secret Tariffs

Whereas forward ownership tends to be procompetitive with linear tariffs (Sections 3.3.1 and 3.4.1), our analysis shows that it increases the supplier's input prices with both observable and unobservable two-part tariffs (Sections 3.3.2 and 3.4.2). The economic reasons for this anticompetitive effect differ, however. Under observable two-part tariffs, the supplier strategically depreciates the outside option profit of the downstream firms in order to extract a larger share of the total profits via the fixed fee. This strategic reduction of the downstream firms' outside options comes at the cost that the total profit is below the joint profit maximum. With partial forward ownership, the supplier attaches a lower weight on strategically reducing the downstream profits (as it internalizes a share of these profits). In turn, it attaches a higher weight on achieving a high total profit that is closer to the joint profit maximum, which increases marginal input and final prices.

This strategic channel is not present with unobservable two-part tariffs. In fact, both downstream firms make the same (zero in the case of upstream monopoly) profit in equilibrium irrespective of whether the supplier internalizes a share of these profits or not. It may therefore seem odd at first glance that forward ownership actually affects the equilibrium input prices as the monopolist supplier does not receive any profit from its forward shareholding on the equilibrium path. Nevertheless, forward ownership allows the supplier to commit to higher input prices as it now internalizes a part of the losses that an off-equilibrium deviation (i.e., its opportunism in terms of a lower marginal input price for the competitor) would cause. This commitment effect leads to higher downstream prices and lower consumer surplus.

In general, vertical ownership links may also change the information structure in the vertical chain. In particular, it is possible that contracts are unobservable under vertical separation but partial ownership links allow the firms to exchange information in a credible way and build trust, such that the the problem of contract unobservability ceases to exist. While we do not model explicitly that partial ownership can have this feature, our analysis is nevertheless instructive for this case. In particular, it allows to compare the equilibrium under contract unobservability and vertical separation with the equilibrium under contract observability and partial forward ownership shares.

For linear supply contracts and the case of vertical separation, Gaudin (2019) shows that double marginalization is more (less) severe under secret contracts than public ones if the downstream firms' actions are strategic complements (substitutes).[12] In our setting, this means for the case of vertical separation that changing the information structure from contract unobservability to observability increases prices if the downstream firms compete in quantities and decreases them if they compete in prices. Hence, partial forward ownership that additionally makes contracts observable is unambiguously welfare enhancing if downstream firms compete in prices while the effects go in opposite directions in the case of quantity competition.

With secret two-part tariffs (and under the belief refinement of passive beliefs), marginal input prices are equal to the supplier's marginal costs under vertical separation. This implies that unless the supplier offers a marginal input prices below its marginal costs if contracts are observable, the change in the information structure leads to higher prices.[13] In this case, both making contracts observable as well as the internalization of downstream profits lead to higher prices and harm consumers.

3.6 Extensions

3.6.1 Partial Ownership versus Profit-Sharing Supply Contracts

One might wonder whether the anticompetitive result obtained for forward ownership and observable two-part tariffs (Proposition 3.2) can emerge without an ownership arrangement, but with a supply contract which involves a marginal input price w_i, a fixed fee f_i, and additionally entitles the supplier to a share σ_i of the downstream profits (similar to "revenue sharing"). We show that this is not the case.[14]

Suppose that the efficient supplier U offers each downstream firm a supply contract (w_i, f_i, σ_i). If the firms are vertically separated, the supplier's maximization problem is

$$\begin{aligned} \max\ \Omega^U &= \pi^U(w_i, w_{-i}) + \sum_{i\in\{A,B\}} \sigma_i\left(\pi_i(w_i, w_{-i}) - f_i\right) + f_i \\ s.t.&\quad (1-\sigma_i)\left(\pi_i(w_i, w_{-i}) - f_i\right) \geq \pi_i(c, w_{-i}),\ \text{for } i, -i \in \{A, B\} \end{aligned} \tag{3.16}$$

[12]In our analysis strategic substitutes relates to the case of Cournot competition and strategic complements to the case of Bertrand competition in the downstream market.

[13]Based on the linear demand specification in Equation (3.2), we find that marginal input prices with observable two-part tariffs can be below the supplier's marginal costs if downstream competition is quantities, the marginal costs of the competitive fringe c are small, and product substitutability γ is large. For the case of Bertrand competition, marginal input prices are above the supplier's marginal cost over the whole parameter space.

[14]For unobservable contracts, Hart and Tirole (1990) show for general contracts $t_{ij}(q_i)$ between upstream firm j and downstream firm j that opportunism cannot be solved on a contractual basis.

If the participation constrains are binding and solving them for $\sigma_i \pi_i (w_i, w_{-i}) + (1-\sigma_i) f_i$, yields the reduced maximization problem

$$\max_{w_A, w_B} \Omega^U = \pi^I (w_A, w_B) - \pi_A (c, w_B) - \pi_B (c, w_A), \tag{3.17}$$

which is the same reduced problem as for the case of vertical separation and observable two-part tariffs (the problem in Equation (3.8) for $\sigma = 0$). Therefore, the supplier has no incentive to charge higher marginal input prices under a profit-sharing contract (w_i, f_i, σ_i) than under a two-part tariff (w_i, f_i) if the firms are vertically separated. Adding a profit-sharing element to an observable two-part tariff does not change the contracting outcome.[15] We summarize this result in

Proposition 3.5. *The anticompetitive result derived for observable two-part tariffs* (w_i, f_i) *under forward ownership does not emerge under vertical separation if firms add a profit-sharing clause* σ_i *to the supply contract.*

Proof. Direct implications of the derivation above. □

3.6.2 Asymmetric Ownership

The focus on symmetric forward ownership in the main analysis helps to keep the model tractable. The results that we present for asymmetric ownership structures are twofold. First, for a given market structure, asymmetric ownership tends to affect the price level (and thus consumer surplus) in the same direction as symmetric ownership. Second, and consistent with the existing literature, our analysis confirms that asymmetric partial ownership may have foreclosure effects: a downstream firm generally pays a higher input price than its competitor when a supplier (partially) internalizes the competitor's profit.

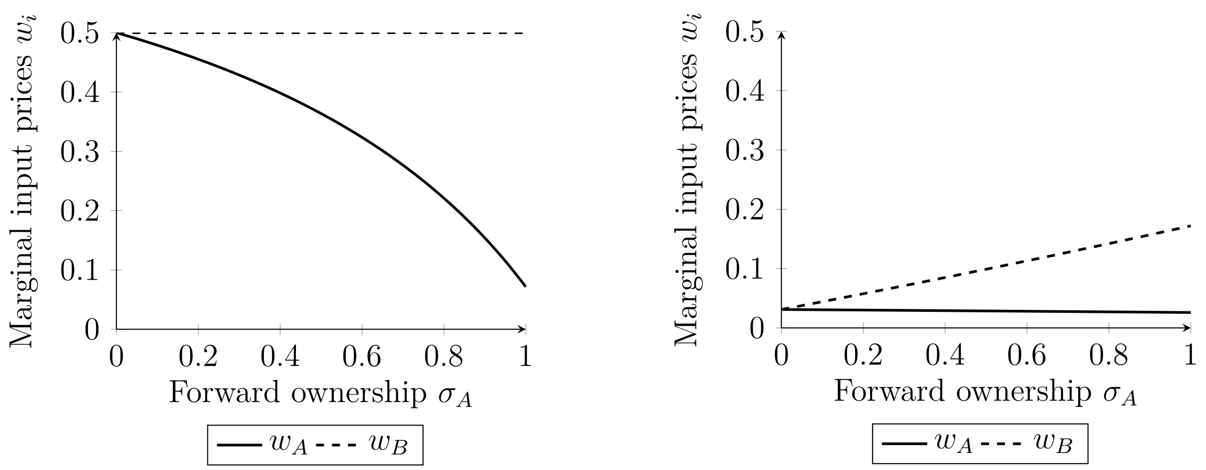
We start by discussing the case of linear tariffs and turn to two-part tariffs afterwards. As in the analysis of symmetric ownership structures it is necessary to distinguish between the cases of upstream competition and upstream monopoly. For upstream competition, we know from Proposition 3.1 that the procompetitive effect of forward ownership does not materialize as the downstream firms' input costs remain at the same level as under vertical separation. For the same reason, asymmetric profit internalization thus does not change marginal input prices either provided that upstream competition is sufficiently strong.

For the case of upstream monopoly and linear tariffs, symmetric forward internalization (as derived in Proposition 3.1) induces U to charge the downstream firms lower input prices than under vertical separation. For the sake of tractability, we analyze the case of asymmetric ownership on the downstream firms' input prices with Cournot competition

[15]Moreover, this result shows that σ_i and f_i are equivalent instruments to make the downstream firms indifferent to their outside option.

and linear demand (Eq. (3.2), with $\gamma = 1/2$). The results are robust to varying degrees of product substitutability γ and are qualitatively similar for Bertrand competition.

In particular, we assume that the supplier holds a partial forward ownership $\sigma_A \in [0,1]$ of downstream firm A but no shares of B. Panel (a) of Figure 3.1 illustrates that asymmetric ownership induces U to set lower input prices to downstream firm A compared to vertical separation. In contrast, as U has an incentive to divert profits from firm B to firm A, the linear input price w_B remains at the same high level as under vertical separation.



(a) Linear tariffs

(b) Two-part tariffs

Figure 3.1: Marginal input prices with forward ownership of firm A

The left panel shows the optimal observable linear input prices for an upstream monopoly (i.e., c sufficiently large). The right panel shows the optimal marginal input prices under observable two-part tariffs when the competitive fringe is a relevant supply alternative (with $c = 0.3$). Both panels show the input prices for $\sigma_A \in [0,1]$ and $\sigma_B = 0$. Competition is in quantities with demand defined in Eq. (3.2) and $\gamma = 1/2$.

With observable two-part tariffs, an unconstrained upstream monopolist obtains the maximal industry profit already under vertical separation. Partial ownership thus appears to be less relevant in this case and does not affect prices. With upstream competition and observable two-part tariffs, our main result is that forward ownership induces the supplier to increase the input prices towards the level that maximizes the industry profit (Proposition 3.2). Using again the linear demand framework introduced above, we find that with asymmetric ownership ($\sigma_A \in [0,1]$ and $\sigma_B = 0$) the supplier wants to increase the channel profit with downstream firm A whereas it still wants to keep B's outside option profit low as in the case of vertical separation. Panel (b) of Figure 3.1 shows that this is possible by increasing the input costs of downstream firm B as this allows A to achieve a higher profit and increases total profits. In contrast, there is only a minor change of A's input costs. Summarizing these results yields

Summary 3.1. Asymmetric partial ownership leads to an *unequal treatment* between the downstream firms. On average, it affects the input prices in the same direction as symmetric forward ownership.

Literature on Asymmetric Integration and Foreclosure. The analysis of asymmetric ownership relates to the literature on vertical integration and foreclosure of competitors. In this regard, our model is closest related to Spiegel (2013) who also considers that the supplier may offer better contract terms to a partially-integrated downstream firm. Spiegel (2013) analyzes the effects of these discriminatory input prices on the downstream firms' investment incentives and, in turn, the propensity to be vertically foreclosed. Vertical foreclosure occurs if one downstream firm successfully improves the product whereas the other one fails to do so. In contrast to Spiegel (2013), who fixes the input price for the integrated downstream firm at the level under vertical separation, we allow the upstream firm to adjust the contract that it offers to the partially-integrated downstream firm and compare the effects under linear and two-part tariffs. Moreover, our focus is not on investment incentives in the downstream market.

Other articles study whether a firm refuses to participate in the market for the intermediate good as supplier or customer. With full vertical integration, Salinger (1988) and Ordover et al. (1990) show that this form of foreclosure can be profitable as it can raise the rivals' costs.[16] As regards partial vertical ownership, Baumol and Ordover (1994) establish that a downstream firm that fully controls a bottleneck supplier, but gets only part of its profit, can have higher incentives to foreclose a downstream rival than under full vertical integration. The partial owner has to bear only a fraction of the upstream costs of foreclosure (foregone input sales), but internalizes the full benefit of relaxed downstream competition. Levy et al. (2018) show that the profitability of such a foreclosure strategy depends on the initial ownership structure.

3.6.3 Profitability of Partial Ownership and Consumer Surplus

We have studied how partial forward ownership affects the market prices. A related question is how this affects the firms' profits, consumer surplus and, ultimately, what ownership structure is likely to arise. If the firms can arrive at efficient agreements about the ownership structure with each other ("Coasian bargaining"), they should implement an ownership arrangement that maximizes their joint (industry) profits. In our setting, symmetric partial forward ownership increases industry profits if it moves the downstream price towards the monopoly level. This generally is the case for linear input prices in the

[16]The analysis of Ordover et al. (1990) has been criticized on the grounds that the integrated supplier needs to commit itself to refusing to supply of the non-integrated downstream firm (Hart and Tirole, 1990; Reiffen, 1992). Among others, Allain et al. (2016) propose a model that does not rely on this form of commitment. They also study the case of partial ownership in an extension and find that forward integration increases the incentive to degrade the conditions offered to the downstream rival.

presence of an upstream monopolist as well for two-part tariffs with upstream competition (and in the case of unobservable two-part tariffs even independently of the degree of upstream competition). The industry should thus have an incentive in these cases to choose an ownership structure that yields monopoly prices, or if this is not attainable, it should choose the highest possible internalization.

For instance, in the presence of effective merger control, the firms in the industry cannot implement ownership structures that maximize the industry profit (the joint profit of U, A, and B in the model). It might still be feasible and profitable for pairs of firms to bilaterally establish an ownership link, however. As in the previous section, we therefore assess the effect of asymmetric ownership structures on the firms' profits as well as on the consumer surplus based on the linear demand in Equation (3.2) with $\gamma = 1$.[17]

In Table 3.1, we report the results of a 15% partial forward ownership share between supplier U and downstream firm A whereas there is no ownership link between U and B. It compares the firms' profits $\pi_A^U = \pi^U + \pi_A$ and π_B, and the consumer surplus CS under this ownership structure to the benchmark case of vertical separation.

	π_A^U	π_B	Consumer surplus CS
Linear tariffs (upstream monopoly)	3.1%	-10.8%	5.6%
Two-part tariffs (upstream comp., $c = 0.3$)	2.2%	-10.8%	-2.5%

Table 3.1: Firm profits and consumer surplus under asymmetric ownership

The table shows the relative changes in firm profits and consumer surplus for a partial forward ownership share of $\sigma_A = 15\%$ and $\sigma_B = 0$ compared to vertical separation. The first line shows the results under observable linear input prices and for an upstream monopoly (i.e., c sufficiently large). The second line shows the results for observable two-part tariffs when the competitive fringe is a relevant supply alternative (with $c = 0.3$). Competition is in quantities with demand defined in Equation (3.2) and $\gamma = 1$.

The first line of Table 3.1 shows the results for observable linear tariffs if the efficient supplier can act as upstream monopolist. Forward ownership between U and A has a positive effect on the joint profit of these firms (+3.1%) and a strong negative effect of -10.8 on B's profit. The consumer surplus (CS) increases by 5.6% due to the lower price level. This result is in line with Panel (a) in Figure 3.1, which documents that under linear tariffs the input prices for A decreases in the forward ownership share.

[17] The results are qualitatively the same for varying degrees of product substitutability γ and also for the case of price competition downstream.

The second line in the table shows the results for observable two-part tariffs. We consider the case that the competitive fringe has marginal costs of $c = 0.3$ and therefore is a relevant supply alternative for the downstream firms. The forward ownership share of 15% increases the joint profit of U and A by 2.2%. In contrast, the profit of downstream firm B decreases by -10.8%. As the overall price level increases if the supply contract is nonlinear, forward ownership decreases consumer surplus in this case (-2.5%).

3.7 Conclusion

We offer novel insights for the competitive assessment of partial ownership in vertically-related industries. The contribution of the present article is to demonstrate that the effects of partial forward ownership crucially depend on the degree of upstream competition as well as on the pricing arrangement between upstream and downstream firms.

Our analysis reveals that partial forward ownership can have strong anticompetitive price effects if the supply contracts are nonlinear. Importantly, we demonstrate that these competitive effects occur both if contracts are observable as well as if they are unobservable, albeit for different economic reasons.

With observable two-part tariffs, a supplier strategically sets marginal prices below the level that maximize industry profits if downstream firms have a relevant supply alternative. This allows the upstream firm to obtain a larger share of the industry profit, at the cost of reducing the total industry profit. This extraction incentive is lower if the supplier internalizes a share of the downstream profits, which implies higher marginal input prices and thus downstream prices as well as higher industry profits than with vertical separation.

Instead, with secret contracting, even an upstream monopolist cannot commit to charging downstream competitors high input prices under vertical separation (Hart and Tirole, 1990). This opens the door for profit-increasing structural arrangements even in case of an upstream monopoly. Our analysis reveals that partial forward ownership effectively enables the upstream firm to commit to higher input prices, which in turn leads to higher consumer prices

Moreover, we contribute to the analysis of partial forward ownership in the presence of linear supply contracts. First, if downstream firms have a relevant supply alternative the procompetitive effect derived by Flath (1989) does not materialize and partial forward ownership is competitively neutral. Second, we extend the established literature that focuses on observable linear contracts to the case of unobservable ones. Building on Gaudin (2019), we demonstrate that partial forward ownership can also reduce double marginalization under the alternative information structure of secret contracts.

Our results are of relevance for the current competition policy debate on how to treat partial ownership acquisitions in merger control. Perhaps most strikingly, such acquisitions are currently not covered by the European Union Merger Regulation.[18] We emphasize that—besides established concerns about foreclosure—the price effects of partial vertical ownership can be detrimental and should be taken into account in the merger review. This is particularly important for the case of forward ownership as the price effects for this ownership structure so far have been considered to be rather procompetitive. In stark contrast, our analysis reveals that such ownership arrangements can lead to higher prices and consumer harm.

[18]Council Regulation (EC) No 139/2004 of 20 January 2004 on the control of concentrations between undertakings (OJ L 24, 29.1.2004, p. 1). Under certain conditions, the review of non-controlling partial ownership acquisitions is currently feasible in other jurisdictions such as Austria, Brazil, Germany, Japan, the UK, and the United States. See the Annex 2 to the Commission Staff Working Document "Towards more effective EU merger control" for an overview of the regulation in these jurisdictions.

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Appendix

Appendix A: Proofs

Proof of Proposition 3.1. If c is sufficiently large $\left(w^l(\sigma) < c\right)$, the symmetric input price $w^l(\sigma)$ that solves the system of first-order conditions defined in Equation (3.6) is the equilibrium input price. Assumption 3.2 ensures that the second-order conditions are fulfilled. Implicit differentiation of the $w^l(\sigma)$ with respect to the degree of forward internalization σ yields

$$\frac{\partial w^l(\sigma)}{\partial \sigma} = -\frac{\partial \pi_i(w_i, w_{-i}) / \partial w_i + \partial \pi_{-i}(w_{-i}, w_i) / \partial w_i}{\partial^2 \Omega^U / \partial^2 w_i + \partial^2 \Omega^U / \partial w_i \partial w_{-i}} < 0. \tag{3.18}$$

By Assumption 3.1, the nominator is negative; the denominator is negative due to the concavity of the supplier's objective function. In a symmetric interior equilibrium, the equilibrium input price $w^l(\sigma)$ thus decreases in the degree of forward internalization σ if c is sufficiently large. This implies that also downstream prices decrease for an increase in the forward ownership share σ.

A downstream firm's participation constraint is violated if $w^l(\sigma) \geq c$. Given the concave optimization problem, the supplier sets the input price as high as possible in this case; that means $w = c$. This is the same input price as under vertical separation because, if the participation constraint is binding at σ, it is also binding at any $\sigma' \in [0, \sigma]$. Thus, downstream prices are at the same level as under vertical separation. This establishes the result. □

Proof of Proposition 3.2. Recall that we denote by $w^{tp}(\sigma)$ the symmetric per-unit input price with observable two-part tariffs that solves the system of first-order conditions in Equation (3.9). Assumptions 3.1 and 3.2 imply that the second-order conditions are fulfilled. Implicit differentiation of $w^{tp}(\sigma)$ with respect to σ yields

$$\frac{\partial w^{tp}(\sigma)}{\partial \sigma} = -\frac{\partial \pi_{-i}(c, w_i) / \partial w_i}{\partial^2 \Omega^U / \partial^2 w_i + \partial^2 \Omega^U / \partial w_i \partial w_{-i}} \geq 0. \tag{3.19}$$

The denominator is negative due to concavity of the supplier's objective function. The nominator is strictly positive if the competitive fringe is a relevant supply alternative

(Assumption 3.1). This implies that the inequality in Equation (3.19) is strict. In this case input prices (and thus downstream prices) increase in the degree of forward internalization σ.

If the competitive fringe is not a relevant supply alternative, we have $\partial\pi_{-i}(c, w_i)/\partial w_i = 0$ which implies $\partial w^{tp}(\sigma)/\sigma = 0$ and that downstream prices are the same for all $\sigma \in [0,1]$. This establishes the result. $\square$

Proof of Proposition 3.3. If c is sufficiently large $\left(w^{lu}(\sigma) < c\right)$, symmetric input price $w^{lu}(\sigma)$ that solves the system of first-order conditions defined in Equation (3.13) is the equilibrium input price. Implicit differentiation of the $w^{lu}(\sigma)$ with respect to the degree of forward internalization σ yields

$$\frac{\partial w^{lu}(\sigma)}{\partial\sigma} = -\frac{\left[-q_i(w_i) + q_{-i}(w_{-i})\frac{\partial p_{-i}(q_{-i}(w_{-i}),q_i(w_i))}{\partial q_i}\frac{\partial q_i(w_i)}{\partial w_i}\right]}{\partial^2\Omega^U/\partial^2 w_i}. \tag{3.20}$$

The denominator is negative by assumption that the supplier's objective function is strictly concave. Hence, the comparative static $\partial w(\sigma)/\partial\sigma$ is negative if the term in the nominator is negative. This term can be written as

$$q_i\left(w_i^{lu}\right)\left(-1 + \frac{\partial p_{-i}\left(q_{-i}\left(w_{-i}^{lu}\right), q_i\left(w_i^{lu}\right)\right)}{\partial q_i}\frac{\partial q_i\left(w_i^{lu}\right)}{\partial w_i}\right), \tag{3.21}$$

as $q_i = q_{-i}$ due to demand symmetry. The term in the brackets of Equation (3.21) is negative if

$$1 > \frac{\partial p_{-i}\left(q_{-i}\left(w_{-i}^{lu}\right), q_i\left(w_i^{lu}\right)\right)}{\partial q_i}\frac{\partial q_i\left(w_i^{lu}\right)}{\partial w_i}. \tag{3.22}$$

Note that from downstream firm i's first order condition, $\partial\pi_i/\partial q_i = 0$, we can derive the comparative static

$$\frac{\partial q_i(w_i)}{\partial w_i} = -\frac{-1}{\left(\partial^2 p_i(q_i, q_{-i})/\partial^2 q_i\right)q_i + 2\left(\partial p_i(q_i, q_{-i})/\partial q_i\right)}. \tag{3.23}$$

Using Equations (3.22) and (3.23) as well as demand symmetry yields

$$2\frac{\partial p_i(q_i, q_{-i})}{\partial q_i} - \frac{\partial p_{-i}(q_{-i}, q_i)}{\partial q_i} + \frac{\partial^2 p_i(q_i, q_{-i})}{\partial^2 q_i}q_i < 0, \tag{3.24}$$

which is negative by Assumption 3.3. This establishes the result that $\partial w^{lu}(\sigma)/\partial\sigma < 0$ if c is sufficiently large. In contrast, a downstream firm's participation constraint is violated if $w^{lu}(\sigma) \geq c$. Given the concave optimization problem, the supplier sets the input price as high as possible in this case. By the same reasoning as in the proof of Proposition 1 downstream prices are thus at the same level as under vertical separation. This establishes the result. □

Proof of Lemma 3.1. First, we derive the supplier's maximization problem and establish equilibrium existence and uniqueness.

Anticipating that its competitor produces the equilibrium quantity Q_{-i}, the profit of downstream firm i when accepting the contract is

$$\pi_i = \left(p_i\left(q_i, Q_{-i}\right) - w_i\right) q_i - f_i. \tag{3.25}$$

Each downstream firm optimally sets the quantity for a given input price w_i and belief about the other firm's quantity (Q_{-i}) as follows:

$$q_i\left(w_i\right) = \arg\max_{q_i} \left(p_i\left(q_i, Q_{-i}\right) - w_i\right) q_i - f_i, \tag{3.26}$$

which is implicitly defined by the downstream firm i's first-order condition $\partial \pi_i / \partial q_i = 0$, which implies

$$\left(p_i\left(q_i, Q_{-i}\right) - w_i\right) + \frac{\partial p_i\left(q_i, Q_{-i}\right)}{\partial q_i} q_i = 0. \tag{3.27}$$

Based on this first-order condition, implicit differentiation of Equation (3.27) yields that the equilibrium quantity decreases monotonically in w_i. That is,

$$\frac{\partial q_i\left(w_i\right)}{\partial w_i} = -\frac{-1}{\partial^2 \pi_i / \partial^2 q_i} < 0, \tag{3.28}$$

where the denominator is negative due to the concavity of i's objective function (Assumption 3.3). Hence, there is a one-to-one mapping between the w_i and $q_i\left(w_i\right)$. Below, we can therefore characterize the supplier's problem as effectively selecting quantities in the downstream market.

If a downstream firm does not accept the contract offers and instead sources from the competitive fringe, its profit is

$$\pi_i\left(c, W_{-i}\right) = \left(p_i\left(q_i, Q_{-i}\right) - c\right) q_i\left(w_i\right), \tag{3.29}$$

which indicates that downstream firm i has input costs of c while it anticipates that its competitor accepts the contract and faces an marginal input price of W_{-i}. Recall that W_{-i} denotes the belief about the rival's contract as the offers are secret and that there is a one-to-one relation between W_{-i} and the expected quantity Q_{-i}. If the competitive fringe is very inefficient (large c), it is not a relevant supply alternative and the efficient supplier is effectively an upstream monopolist.

Next, we turn to the contract offers of the efficient supplier U. For given beliefs of the downstream firms, the supplier's objective function is

$$\begin{aligned}\Omega^U = \ & \textstyle\sum_{i \in \{A,B\}} \ w_i q_i (w_i) + f_i \\ & \qquad + \sigma \left(\left(p_i \left(q_i (w_i), q_{-i} (w_{-i}) \right) - w_i \right) q_i (w_i) - f_i \right),\end{aligned} \tag{3.30}$$

subject to the constraint that each downstream firms is willing to accept its contract offer. The supplier internalizes a share σ of each downstream firm's actual profit (which equals the flow profit $\left(p_i \left(q_i (w_i), q_{-i} (w_{-i}) \right) - w_i \right) q_i (w_i)$ minus the fixed fee f_i). It makes the downstream firms, given their beliefs, indifferent to their outside option of $\pi_i (c, W_{-i})$ by setting

$$f_i \ = \ \left(p_i \left(q_i (w_i, Q_{-i}), Q_{-i} \right) - w_i \right) q_i (w_i) - \pi_i (c, W_{-i}). \tag{3.31}$$

Importantly, note that a downstream firm's outside option $\pi_i (c, W_{-i})$ does not depend on its own marginal input price w_i.

By substituting the fixed fees from (3.31), we can therefore write the supplier's objective function as follows:

$$\begin{aligned} & \Omega^U \\ = & \sum_{i \in \{A,B\}} \left(\sigma p_i \left(q_i (w_i), q_{-i} (w_{-i}) \right) q_i + (1-\sigma) \left(p_i \left(q_i (w_i), Q_{-i} \right) q_i (w_i) - \pi_i (c, W_{-i}) \right) \right).\end{aligned} \tag{3.32}$$

The first term in Equation (3.32) is proportional to the industry profit

$$\pi^I = \sum_{i \in \{A,B\}} p_i (q_i, q_{-i}) q_i,$$

which is a strictly concave function in w_A and w_B (Assumption 3.4). The second term contains the supplier's objective function under vertical separation, which is strictly concave in w_A and w_B as in Rey and Vergé (2004) (see Proposition 1 therein). Note that even a positive outside option $\pi_i (c, W_{-i}) > 0$ does not change this result as it does not depend on the contract offer w_i directly but only on the downstream firm's belief about its rival's contract offer W_{-i}. Hence, the objective function in Equation (3.32) is strictly concave, which means that the sufficient conditions for equilibrium existence and uniqueness are fulfilled.

As derived in Equation (3.28), there is a one-to-one mapping between the effective input prices and the equilibrium quantities. It is thus convenient to characterize the supplier's maximization problem as selecting the downstream quantities directly.

Next, we show that the equilibrium does not involve marginal input prices equal to the supplier's marginal costs if the supplier internalizes a share $\sigma > 0$ of the downstream firms' profits. The first-order condition with respect to (say) q_A is

$$\begin{aligned}\frac{\partial \Omega^U}{\partial q_A} &= \sigma \left(\underbrace{\frac{\partial p_A(q_A, q_B)}{\partial q_A} q_A + p_A(q_A, q_B)}_{=w_A} + \frac{\partial p_B(q_B, q_A)}{\partial q_B} q_B \right) \\ &+ (1-\sigma) \underbrace{\left(\frac{\partial p_A(q_A, Q_B)}{\partial q_A} q_A + p_A(q_A, Q_B) \right)}_{=w_A} = 0.\end{aligned} \tag{3.33}$$

Denote the symmetric equilibrium quantity that solves the supplier's system of first-order conditions as $q_A(\sigma) = q_B(\sigma) = q(\sigma)$ and the symmetric input price, which induces this quantity in the downstream market, with $w_A^{tpu}(\sigma) = w_B^{tpu}(\sigma) = w^{tpu}(\sigma)$, where tpu indicates that the supplier uses two-part tariffs that are unobservable.

From the downstream firm's first-order condition (Equation (3.27)), we can infer that the first two terms in the bracket in the first line and the term in the brackets in the second line equals the marginal input price w_A. Note that $p_A(q_A, q_B) = p_A(q_A, Q_B)$ as beliefs are correct in equilibrium.

Note that marginal input prices equal to the suppliers marginal costs, that is, $w^{tpu}(\sigma) = 0$ do not solve the first-order condition in Equation (3.33) if $\sigma > 0$. In particular, we observe that at $w = 0$ the term in the first line of Equation (3.33) is positive: $(\partial p_B(q_B, q_A)/\partial q_A) \cdot q_B > 0$. We conclude that input prices equal to the supplier's marginal costs do not fulfill the necessary condition for an equilibrium in this case. This establishes the result. □

Proof of Proposition 3.4. Lemma 3.1 establishes existence and uniqueness of the equilibrium. Moreover, it shows that input costs equal to the supplier's marginal costs are not an equilibrium for $\sigma > 0$. Here, we characterize the equilibrium for $\sigma > 0$.

The supplier's first-order condition with respect to q_A in Equation (3.33) can be expressed in terms of the derivation of the industry profit π^I with respect to q_A (i.e., $\partial \pi^I(q_A, q_B)/\partial q_A$, first line in Eq. (3.33)) and in terms of the derivation of the joint profit between U and A with respect to q_A (i.e., $\partial \pi_A^U(q_A, q_B)/\partial q_A$, second line in Eq. (3.33)). This implies that

$$\frac{\partial \Omega^U(q_A, q_B)}{\partial q_A} = \sigma \frac{\partial \pi^I(q_A, q_B)}{\partial q_A} + (1-\sigma) \frac{\partial \pi_A^U(q_A)}{\partial q_A} = 0. \tag{3.34}$$

Implicit differentiation of the symmetric downstream quantity $q(\sigma)$ with respect to σ yields

$$\frac{\partial q(\sigma)}{\partial \sigma} = -\frac{\partial \pi^I(q_A, q_B)/\partial q_A - \partial \pi_A^U(q_A)/\partial q_A}{\partial^2 \Omega^U(q_A, q_B)/\partial^2 q_A + \partial^2 \Omega^U(q_A, q_B)/\partial q_A \partial q_B} < 0. \tag{3.35}$$

By Lemma 3.1, the denominator is negative. For quantities in the range between the level that maximizes the industry profit and the level that maximizes the bilateral profit of the supplier with one downstream firm, we have that $\partial \pi^I (q_A, q_B) / \partial q_A < 0$ and $\partial \pi_A^U (q_A, q_B) / \partial q_A > 0$. Hence, the nominator is negative and the quantity $q(\sigma)$ thus decreases (and downstream prices increase) in σ. This establishes the result. □

Appendix B: Secret Two-Part Tariffs and Price Competition Downstream

Preliminaries

In this appendix, we show that partial forward ownership is anticompetitive if the supplier charges unobservable two-part tariffs and the downstream firms compete in prices. The supplier holds a symmetric forward ownership σ of both downstream firms. In order to analyze Bertrand competition, we first introduce additional notation. Building on Rey and Vergé (2004), we assume that the demand for each downstream firm, $q_i (p_i, p_{-i})$ is symmetric with $\frac{\partial q_i}{\partial p_i} + \frac{\partial q_i}{\partial p_{-i}} < 0 < \frac{\partial q_i}{\partial p_{-i}}$. Given that both downstream firms accept the supplier's contract offer, a downstream firm's objective function can be written as

$$\pi_i (p_i, p_{-i}) = (p_i - w_i) q_i (p_i, p_{-i}) - f_i. \tag{3.36}$$

We further maintain the assumption that downstream firms' objective functions are strictly concave (see Assumption 3.3 in the analysis of Cournot competition).

As emphasized by Rey and Vergé (2004) for the case of vertical separation, the supplier's objective function is not necessarily concave with unobservable contracts and thus a perfect Bayesian-Nash equilibrium may fail to exist. We impose

Assumption 3.5. *There exists a unique symmetric solution to the first-order conditions of the supplier's maximization problem and the objective function $\Omega^U (w_A, w_B)$ has negative second-order derivatives: $\partial^2 \Omega^U / \partial^2 w_i$.*

This assumption is fulfilled under vertical separation (Rey and Vergé, 2004). Assumption 3.5 ensures that this extends to the case of partial forward ownership. In general, it is satisfied if the second derivatives of demand are not too positive, and for instance, if demand is linear.[19] For equilibrium existence, we additionally need to check that the sufficient conditions are also fulfilled. This means that, in addition, the Hessian needs to be negative definite.

Recall that we denote a downstream firm's contract offer as $t_i = (w_i, f_i)$ and the passive beliefs about the other downstream firm's contract offer as $T_{-i} = (W_{-i}, F_{-i})$. Similarly,

[19] See, for instance, Pagnozzi and Piccolo (2012) for a related assumption on the supplier's objective function.

downstream firm i expects that the rival $-i$ sets the price $P_{-i} = p_{-i}(W_{-i})$. In equilibrium, beliefs are correct.

Analysis and Proofs

We first establish that there is no equilibrium with input prices equal to the suppliers marginal costs also for the case of Bertrand competition.

Lemma 3.2. *Suppose supplier U charges unobservable two-part tariffs and holds a symmetric forward ownership share σ of both downstream firms. If the downstream firms compete in prices and hold passive beliefs, input prices equal to the supplier's marginal costs are not an equilibrium.*

Proof of Lemma 3.2. In the case of Bertrand competition, downstream firm i sets the optimal price given passive beliefs about W_{-i} and the resulting P_{-i} as follows:

$$p_i(w_i) = \arg\max_{p_i} (p_i - w_i)\, q_i(p_i, P_{-i}), \tag{3.37}$$

which is implicitly defined by the first order condition $\partial \pi_i / \partial p_i = 0$, that is,

$$(p_i - w_i) \frac{\partial q_i(p_i, P_{-i})}{\partial p_i} + q_i(p_i, P_{-i}) = 0. \tag{3.38}$$

The equilibrium price $p_i(w_i)$ increases monotonically in w_i:

$$\frac{\partial p_i(w_i)}{\partial w_i} = \frac{\frac{\partial q_i(p_i, P_{-i})}{\partial p_i}}{(p_i - w_i)\frac{\partial^2 q_i(p_i, P_{-i})}{\partial^2 p_i} + 2\frac{\partial q_i(p_i, P_{-i})}{\partial p_i}} > 0. \tag{3.39}$$

The inequality holds as the denominator is negative (due to the downstream firm's strictly concave profit function) and as $\partial q_i / \partial p_i < 0$. Denote with $q_i(p_i(w_i), P_i)$ the quantity that downstream firm i expects to sell given its own price $p_i(w_i)$ and the expected competitor's price P_{-i}. The supplier sets the fixed fee such that the downstream firms are indifferent between the contract offer and being inactive. This implies

$$f_i = (p_i(w_i) - w_i)\, q_i(p_i(w_i), P_{-i}) - \pi_i(c, W_{-i}), \tag{3.40}$$

where $\pi_i(c, W_{-i})$ denotes a downstream firm's outside option in case the competitive fringe is a relevant supply alternative.

The supplier can correctly infer the downstream prices and quantities, as it knows the input prices that it offers to both downstream firms. Hence, denote with $q_i(p_i(w_i), p_{-i}(w_{-i}))$ the quantity that downstream firm i ends up selling when the supplier offers input prices of (w_i, w_{-i}). The supplier's objective function can be written as

$$\begin{aligned}\Omega^U(w_A, w_B, f_A, f_B) &= \sum_{i\in\{A,B\}} w_i q_i(p_i(w_i), p_{-i}(w_{-i})) + f_i \\ &+ \sigma((p_i(w_i) - w_i) q_i(p_i(w_i), p_{-i}(w_{-i})) - f_i).\end{aligned} \tag{3.41}$$

Substituting for the fixed fees (Equation (3.40)) and suppressing the dependence of p_i on w_i, we can express U's objective function as

$$\begin{aligned}\Omega^U(w_A, w_B) = \; & \textstyle\sum_{i\in\{A,B\}} \; \sigma\cdot(p_i q_i(p_i, p_{-i})) + (1-\sigma)\cdot(p_i q_i(p_i, P_{-i})) \\ &+ (1-\sigma)\cdot(w_i(q_i(p_i, p_{-i}) - q_i(p_i, P_{-i}))).\end{aligned} \tag{3.42}$$

The unique candidate equilibrium prices solve the system of the supplier's first-order conditions. The first-order condition to the supplier's objective function in Equation (3.42) with respect to (say) w_A is

$$\begin{aligned}\frac{\partial\Omega^U}{\partial w_A} &= \sigma\left(q_A(p_A, p_B) + p_A\frac{\partial q_A(p_A, p_B)}{\partial p_A}\right)\frac{\partial p_A}{\partial w_A} \\ &+ (1-\sigma)\left(q_A(p_A, P_B) + p_A\frac{\partial q_A(p_A, P_B)}{\partial p_A}\right)\frac{\partial p_A}{\partial w_A} \\ &+ \left((\sigma p_B + (1-\sigma) w_B)\frac{\partial q_B(p_B, p_A)}{\partial p_A}\right)\frac{\partial p_A}{\partial w_A} \\ &+ (1-\sigma)\left(w_A\left(\frac{\partial q_A(p_A, p_B)}{\partial p_A} - \frac{\partial q_A(p_A, P_B)}{\partial p_A}\right)\right)\frac{\partial p_A}{\partial w_A} \\ &+ (1-\sigma)(q_A(p_A, p_B) - q_A(p_A, P_B)) = 0.\end{aligned} \tag{3.43}$$

Equation (3.43) can be simplified by employing that beliefs are correct in equilibrium ($p_i = P_i$). This implies that the terms in the first two lines can be simplified to

$$q_A(p_A, p_B) + p_A\frac{\partial q_A(p_A, p_B)}{\partial p_A}.$$

Moreover, note that the last two lines of Equation (3.43) are equal to zero due to fact that beliefs are correct in equilibrium. Taking these simplifications into account and dividing the first-order condition by $\partial p_A/\partial w_A$ yields

$$\begin{aligned}\frac{\partial\Omega^U}{\partial w_A} &= q_A(p_A, p_B) + p_A\frac{\partial q_A(p_A, p_B)}{\partial p_A} \\ &+ (\sigma p_B + (1-\sigma) w_B)\frac{\partial q_B(p_B, p_A)}{\partial p_A} = 0.\end{aligned} \tag{3.44}$$

From rearranging the downstream firm's first-order condition $\partial \pi_A / \partial p_A = 0$, we obtain

$$q_A + p_A \frac{\partial q_A}{\partial p_A} = w_A \frac{\partial q_A}{\partial p_A}, \tag{3.45}$$

Substituting the right-hand side from Equation (3.45) in the second line of Equation (3.43) yields

$$w_A \frac{\partial q_A (p_A, p_B)}{\partial p_A} + (\sigma p_B + (1-\sigma) w_B) \frac{\partial q_B (p_B, p_A)}{\partial p_A} \quad = \quad 0 \tag{3.46}$$

The first-order condition with respect to w_B can be derived accordingly. Denote the symmetric marginal input price that solves the system of first-order conditions by $w_A^{tpu}(\sigma) = w_B^{tpu}(\sigma) = w^{tpu}(\sigma)$. For $\sigma = 0$ (vertical separation), the unique solution to the system of first-order conditions is $w^{tpu}(0) = 0$. For $\sigma > 0$, however, $w^{tpu}(\sigma) = 0$ does not solve the system of first-order conditions. In particular, in this case the left-hand side of Equation (3.46) becomes $\sigma p_B \cdot \partial q_B (p_B, p_A) / \partial p_A$, which is positive. Input prices equal to the supplier's marginal costs thus do not solve the first-order condition and the supplier. This establishes the result. □

In the following proposition, we derive the conditions for equilibrium existence and characterize the comparative static of the marginal input price in the forward ownership share σ.

Proposition 3.6. *Suppose supplier U charges unobservable two-part tariffs and holds a symmetric forward ownership share σ of both downstream firms. If the downstream firms compete in prices and hold passive beliefs, there exists a unique symmetric perfect Bayesian-Nash equilibrium if and only if the cross elasticity of substitution is sufficiently small. For linear demand, the condition is*

$$\frac{\epsilon}{2} \quad > \quad \left(1 - \frac{\sigma}{2}\right) \epsilon_s, \tag{3.47}$$

with ϵ and ϵ_S defined in Equation (3.49). Equation (3.53) contains the condition for non-linear demand.

The marginal input prices and downstream prices increase in the forward ownership share σ.

Proof of Proposition 3.6. We first establish equilibrium existence and then derive the comparative static results for partial forward ownership. As analyzed in Rey and Vergé (2004) for vertical separation (see Proposition 2 therein), an equilibrium exists if the cross-price elasticity of demand is small enough in relation to the own-price elasticity:

$$\epsilon_s < \frac{\epsilon}{2}, \tag{3.48}$$

where

$$\epsilon \equiv -\frac{\partial q_i(p_i, p_{-i})}{\partial p_i} \frac{p_i}{q_i(p_i, p_{-i})}, \ \epsilon_s \equiv \frac{\partial q_i(p_i, p_{-i})}{\partial p_{-i}} \frac{p_{-i}}{q_i(p_i, p_{-i})}. \tag{3.49}$$

If the cross elasticity ϵ_s is larger, Rey and Vergé (2004) demonstrate a profitable multilateral deviation from the candidate equilibrium for the supplier, which implies that a perfect Bayesian-Nash equilibrium in passive beliefs does not exist.

We now derive the condition that there is no profitable multilateral deviation from the candidate equilibrium under partial vertical ownership. A sufficient condition that the candidate equilibrium establishes a perfect Bayesian equilibrium is to verify that the Hesse matrix of second-order derivatives $M = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$ is negative definite at the candidate equilibrium input prices. In a symmetric equilibrium, it holds $a = d = \partial^2\Omega^U/\partial^2 w_A$ and $b = c = \partial^2\Omega^U/\partial w_A \partial w_B$ for the elements of the Hesse matrix. We obtain the second-order condition of U's maximization problem in Equation (3.42) with respect to w_A by differentiating Equation (3.43) with respect to w_A. Evaluating the second-order condition at the symmetric candidate equilibrium (at which $w_A = w_B$ and $p_A = p_B$ such that the downstream firms' first-order conditions hold) yields

$$\begin{aligned} \frac{\partial^2\Omega^U}{\partial^2 w_A} &= \left(2\frac{\partial q_A(p_A, p_B)}{\partial p_A} + p_A \frac{\partial^2 q_A(p_A, p_B)}{\partial^2 p_A}\right)\left(\frac{\partial p_A}{\partial w_A}\right)^2 \\ &+ (\sigma p_A + (1-\sigma) w_A) \frac{\partial^2 q_B(p_B, p_A)}{\partial^2 p_A}\left(\frac{\partial p_A}{\partial w_A}\right)^2. \end{aligned} \tag{3.50}$$

This second-order derivative is negative by Assumption 3.5. This assumption is fulfilled for instance if $\partial^2 q_i(p_i, p_{-i})/\partial^2 p_i \leq 0$ and $\partial^2 q_i(p_i, p_{-i})/\partial^2 p_{-i} \leq 0$. The second element of the Hesse matrix evaluated at the symmetric candidate equilibrium is

$$\begin{aligned} \frac{\partial^2\Omega^U}{\partial w_A \partial w_B} &= 2\left(1 - \sigma + \sigma\frac{\partial p_A}{\partial w_A}\right)\frac{\partial q_A(p_A, p_B)}{\partial p_B}\frac{\partial p_A}{\partial w_A} \\ &+ 2(\sigma p_A + (1-\sigma) w_A)\frac{\partial^2 q_A(p_A, p_B)}{\partial p_A \partial p_B}\left(\frac{\partial p_A}{\partial w_A}\right)^2, \end{aligned} \tag{3.51}$$

where we again use that the demand and the equilibrium are symmetric ($p_A = p_B$, $\partial q_A(p_A, p_B)/\partial p_B = \partial q_B(p_B, p_A)/\partial p_A$, $\partial p_A/\partial w_A = \partial p_B/\partial w_B$), as well as that the beliefs are correct in equilibrium.

The Hessian is negative definite if $-\partial^2\Omega^U/\partial^2 w_A > \left|\partial^2\Omega^U/\partial w_A \partial w_B\right|$. The second-order derivative $\partial^2\Omega^U/\partial^2 w_A$ is negative by assumption and the sign of $\partial^2\Omega^U/\partial w_A \partial w_B$ can be either positive or negative. By inserting Equations (3.50) and (3.51) in the inequality above, we obtain

$$\left(2\frac{\partial q_A(p_A,p_B)}{\partial p_A}+p_A\frac{\partial^2 q_A(p_A,p_B)}{\partial^2 p_A}\right)\left(\frac{\partial p_A}{\partial w_A}\right)^2+(\sigma p_A+(1-\sigma)w_A)\frac{\partial^2 q_B(p_B,p_A)}{\partial^2 p_A}\left(\frac{\partial p_A}{\partial w_A}\right)^2$$
$$> \left|2\left(1-\sigma+\sigma\frac{\partial p_A}{\partial w_A}\right)\frac{\partial q_A(p_A,p_B)}{\partial p_B}\frac{\partial p_A}{\partial w_A}+2(\sigma p_A+(1-\sigma)w_A)\frac{\partial^2 q_A(p_A,p_B)}{\partial p_A\partial p_B}\left(\frac{\partial p_A}{\partial w_A}\right)^2\right| \quad (3.52)$$

Simplifying the inequality and using that $\frac{\partial p_A}{\partial w_A}=-\frac{\partial^2\pi_A/\partial p_A\partial w_A}{\partial^2\pi_A/\partial^2 p_A}$ allows to rewrite this inequality as

$$-\frac{\partial q_A(p_A,p_B)}{\partial p_A}+(\sigma p_A+(1-\sigma)w_A)\frac{\partial^2 q_B(p_B,p_A)}{\partial^2 p_A}\frac{\partial p_A}{\partial w_A}+w_A\frac{\partial^2 q_A(p_A,p_B)}{\partial^2 p_A}\frac{\partial p_A}{\partial w_A} \quad (3.53)$$
$$> \left|2\left(1-\sigma+\sigma\frac{\partial p_A}{\partial w_A}\right)\frac{\partial q_A(p_A,p_B)}{\partial p_B}+2(\sigma p_A+(1-\sigma)w_A)\frac{\partial^2 q_A(p_A,p_B)}{\partial p_A\partial p_B}\frac{\partial p_A}{\partial w_A}\right|.$$

If Condition (3.53) holds at the candidate marginal input price $w^{tpu}(\sigma)$, the necessary and sufficient conditions for a perfect Bayesian equilibrium with passive beliefs and partial forward ownership to exist are fulfilled.[20]

With linear demand, the inequality in (3.53) simplifies to

$$-\frac{\partial q_A(p_A,p_B)}{\partial p_A} > \left|2\left(1-\frac{\sigma}{2}\right)\frac{\partial q_A(p_A,p_B)}{\partial p_B}\right|, \quad (3.55)$$

as $\frac{\partial p_A}{\partial w_A}=1/2$ in this case (see Equation (3.39)). Using the definitions of the demand elasticities (Equation (3.49)), Condition 3.55 can be written as

$$\frac{\epsilon}{2} > \left(1-\frac{\sigma}{2}\right)\epsilon_s. \quad (3.56)$$

This condition is reported in the proposition. It implies that the condition for equilibrium existence is easier to fulfill with forward ownership than under vertical separation.

Last, we characterize the comparative static of the marginal input price $w^{tpu}(\sigma)$ (which is implicitly defined by Equation (3.46)) with respect to the forward ownership share σ. Suppose that Condition (3.53) is fulfilled such that an equilibrium exists. Using the symmetry of the demand and candidate equilibrium (with $w_A^{tpu}=w_B^{tpu}=w^{tpu}$ and $p_A=p_B=p$), we can write the supplier's first-order condition in Equation (3.46) as

$$\left(\sigma p+(1-\sigma)w^{tpu}\right)\frac{\partial q_{-i}(p,p)}{\partial p_i} + w^{tpu}\frac{\partial q_i(p,p)}{\partial p_i}=0, \quad (3.57)$$

[20] Under vertical separation ($\sigma=0$), the same condition as in Rey and Vergé (2004) emerges (as $w_i=0$ in this case):

$$-q_A(p_A,p_B)>2\frac{\partial q_A(p_A,p_B)}{\partial p_B} \iff \frac{\epsilon}{2}\geq\epsilon_s. \quad (3.54)$$

Implicit differentiation yields

$$\frac{\partial w^{tpu}(\sigma)}{\partial \sigma} = -\frac{(p-w)\frac{\partial q_{-i}(p,p)}{\partial p_i}}{\partial^2 \Omega^U / \partial^2 w} > 0, \tag{3.58}$$

which is positive as the denominator is negative if an equilibrium exists, and the nominator is positive as $p > w$ and $\frac{\partial q_{-i}(p_B,p_A)}{\partial p_i} > 0$. We conclude that the marginal input price $w^{tpu}(\sigma)$ increases in σ. As there is a one-to-one mapping between the input prices and the downstream prices, this implies that also the symmetric downstream prices $p_A(\sigma)$ and $p_B(\sigma)$ increase in σ. This establishes the result. □

Appendix C: Secret Two-Part Tariffs under Wary Beliefs

In this appendix, we extend the analysis of unobservable two-part tariffs with passive beliefs to the belief refinement of wary beliefs. We focus on the case of Cournot competition as in Section 3.4.

With forward ownership, a supplier's optimal contract offer to one firm generally depends on the supply contract it has offered to the other firm, even with downstream quantity competition (see Section 3.4). This is in contrast to the result, that a supplier's contract offer is not affected from the other contract in the case of vertical separation (Hart and Tirole, 1990; Rey and Vergé, 2004). With wary beliefs, we account for the fact that a downstream firm updates its belief about the competitor's contract offer. In particular, given its own contract offer, a downstream firm with wary beliefs anticipates that the supplier will behave optimally as regards the other downstream firm. We focus on wary beliefs that depend only on the wholesale price and that are defined as follows (see McAfee and Schwartz 1994; Rey and Vergé 2004):

Definition 3.1. *When downstream firm i receives a contract $t_i = (w_i, f_i)$, it believes that*

(i) the manufacturer expects it to accept this contract,

(ii) the manufacturer offers downstream firm $j \neq i$ the contract $(W_j(w_i), F_j(w_i))$ that is best for the monopolist, given that firm i accepts (w_i, f_i), from among all contracts acceptable to firm j, and

(iii) downstream firm j reasons the same way.

In the following proposition, we summarize our results for the belief refinement of wary beliefs. Note that we do not derive equilibrium existence in this case but characterize marginal input prices provided that an equilibrium exists.[21]

[21]For the case of vertical separation, Rey and Vergé (2004) derive equilibrium existence with polynomial beliefs.

Proposition 3.7. *Suppose supplier U internalizes $\sigma \in (0,1)$ of the downstream firms' profits and charges secret two-part tariffs. The downstream firms compete in quantities and hold wary beliefs (Definition 3.1). In any equilibrium, the input prices are above the supplier's marginal costs and below the industry-maximizing level. The input prices increase in the degree of forward internalization σ.*

Proof of Proposition 3.7. By Definition 3.1, (say) downstream firm A believes that the supplier charges its competitor B an input price $W_B(w_A)$ that is optimal given w_A:

$$\begin{aligned} W_B(w_A) &= \arg\max_{w_B} \;\; \pi^U(q_A(w_A), q_B(w_B)) + (1-\sigma)(f_A + f_B) \\ &\qquad\qquad +\sigma(\pi_A(q_A(w_A), q_B(w_B)) + \pi_B(q_B(w_B), q_A(w_A))) \\ &\qquad s.t. \\ &\qquad\qquad f_B \leq \pi_B(q_B(w_B), Q_A(W_A(w_B))), \end{aligned} \tag{3.59}$$

with

$$\pi^U(q_A(w_A), q_B(w_B)) = \sum_{i\in\{A,B\}} w_i q_i(w_i),$$

and

$$\pi_i(q_i(w_i), q_{-i}(w_{-i})) = (p_i(q_i(w_i), q_{-i}(w_{-i})) - w_i)\, q_i(w_i).$$

Solving the participation constraints that hold with equality and substituting for the fixed fees yields the supplier's reduced objective function

$$\begin{aligned} \Omega^U(w_A, w_B) &= \pi^U(q_A(w_A), q_B(w_B)) \\ &+ (1-\sigma)(\pi_A(q_A(w_A), Q_B(W_B(w_A))) + \pi_B(q_B(w_B), Q_A(W_A(w_B)))) \\ &+ \sigma(\pi_A(q_A(w_A), q_B(w_B)) + \pi_B(q_B(w_B), q_A(w_A))). \end{aligned} \tag{3.60}$$

The resulting first-order condition of Ω^U with respect to (say) w_A is

$$\begin{aligned} \frac{\partial \Omega^U}{\partial w_A} &= \left(\frac{\partial \pi^U(q_A(w_A), q_B(w_B))}{\partial q_A} + \frac{\partial \pi_A(q_A(w_A), Q_B(W_B(w_A)))}{\partial q_A}\right)\frac{\partial q_A(w_A)}{\partial w_A} \\ &+ \left(\sigma\left(1 - \frac{\partial W_B}{\partial w_A}\right) + \frac{\partial W_B}{\partial w_A}\right)\frac{\partial \pi_A(q_A(w_A), Q_B(W_B(w_A)))}{\partial Q_B}\frac{\partial q_A(w_A)}{\partial w_A} = 0. \end{aligned} \tag{3.61}$$

For $\sigma = 0$, we know that that a downstream firm's belief about the competitor's input price does not change if its own input price changes: $\partial W_B(w_A)/\partial w_A = 0$. Hence, we obtain, as with passive beliefs, that the supplier optimally sets $w_i = 0$, $i \in \{A, B\}$ in order to maximize the bilateral profit $\pi^U + \pi_i$ (Rey and Vergé, 2004).

For $\sigma > 0$, it is in general not true that the belief does not depend on the own contract offer. In order to assess the first-order condition for $\sigma > 0$, we therefore evaluate how downstream firm A updates its belief $W_B(w_A)$ if the input price w_A changes. The definition of wary beliefs implies $\frac{\partial \Omega^U(w_A = W_A(w_B), w_B)}{\partial w_A} = 0$ and $\frac{\partial \Omega^U(w_A, w_B = W_B(w_A))}{\partial w_B} = 0$.

Differentiating $\frac{\partial \Omega^U(w_A = W_A(w_B), w_B)}{\partial w_A} = 0$ with respect to w_B is hence zero by definition of wary beliefs. That is,

$$
\begin{aligned}
\frac{\partial^2 \Omega^U\left(w_A, w_B = W_B\left(w_A\right)\right)}{\partial w_B \partial w_A} &= \frac{\partial^2 \Omega^U\left(w_A, w_B = W_B\left(w_A\right)\right)}{\partial^2 W_B} \frac{\partial W_B\left(w_A\right)}{\partial w_A} \\
&+ \frac{\partial^2 \Omega^U\left(w_A, w_B = W_B\left(w_A\right)\right)}{\partial w_B \partial w_A} = 0.
\end{aligned}
\tag{3.62}
$$

Evaluating this expression at the equilibrium input prices yields

$$
\frac{\partial W_A\left(w_B\right)}{\partial w_B} = -\frac{\partial^2 \Omega^U\left(w_A, w_B\right) / \partial w_B \partial w_A}{\partial^2 \Omega^U\left(w_A, w_B\right) / \partial^2 w_B}. \tag{3.63}
$$

Moreover, if the second-order conditions of the supplier's maximization problem is fulfilled, we have

$$
\left|\frac{\partial^2 \Omega^U\left(w_A, w_B\right)}{\partial^2 w_B}\right| \geq \left|\frac{\partial^2 \Omega^U\left(w_A, w_B\right)}{\partial w_A \partial w_B}\right|, \tag{3.64}
$$

which implies

$$
\left|\frac{\partial W_B\left(w_A\right)}{\partial w_A}\right| \leq 1. \tag{3.65}
$$

Based on this result, we can evaluate the comparative static of the marginal input price with respect to the forward ownership share. The first-order condition in Equation (3.61) implies for this comparative static:

$$
\frac{\partial w_A(\sigma)}{\partial \sigma} = -\frac{\left(1 - \frac{\partial W_B}{\partial w_A}\right)\left(\partial \pi_A\left(q_A\left(w_A\right), Q_B\left(W_B\left(w_A\right)\right)\right)\right) / \partial Q_B}{\partial^2 \Omega^U / \partial^2 w_A + \partial^2 \Omega^U / \partial w_A \partial w_B} \geq 0, \tag{3.66}
$$

with $\partial^2 \Omega^U / \partial^2 w_A + \partial^2 \Omega^U / \partial w_A \partial w_B < 0$. The nominator is (weakly) positive as $\partial W_B\left(w_A\right) / \partial w_A \in [-1, 1]$ (see Equation (3.65)).

Moreover, we can add and subtract $\frac{\pi_B(q_B(w_B), q_A(w_A))}{\partial q_A} \frac{\partial q_A(w_A)}{\partial w_A}$ to Equation (3.61) and re-write it as

$$
\begin{aligned}
\frac{\partial \Omega^U}{\partial w_A} &= \frac{\partial \pi^I\left(q_A\left(w_A\right), q_B\left(w_B\right)\right)}{\partial q_A} \frac{\partial q_A\left(w_A\right)}{\partial w_A} \\
&+ (1-\sigma) \frac{\partial \pi_A\left(q_A\left(w_A\right), Q_B\left(W_B\left(w_A\right)\right)\right)}{\partial Q_B} \frac{\partial Q_B\left(W_B\left(w_A\right)\right)}{\partial W_B}\left(\frac{\partial W_B}{\partial w_A} - 1\right).
\end{aligned}
\tag{3.67}
$$

It is immediate that for $\sigma < 1$ the optimal input prices are below the industry-maximizing level as the second line is negative at $w_i = w_i^I$. This establishes the result. □

Chapter 4

No-Challenge Clauses in Patent Licensing - Blessing or Curse?

with Benno Buehler and Matthias Hunold

4.1 Introduction

License agreements commonly contain obligations on the licensee to not challenge the validity of the intellectual property rights of the patent holder. The inclusion of these provisions (henceforth referred to as no-challenge clauses) into technology licensing agreements has been treated rather unfavorably in a number of court decisions, both in the US and in the EU. The US Supreme Court held in *Lear, Inc. vs. Adkins* that a licensee is free to challenge the validity of a patent, and expressed that licensees can play an important role in identifying and challenging invalid patents:

> "Licensees may often be the only individuals with enough economic incentive to challenge the patentability of an inventor's discovery." (*Lear, Inc. vs. Adkins*, 395 US 653 at 670.)[1]

The Second Circuit of Appeals consequently held in *Rates Technology, Inc. vs. Speakeasy, Inc.* that a no-challenge clause reduces the likelihood of weak patents being challenged and is contrary to the public interest of permitting the free use of technologies that are part of the public domain.[2] Similarly, European courts held in *Windsurfing International vs. Commission*[3] and in *Bayer vs. Süllhöfer*[4] that an obligation on the licensee to not challenge the validity of the underlying patents restricts competition within the meaning of Article 101(1) TFEU.[5]

While sustaining wrongly-granted intellectual property rights is against the public interest, no-challenge clauses can also have positive welfare effects:

1. Litigation imposes substantial private and social costs (Farrell and Merges, 2004; Bessen and Meurer, 2012; Hall and Harhoff, 2012). No-challenge clauses avoid later (legal) conflicts between the licensor and the licensee and thus potentially wasteful litigation costs. For instance, based on an empirical model, Schankerman and Schuett (2020) find that the litigation costs of patent challenges exceed the social benefits.

2. No-challenge clauses can foster inventions and promote the public disclosure of those inventions (Goldstucker, 2008; Server and Singleton, 2011; Brenner, 2013).

[1] Historically, the situation in the US was different as even absent contractual provisions, it was not possible for a licensee to challenge the validity of a patent (*Kinsman vs. Parkhurst*, 59 U.S. 18 How. 289 (1855)).

[2] *Rates Tech. Inc. vs. Speakeasy, Inc.*, No. 11-4462 (2nd Cir. 2012).

[3] Case 193/83 *Windsurfing International Inc. vs. Commission,* paras 89-94.

[4] Case 65/86 *Bayer AG and Maschinenfabrik Hennecke GmbH vs. Heinz Süllhöfer,* paras 89-93.

[5] In Europe, no-challenge clauses are also regarded as excluded restrictions and, thus, are removed from the scope of the Technology Transfer Block Exemption Regulation (Commission Regulation (EC) No. 772/2004) and from the R&D Block Exemption Regulation (Commission Regulation (EC) No. 1217/2010).

3. The patent holder may offer reduced royalty rates as a compensation for the obligation to not challenge the validity of patents.[6]

Despite the long-standing legal debate about no-challenge clauses, there is surprisingly little economic analysis of their effects on the royalty rates or on efficiency and consumer surplus. We contribute by analyzing how no-challenge clauses affect the royalty rates and social welfare, as well as whether they reduce the equilibrium frequency of patent litigation.

We build on the seminal model of Farrell and Shapiro (2008) and extend this in various ways to allow for a comprehensive analysis of no-challenge clauses. The model incorporates probabilistic patents in the sense that a patented technology does not deserve patent protection with some probability and could be declared invalid if challenged in court (Lemley and Shapiro, 2005). This assumption is based on studies which estimate that large fractions of patents in the US and Germany would be found invalid if challenged in court.[7] For the main analysis, we consider that a patent holder licenses the patented technology to a number of downstream firms with non-discriminatory two-part tariffs, consisting of a fixed fee F and a running royalty r. A licensee learns about the patent's validity with some probability after contract acceptance and can decide to challenge its validity in court.

A main finding of our analysis is that a ban of no-challenge clauses does not necessarily increase the frequency that wrongly-granted patents are invalidated in equilibrium (first column in Table 4.1). In this case the main justification for banning no-challenge clauses (as expressed e.g., in *Lear vs. Adkins)* is not warranted and—as we show—a ban can even be detrimental for welfare. Absent a no-challenge clause, the patent holder may offer license terms that make it financially unattractive for licensees to challenge the underlying patent. This can occur even if the licensee knows with certainty that a court would invalidate the patent in the event of a lawsuit.[8]

A contract offer that renders a patent challenge unprofitable is particularly beneficial for the patent holder in the case of weak patents (where the probability of the patent being valid is below a certain threshold). For such patents in particular, there is arguably a large public interest in successful invalidation as the patent holder is granted a quasi-

[6]The German patent law acknowledges that royalties for a compulsory license should reflect whether a licensee has the ability to challenge the licensed patent or not. See MSD vs. Shionogi (Federal Court of Justice, X ZB 2/17, No. 28).

[7]For the US, Miller (2013) estimates that 28 percent of all patents would be found invalid if subject to an innovation-based (i.e., anticipation or obviousness) decision. For Germany, and focusing on all potential invalidation reasons, Henkel and Zischka (2019) predict in a similar study the probability of a partial or full invalidation of a randomly drawn patent to be around 80 percent.

[8]Other market participants may not have an incentive to challenge a patent either. For instance, Choi (2005) shows that patent holders of substitute patents lack the incentives to invalidate patents through litigation. Kesan and Gallo (2006) and Schankerman and Schuett (2020) analyze a competitor's incentives to challenge and—among other aspects—point out that the patent is not challenged if litigation costs are high.

monopoly although, with a high probability, a detailed assessment would reveal that the requirements for granting such market power are not fulfilled. A free-riding problem among the licensees, however, makes it feasible and profitable for the patent holder to prevent patent invalidation: if a patent is invalidated, all firms in an industry are free to use the technology without the obligation to pay royalties.[9] For weak patents, a ban of no-challenge clauses therefore does not increase the likelihood of licensees challenging invalid patents.

	Effects of a no-challenge clause (relative to no such clause)	
	Frequency of successful patent challenges	Consumer surplus
Weak patents (i.e., invalid with high probability)	none (zero in both cases)	↑ or equal
Strong patents (i.e., valid with high probability)	↓	↓

Table 4.1: Effects of a no-challenge clause on invalidation probability and consumer surplus.

The overall effect of a no-challenge clause on consumer surplus and social welfare also depends on the patent strength (second column of Table 4.1). If a patent challenge is contractually feasible, holders of weak patents induce the licensees to not challenge the patent. In this case, we find that a no-challenge clause can increase both consumer and total surplus (or, at worst, leaves them unaffected). Absent a no-challenge clause, the patent holder optimally avoids a challenge by offering a low fixed fee to the downstream firms. Importantly, this license contract involves a (weakly) higher running royalty rate (and therefore also consumer prices) than with a no-challenge clause. Hence, the patents will not be invalidated—neither with nor without a no-challenge clause—but the running royalties and consumer prices can be higher absent such a clause.

The situation is different for patents where the probability of success in a patent challenge is low (strong patents). Holders of such patents accept a positive invalidation risk absent a no-challenge clause. Intuitively, they do not benefit from offering higher profits to the downstream firms just to prevent relatively rare cases of successful patent challenges. We show that the running royalties for a strong patent and the resulting consumer prices are lower absent a no-challenge clause. Unsurprisingly, this holds when the patent is challenged and invalidated as all downstream firms can then use the technology free of charge. Interestingly, the result also holds when the patent remains unchallenged and

[9]Farrell and Merges (2004) have pointed out this public-good problem. In the US, licensees may avoid further royalty payments, regardless of the provisions of their contract, once a third party proves that the patent is invalid. See Supreme Court decision *Blonder-Tongue Labs, Inc. vs. University of Illinois Foundation*, 402 US 313 (1971).

valid. Hence, for strong patents, consumer surplus is higher without a no-challenge clause, and social welfare also increases if litigation costs to challenge the patent in court are not too large.

In summary, the results of our analysis indicate that a no-challenge clause affects both the royalty rates as well as the frequency of patent challenges. Importantly, while banning a no-challenge clause may be an effective instrument to incentivize licensees to challenge the validity of strong patents, this may not hold for weak patents. We therefore find that these clauses can even have positive effects on consumer surplus and social welfare.

Our results complement the existing literature. Closely related to our article is Miller and Gal (2015). They provide a detailed legal assessment of no-challenge clauses and an initial formal analysis of how such contract clauses affect social welfare. Miller and Gal find that no-challenge clauses affect social welfare only through the probability that an invalid patent will be successfully challenged. Gal and Miller (2017) call for a prohibition of such contract clauses because they would harm competition without having pro-competitive effects. We contribute by emphasizing that a patent holder can deliberately avoid a patent challenge even absent a no-challenge clause and by showing how the presence of no-challenge clauses affects the license terms. We find that banning no-challenge clauses can increase consumer prices without necessarily increasing the frequency of invalidation, in particular for weak patents. Based on our analysis, and given further efficiency justifications for such clauses described above, a general prohibition, as proposed in Gal and Miller (2017), may not be optimal. This is in line with Cheng (2015) who discusses no-challenge clauses from an antitrust law perspective and also calls for a rule-of-reason approach.

The above results lead to the question of whether licensees can be further incentivized to challenge the validity of patents. One approach is to remove the downsides for licensees of failed patent challenges by allowing licensees to challenge the licensed patents while keeping the license contract. The US Supreme Court actually took a decision in this direction in the landmark case *MedImmune, Inc. vs. Genentech, Inc.* of 2007.[10] Commentators have noted that this decision has substantially shifted the bargaining position from the patent holder to the licensees (Dreyfuss and Pope, 2009). We study whether this increases patent challenges in equilibrium. Interestingly, despite the fact that the prospects of challenging a patent should be substantially higher in this case, we obtain results similar to our benchmark model: the patent holder can nevertheless avoid a patent challenge with a license contract that specifies higher running royalties compared to a license contract with a no-challenge clause. Due to the increased risk of a patent challenge, the incentive to avoid a patent challenge can be substantially larger than before *MedImmune* leading to even fewer invalid patents that are successfully challenged in court.

[10] *MedImmune, Inc. vs. Genentech, Inc.*, 549 US 118 (2007).

Finally, we show that our main result is robust if we restrict the analysis to linear license tariffs. Similarly to the benchmark model with two-part tariffs, patent challenges occur in equilibrium only if the patent is sufficiently strong. In this case, the welfare effects of a no-challenge clause are ambiguous. On the downside, the invalidation of wrongly-granted patents is less frequent, whereas on the upside the royalty rates (and consumer prices) are lower and litigation costs are saved. For weak patents, we find that license contracts are such that downstream firms have no incentive to challenge the patent. In this case, a no-challenge clause (weakly) reduces welfare as the invalidation probability remains at zero but royalty rates and consumer prices increase.

The remainder of the article is structured as follows: In Section 4.2 we introduce the model and describe the equilibrium payoffs for the different regimes. In Section 4.3 we analyze the benchmark model of two-part tariffs and derive our main results. In Section 4.4 we provide a detailed analysis of the effects of the *MedImmune, Inc. vs. Genentech, Inc.* judgment on the license outcome. Moreover, we extend the analysis to linear license contracts and show that patent holders can prevent a patent invalidation by means of favorable license terms similar to the case of two-part tariffs. In Section 4.5 we conclude with a summary of our findings.

4.2 Model

We model the licensing of probabilistic patents in the shadow of litigation, building on and extending the model of Farrell and Shapiro (2008). The patent holder P offers non-discriminatory licenses with a fixed fee F and a running royalty r to n symmetric downstream firms.[11][12] The patent holder does not compete with the downstream firms. The patented technology is available to society and allows production of final products at zero marginal production costs.[13] There also exists an alternative technology to produce final products with higher marginal costs equal to v. The parameter v is hence a measure of the patent size.

Ex-ante the patent is valid with publicly-known probability $\theta \in (0, 1)$ and invalid otherwise.[14] Valid means that the technology qualifies as a non-obvious and novel invention

[11] Empirical studies show that a majority of license contracts contain a combination of running royalties and fixed fees (Rostoker, 1983; Bousquet et al., 1998; Hegde, 2014).

[12] As discussed by Farrell and Shapiro (2008), the literature on multilateral vertical contracting has shown that the equilibrium outcome depends on the form of contracts allowed, on the downstream firms' information, and on their beliefs about what they cannot observe. Requiring non-discriminatory offers avoids obtaining extreme results. Moreover, non-discriminatory offers are used in practice and are typically required for the licensing of patents incorporated into industry standards.

[13] Equivalently, the technology makes each unit of the product worth an extra v to all customers. Encaoua and Lefouil (2009) also analyze seminal inventions that enable a firm to produce entirely new products.

[14] The assumption of a publicly-known patent strength abstracts from potentially conflicting assessments of the patent holder and the licensees about the patent strength. It has been used in related analyses (Farrell and Shapiro (2008); Encaoua and Lefouil (2009); Palikot and Pietola (2019)).

that deserves patent protection. Invalid means that the technology belongs in the public domain and should not be protected by a patent. A court challenge is necessary and sufficient to identify the patent as invalid, and in this case all market participants can use the technology for free. If the patent is invalid (with probability $1-\theta$), a randomly drawn licensee receives a conclusive invalidity signal with probability γ. Otherwise, no downstream firm receives an invalidity signal.[15]

We solve for a symmetric subgame-perfect Nash equilibrium as the contract offers are public and all actions common knowledge in later stages. We focus on the equilibrium in which all downstream firms accept the patent holder's non-discriminatory contract offer.[16] A downstream firm accepting a license with per-unit royalty r has marginal cost r. If the patent is invalidated, all licensees can use the patent free of charge and have zero marginal costs. For the analysis, it is sufficient to consider situations in which a downstream firm has marginal costs of a while all its competitors have marginal costs of b. Denote a firm's output by $x(a,b)$ and profits gross of fixed fees by $\pi(a,b)$.

We structure the description of the game along the licensees' decisions regarding (i) contract acceptance and (ii) challenge decision.

Contract Offer and Acceptance Decision. The patent holder offers a non-discriminatory license contract $\{F,r\}$ to the n downstream firms, either with or without a no-challenge clause. We follow Farrell and Shapiro (2008) in imposing $r \leq v$.[17] Each downstream firm decides simultaneously and individually whether to accept the contract offer. Alternatively, a downstream firm can decide to (a) reject the contract offer and use the old technology, or to (b) use the new technology without license, and thereby infringe on the patent, incurring litigation costs of $L^{\mathcal{I}}$. In order to avoid the case distinction between these two outside options, we impose for the main part of the analysis

Assumption 4.1. $L^{\mathcal{I}} < (1-\theta)\left(1-\frac{\gamma(n-1)}{n}\right)(\pi(0,0)-\pi(v,v))\,,$

which implies that patent infringement (Option (b)) is the relevant alternative to contract acceptance for the downstream firms:[18] it is not profitable for a downstream firm to use

[15] The invalidity signal is independent of patent strength θ. Assuming that only one downstream firm potentially finds this evidence simplifies the model without significant loss of generality. Thereby, we abstract from the question of how licensees coordinate to challenge a patent in court and share the litigation costs in the case that several licensees receive the invalidity signal.

[16] See Encaoua and Lefouil (2009) for an analysis of asymmetric equilibria, in which only a subset of downstream firms accepts the contract offer and litigation cannot be excluded. We abstract from this issue as our main focus is to analyze whether a patent holder is able to fully prevent patent litigation by means of no-challenge clauses or appropriate royalty rates, and the effects of these provisions on the contracting outcome.

[17] Such a restriction may be imposed by competition law, as higher royalty levels are likely to be anticompetitive. See Farrell and Shapiro (2008), footnote 22.

[18] Patent infringement yields a higher profit than using the old technology if $\theta\pi(v,r) + (1-\theta)\pi(0,0) - L^{\mathcal{I}} > \frac{(1-\theta)(n-1)\gamma}{n}\pi(0,0) + \left(1-\frac{(1-\theta)(n-1)\gamma}{n}\right)\pi(v,r) \iff L^{\mathcal{I}} <$

the old technology even if there is some probability that one of the remaining downstream firms will challenge and invalidate the patent.

As in Farrell and Shapiro (2008), the patent holder sues any infringing downstream firm and a court publicly determines the validity of the patent. If it is held valid, the patent holder can again offer a contract to the infringing downstream firm. If the patent is invalid, all downstream firms can use it free of charge. For simplicity, we focus on the case of conclusive evidence in the sense that a court invalidates the patent with certainty in view of this evidence.[19] With a no-challenge clause, the description of the game is complete at this stage and payoffs realize.

Challenge Decision. Absent a no-challenge clause and after contract acceptance, the licensees can decide to challenge the licensed patent in court. This decision can be contingent on having received an invalidity signal. In the main model, we assume that a licensee has to terminate the contract in order to challenge the patent.[20] A licensee with conclusive evidence about the patent's invalidity incurs costs of $L^{\mathcal{C}}$ when going to court whereas an uninformed licensee without such evidence incurs L^{CU}.[21] We abstract from out-of-court settlements between the patent holder and the challenging licensee.[22] Our focus is a patent holder's incentive and ability to avoid a public invalidation of the patented technology. We show that—even absent the possibility of private settlements—a patent holder can effectively prevent invalidation.

We focus in our analysis on the economically interesting case that a licensee can have the economic incentive to challenge a patent's validity and that the inclusion of a no-challenge clause actually alters the license contract. If a patent challenge was prohibitively costly for any licensee, a patent holder would not need to contractually avoid a patent challenge by imposing a no-challenge clause. For this, we assume that challenging the patent after

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$(1-\theta)\left(1-\frac{\gamma(n-1)}{n}\right)(\pi(0,0)-\pi(v,r))$. This inequality holds for all admissible commission rates $r \in [0,v]$ if $L^{\mathcal{I}} < (1-\theta)\left(1-\frac{\gamma(n-1)}{n}\right)(\pi(0,0)-\pi(v,v))$. We obtain qualitatively the same results for higher litigation costs $L^{\mathcal{I}}$ when using the old technology is the relevant outside option for the downstream firms (see Appendix C).

[19]If the patent holder can avoid patent challenges if licensees are certain about the litigation process, it can certainly also do so in the presence of uncertainty. See Henkel and Zischka (2019) for an overview of the empirical evidence on validity decisions on litigated patents.

[20]This is in line with the actual controversy requirement, which is a common legal prerequisite for a patent challenge. In Section 4.4.1, we relax the requirement of actual controversy, which is in line with the *MedImmune, Inc. vs. Genentech, Inc.* judgment.

[21]We assume $L^{CU} \geq L^{\mathcal{I}}$ in order to rule out the implausible case that a patent challenge becomes attractive just because challenging the patent is less costly than infringing the patent if the licensee does not gain additional information.

[22]There are various reasons why court procedures may dominate settlements. For example, a patent holder can have reputation concerns to discourage patent challenges by refusing to agree to patent settlements. Moreover, an indirect representative (straw man) can be allowed to file post-grant oppositions whereby the true identity of the challenging opponent remains undisclosed (see Köster and Sekiguchi, 2017).

receiving the invalidity signal yields a higher profit for the downstream firm than infringing the patent or using the old technology at the contract acceptance stage:

Assumption 4.2. $L^{C} < \theta\left(\pi\left(0,0\right) - \pi\left(v,v\right)\right),$

If the patent is challenged, a court publicly determines whether the patent is valid. This has the same consequences as in the case of patent infringement. The downstream firms simultaneously make their production decisions and payoffs realize (downstream revenues and all license payments).

We illustrate the possible events for a patent challenge in Figure 4.1 from the perspective of downstream firm D_i. Suppose that all n downstream firms have accepted the contract offer, and that downstream firm D_i obtains the invalidity signal (which occurs with probability $(1-\theta)\frac{1}{n}\gamma$).[23]

- If D_i challenges the patent in court, it incurs litigation costs L^{C} and invalidates the patent with certainty. This yields a profit of $\pi\left(0,0\right) - L^{C}$ for D_i and a profit of $\pi\left(0,0\right)$ for each of the other downstream firms as everyone can now use the patented technology free of charge.

- If D_i does not challenge the patent, it avoids the litigation costs L^{C} and the initial contract remains in place, yielding a profit of $\pi\left(r,r\right) - F$ for each downstream firm.

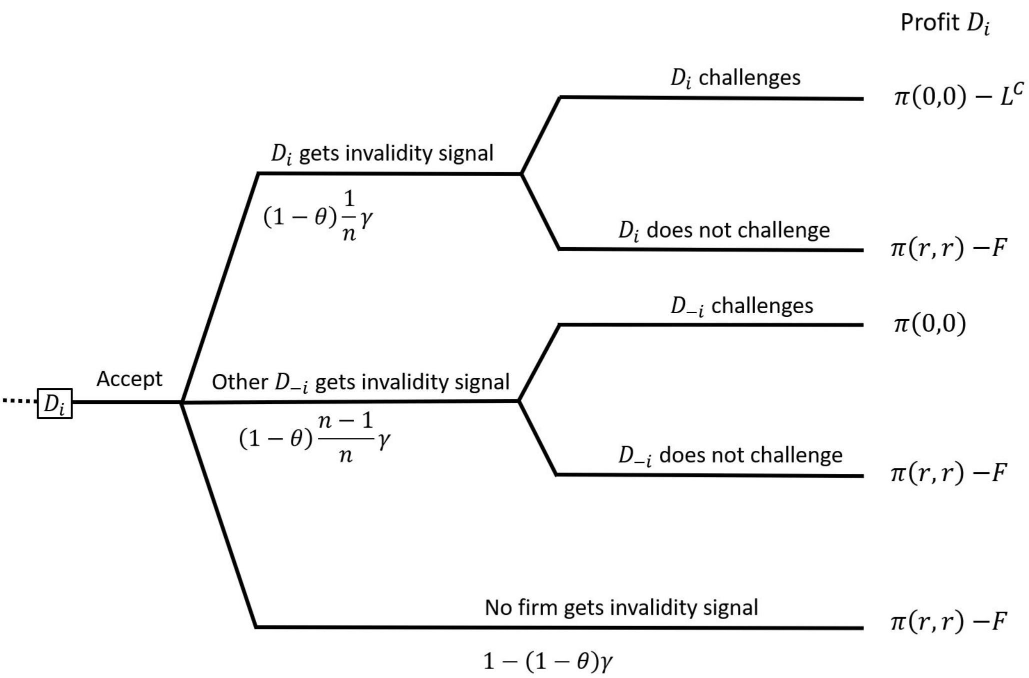


Figure 4.1: Challenge decision after contract acceptance from the perspective of one downstream firm (D_i).

[23]We can focus on the challenge decision of a downstream firm with a signal as licensees without a signal do not benefit from a challenge. See Lemma 4.3 in Appendix A.

With probability $(1-\theta)\frac{n-1}{n}\gamma$, another downstream firm (denoted D_{-i} in the figure) gets the invalidity signal and faces the same decision. With the remaining probability of $1-(1-\theta)\gamma$ no licensee obtains the invalidity signal and the initial contract remains in place.

Assumptions on Profits and Patent Size. We follow Farrell and Shapiro (2008) in imposing standard assumptions on the reduced-form profits. These assumptions are satisfied, for instance, with demand that is linear in prices.

Assumption 4.3. *The operational profit of a downstream firm satisfies*

(i) $\pi_1(a,b)<0$*: a firm's profits decrease in its own costs;*[24]

(ii) $\pi_2(a,b)\geq 0$*: a firm's profits weakly increases in the other firms' costs, with* $\pi_{22}(a,b)$ *not too negative;*[25]

(iii) $\pi_1(a,a)+\pi_2(a,a)<0$*: each firm's profits fall if all firms' costs increase from the same level.*

In order to illustrate some of our results, we provide parametric solutions based on the case of $n=2$ downstream firms competing in prices and the linear demand system

$$x^i\left(p^i,p^{-i}\right)=\left(1/\left(1+\sigma\right)\right)\left(1-\left(1/\left(1-\sigma\right)\right)p^i+\left(\sigma/\left(1-\sigma\right)\right)p^{-i}\right), \tag{4.1}$$

where $x^i\left(p^i,p^{-i}\right)$ is the demand that downstream firm i realizes if it charges a price of p^i while its competitor charges a price of p^{-i}.

If all downstream firms use the patented technology and pay royalties of r, the total (upstream and downstream) profits generated per downstream firm is

$$T(r)\equiv r\cdot x(r,r)+\pi(r,r). \tag{4.2}$$

On the total profit, we impose

Assumption 4.4. $T(r)$ *is strictly concave on the relevant range.*

Define the monopoly running royalty level $m=\arg\max_r T(r)$ that maximizes the industry profits. As in Farrell and Shapiro (2008), we assume that the patent size is (weakly) smaller than the monopoly running royalty, $v\leq m$. This corresponds to an incremental innovation for which the old technology still imposes a competitive constraint.

[24] We denote with g_j the partial derivative of $g(x_1,...,x_N)$ with respect to its jth argument.

[25] The last part ensures that the patent holder's maximization problem has a unique maximum. See the related assumption in Farrell and Shapiro (2008) footnote 22.

Welfare. Welfare is the sum of the industry profit and consumer surplus minus litigation costs. When all firms use the new technology as licensees, increasing the royalty r reduces output and lowers welfare (for $0 \leq r \leq v$) as the downstream price exceeds the social marginal costs at all positive running royalty levels.

Timing of License Payments. We assume that the license payments are payable after the potential invalidation decision of the court. This means that the fixed fee F is not transferred to the patent holder if the patent is found to be invalid. We explain below why this is a plausible case. Moreover, we show in Appendix B that it is possible to obtain our main results even if the fixed fee is sunk at the time of contract acceptance and thus before the decision to challenge the patent.

In general, if the fixed fee is an important instrument for the patent holder to financially incentivize the licensees not to challenge the patent, we expect that a patent holder offers a license contract for which (a share of) the fixed fee is not sunk at the challenge decision. For instance, this is consistent with so-called milestone payments, which are fixed payments that licensees have to pay during or at the end of the contract period (Hegde, 2014). Moreover, the timing is also consistent with a situation in which a licensee can recover royalties paid during the time that an invalidation lawsuit is pending. For instance, after the Supreme Court judgment *MedImmune, Inc. vs. Genentech, Inc.*, there was considerable debate among practitioners on whether royalties for a challenged patent should be paid into an escrow account, from which they can be recovered in the event of the patent being invalidated (Dreyfuss and Pope, 2009).

4.3 Equilibrium analysis

We highlight that a ban of a no-challenge clause does not necessarily improve the frequency with which invalid patents are challenged. The main mechanism for this result is that the patent holder can offer financial incentives that make it unprofitable for any licensee to challenge the patent even absent a no-challenge clause. This complements the analysis of Miller and Gal (2015) who do not relate the patent holder's offered royalty rate to the licensee's propensity to challenge the patent and thus draws different policy implications. Moreover, we analyze the license terms in each scenario to derive the consequences on consumer surplus and social welfare, which depend on both the equilibrium challenge decisions and license terms.

4.3.1 Invalidation Probability

With a no-challenge clause, the invalidation probability is zero. We now derive the equilibrium invalidation probability absent a no-challenge clause. Let us introduce the definition of two pricing regimes, which will turn out in the analysis absent no-challenge clauses, depending on the patent strengths.

Definition 4.1 (Challenge-acceptance pricing)**.** *The license terms are such that the licensees have incentives to challenge the patent upon receiving the invalidity signal.*

Definition 4.2 (Challenge-avoidance pricing)**.** *The license terms are such that the licensees have no incentive to challenge the patent upon receiving the invalidity signal.*

We highlight an important trade-off for the patent holder between the invalidation risk and the royalty payments from the license contract. The ex-ante probability that a licensee learns about the patent's invalidity after contract acceptance is $(1-\theta)\,\gamma/n$. In this event, it is not profitable to challenge the patent if invalidating the patent yields lower profits for the licensee than sticking to the initial contract:

$$\pi\,(0,0) - L^{\mathcal{C}} \quad \leq \quad \pi\,(r,r) - F. \tag{4.3}$$

The condition in Equation (4.3) pins down a minimum profit level that the patent holder has to grant to each licensee in order to financially incentivize them to not challenge the patent upon receiving the invalidity signal. Otherwise, a licensee that receives the invalidity signal challenges and thereby invalidates the patent. In this case the expected profit of a licensee at the stage of the contract acceptance is

$$(1-\theta)\,\gamma\left(\pi\,(0,0) - \frac{L^{\mathcal{C}}}{n}\right) + (1-(1-\theta)\,\gamma)\,(\pi\,(r,r) - F)\,. \tag{4.4}$$

With probability $(1-\theta)\,\gamma$, one of the downstream firms invalidates the patent and every downstream firm realizes a flow profit of $\pi\,(0,0)$. A downstream firm has to incur the litigation costs only in the event in which the firm itself receives the invalidity signal, which implies that its expected litigation costs are $L^{\mathcal{C}}/n$ at the contract acceptance stage. The outcome of no downstream firm receiving the invalidity signal arises either because the patent is valid or because no licensee learns about its invalidity. This outcome has a probability of $(1-(1-\theta)\,\gamma)$ and implies a profit of $\pi\,(r,r) - F$ from the license contract for each downstream firm.

If the patent holder does not incentivize downstream firms to refrain from patent challenges, as in Condition (4.3), it has to offer the downstream firms a license contract which yields at least an expected profit equal to their outside option when not accepting the license contract. Under Assumption 4.1, the relevant outside option of a downstream firm expecting the remaining $n-1$ downstream firms to accept the contract $\{F,r\}$ is to infringe the patent, which yields a profit of

$$\theta \cdot \pi (v, r) + (1 - \theta) \cdot \pi (0, 0) - L^{\mathcal{I}}. \tag{4.5}$$

The patent holder sues the infringing downstream firm and the court invalidates the patent with probability $1 - \theta$. This yields a profit of $\pi(0, 0)$ as the competitors then also use the formerly patented technology free of charge. If the court validates the patent (with probability θ), the patent holder makes another take-it-or-leave-it offer to the infringing downstream firm. As the patent is valid with certainty in this case, the offer makes the downstream firm indifferent to its reservation payoff, which is equal to $\pi (v, r)$. Moreover, the infringing downstream firm needs to pay the litigation costs $L^{\mathcal{I}}$.

According to Assumption 4.2, the minimum profit level that prevents a challenge (Equation (4.3)) is larger than the minimum profit level that ensures contract acceptance (Equation (4.5)). The patent holder therefore faces a trade-off between invalidation risk and royalty payments when deciding on the contract offer: it can avoid the risk of patent invalidation (an event in which the patent holder realizes zero profit) but has to compensate the licensees by giving them a larger share of the profits. This trade-off is addressed in

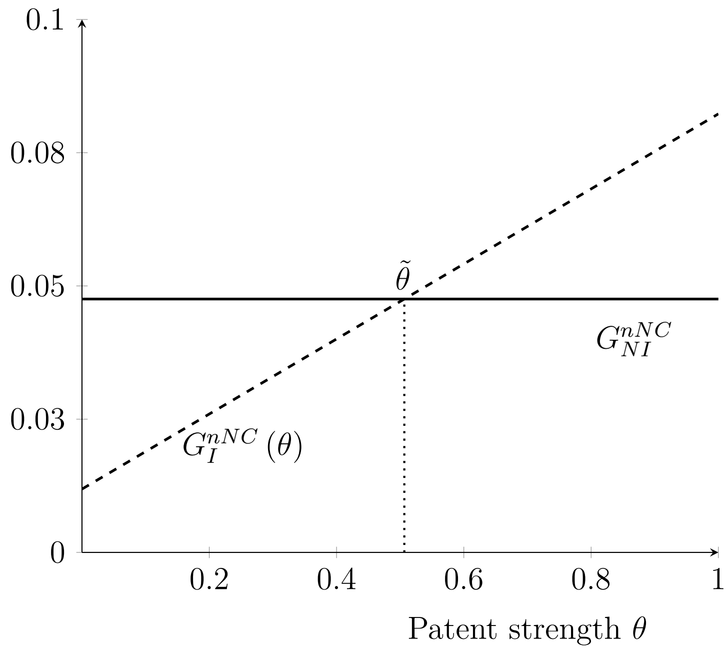
Proposition 4.1. *Suppose there is no no-challenge clause. If the probability of the invalidity signal exceeds*

$$\gamma > \frac{L^{\mathcal{I}}}{T(v) - \pi (0, 0)},$$

there exists a threshold value $\theta < \tilde{\theta}$. Otherwise, a licensee with the invalidity signal challenges and thereby invalidates the patent.

Proof. See Appendix A □

Under the conditions specified in Proposition 4.1, a patent holder offers favorable license fees that render a patent challenge unattractive for any licensee even if it receives the invalidity signal (challenge-avoidance pricing). Intuitively, this strategy is profitable for the patent holder if the probability that a licensee receives the invalidity signal post contract acceptance $(1 - \theta) \gamma$ is large. This is the case for weak patents (i.e., small θ) where the signal probability γ is large enough. If the risk of a patent invalidation is sufficiently small, the patent holder accepts a positive invalidation risk in order to extract a larger share of the total profits from the licensees.



The figure plots the patent holder's profit depending on patent strength θ absent a no-challenge clause with positive invalidation risk (I) and with no invalidation (NI) for the case of $n = 2$ licensees competing in prices. Marginal costs of old technology: $v = 1/10$; litigation costs are zero: $L^{\mathcal{C}} = L^{\mathcal{I}} = 0$; signal probability: $\gamma = 3/4$. Demand is defined in Equation (4.1), with $\sigma = 3/4$.

Figure 4.2: Patent holder's profit in invalidation (I) and no-invalidation (NI) case.

Figure 4.2 illustrates the result of Proposition 4.1. Denote with G_{NI}^{nNC} the patent holder's profit absent a no-challenge clause (nNC) if it offers financial incentives to not invalidate (NI) the patent.[26] This profit level is independent of the patent strength θ. In contrast, G_{I}^{nNC} denotes the patent holder's profit for the case in which a patent challenge is profitable for a licensee upon receiving the invalidity signal (I). The dashed line in Figure 4.2 illustrates that this profit increases in the patent strength. A stronger patent reduces the probability of patent invalidation, which is an event in which the patent holder realizes zero profits. At $\tilde{\theta}$, as described in Proposition 4.1, the patent holder is indifferent between challenge-avoidance pricing and challenge-acceptance pricing, that is, G_{NI}^{nNC} and G_{I}^{nNC} intersect. For patents stronger than $\tilde{\theta}$, the risk of patent invalidation under challenge-acceptance pricing is sufficiently small, so that the patent holder accepts a positive invalidation risk. For weaker patents, in contrast, it offers a license contract that induces the licensees to not challenge the patent even if they hold conclusive evidence about the invalidity of the patent. In this example, the patent holder prevents a patent challenge for patent strengths $\theta \lesssim 50\%$, which is well above the average patent strength of around 20%, as reported in Henkel and Zischka (2019) for the German patent system.

[26] The examples and figures in this part are based on the assumption $L^{\mathcal{I}} = L^{\mathcal{C}} = 0$ in order to represent the results for the whole support of patent strengths $\theta \in (0, 1)$. For $L^{\mathcal{I}}, L^{\mathcal{C}} > 0$ the results are comparable but require case distinctions as either Assumption 4.1 or 4.2 can be violated for some patent strengths.

This result has important implications for the expectation expressed in *Lear, Inc. vs. Adkins, Inc.* that the licensees could be *"the only individuals with enough economic incentive to challenge the patentability of an inventor's discovery."* The analysis highlights that

(i) a licensee who challenges an invalid patent exerts a positive externality on consumers and on other licensees, who can then also use the technology without royalty payments; and

(ii) whether the licensee has enough incentive to challenge a patent crucially depends on the design of the license fees.

It is therefore possible that the main justification for a ban of no-challenge clauses is not warranted, as wrongly-granted patents are not necessarily challenged and invalidated in equilibrium. Proposition 4.1 shows that this mechanism occurs for weak patents where the public interest in invalidation is arguably particularly high.

4.3.2 License Terms

License Terms with No-Challenge Clause. Next, we compare the license terms with a no-challenge clause with the ones absent a no-challenge clause. To this end, we characterize the license terms both with and without a no-challenge clause. Suppose that the patent holder's contract contains a no-challenge clause. All market participants know that the licensed patent will not be challenged, and possibly discovered invalidity information will remain unused. The patent holder maximizes its profit per downstream firm

$$G^{NC} = r \cdot x(r,r) + F, \tag{4.6}$$

subject to the constraint that the licensees prefer the contract offer over their outside option. That is, the patent holder sets the fixed fee such that downstream firms are indifferent to their second-best alternative of infringing the patent:

$$\theta\pi(v,r) + (1-\theta)\pi(0,0) - L^{\mathcal{I}} = \pi(r,r) - F. \tag{4.7}$$

The superscript NC indicates that the license contract contains a no-challenge clause.

Solving for the fixed fee and inserting it in Equation (4.6) yields the reduced maximization problem

$$\max_r \; G^{NC}(r,\theta) = \max_r \left[\underbrace{T(r)}_{\text{total profit per-firm}} - \underbrace{\left(\theta\pi(v,r) + (1-\theta)\pi(0,0) - L^{\mathcal{I}}\right)}_{\text{downstream outside option profit}} \right]. \tag{4.8}$$

The patent holder obtains the total profit per-downstream firm minus the downstream firms' outside option of infringing the patent. Importantly, the value of the licensees' outside option depends positively on the running royalty r: if a downstream firm has marginal costs of v and the remaining $n-1$ licensees face a running royalty of r, the downstream firm's profit $\pi(v,r)$ increases in r (Assumption 4.3). Hence, the patent holder can strategically reduce the running royalty in order to decrease the value of the outside option for the downstream firm. Moreover, the first-order condition to the maximization problem in (4.8) reveals that this strategic effect increases in the patent strength θ:

$$G_1^{NC}(r,\theta) = T_1(r) - \theta\pi_2(v,r) = 0. \tag{4.9}$$

Let $r^{NC}(\theta)$ denote the optimal running royalty. Implicit differentiation of Equation (4.9) yields $\partial r^{NC}(\theta)/\partial\theta < 0$ for

$$\theta > \theta_V^{NC} \equiv T_1(v)/\pi_2(v,v). \tag{4.10}$$

For $\theta \leq \theta_V^{NC}$, the optimal running royalty equals $r^{NC}(\theta) = v$ because the running royalty implied by Equation (4.9) exceeds v. Recall that running royalties above v are ruled out by assumption. The following lemma summarizes the equilibrium outcome for the case with a no-challenge clause.

Lemma 4.1. *Suppose the patent holder includes a no-challenge clause in the license contract. The running royalty $r^{NC}(\theta)$ equals v if $\theta \leq \theta_V^{NC}$. Otherwise, $r^{NC}(\theta)$ is implicitly defined by the first-order condition in Equation (4.9). For $\theta > \theta_V^{NC}$, the running royalty $r^{NC}(\theta)$ (weakly) decreases in θ. The fixed fee is $F^{NC} = \pi\left(r^{NC}(\theta), r^{NC}(\theta)\right) - \left(\theta\pi\left(v, r^{NC}(\theta)\right) + (1-\theta)\pi(0,0) - L^{\mathcal{I}}\right)$.*

Proof. See Appendix A □

The result of Lemma 4.1 replicates the result of Farrell and Shapiro (2008) for possibly positive litigation costs of patent infringement $\left(L^{\mathcal{I}} \geq 0\right)$. The litigation costs have a positive effect on the fixed fee F^{NC}. The running royalty $r^{NC}(\theta)$ weakly decreases in θ and is characterized by the same optimality condition as in Farrell and Shapiro (2008).

License Terms Absent a No-Challenge Clause. We first compare the license contract with a no-challenge $\left\{F^{NC}, r^{NC}\right\}$ characterized in Lemma 4.1 to the license contract $\left\{F_{NI}^{nNC}, r_{NI}^{nNC}\right\}$ that, absent a no-challenge clause, induces the licensees financially to not challenge the patent (challenge-avoidance pricing). Recall that the risk of patent invalidation is zero in both cases, which implies that only differences in the royalty rates affect the consumer surplus. Absent a no-challenge clause, the relevant outside option is $\pi(0,0) - L^{\mathcal{C}} \leq \pi(r,r) - F$ (Equation (4.3)). As derived in the proof of Lemma 4.4 in

Appendix A, the patent holder chooses the running royalty in order to

$$\max_r \; G_{NI}^{nNC} = \max_r \left[T(r) - \pi(0,0) + L^{\mathcal{C}} \right]. \tag{4.11}$$

In contrast to the case with a no-challenge clause, the downstream firm's outside option in this case is independent of the running royalty because in the event of a successful challenge no downstream firm has to pay royalty rates. Consequently, the patent holder sets $r_{NI}^{nNC} = v$ in order to maximize the total profit $T(r)$ per downstream firm.

Comparing the license rates of the two contracts yields that a ban of a no-challenge clause (weakly) increases the running royalty to the level of the cost savings v under challenge-avoidance pricing. In particular, in the interval $\theta \in \left(\theta_V^{NC}, \tilde{\theta}\right)$ the patent holder charges strictly higher running royalties absent a no-challenge clause than with a no-challenge clause.[27] Consumer prices are therefore also strictly higher without a no-challenge clause. Below θ_V^{NC}, consumer surplus is unaffected by a ban of a no-challenge clause but it shifts profits from the patent holder to the licensees as they are financially incentivized to not challenge the patent absent a no-challenge clause (see Lemma 4.1). We summarize in

Proposition 4.2. *A ban of a no-challenge clause leads to (weakly) higher running royalties at the level of v and consumer prices if the patent holder practices challenge-avoidance pricing absent a clause.*

Proof. Direct implication of the license terms in Lemmas 4.1 and 4.4. □

Proposition 4.2 highlights that a no-challenge clause can affect consumer surplus not only via its effect on the invalidation frequency but also through its effects on the license terms and prices, which complements the analysis of Miller and Gal (2015). In particular, a ban of a no-challenge clause can lead to lower consumer surplus even if the invalidation frequency remains unaffected.

Second, we compare the license contract with a no-challenge clause $\left\{F^{NC}, r^{NC}\right\}$ to the license contract that allows for a positive invalidation frequency $\left\{F_I^{nNC}, r_I^{nNC}\right\}$ (challenge-acceptance pricing). We characterize the latter license contract in Lemma 4.5 in Appendix A. The derivation is qualitatively the same as in the case with a no-challenge clause (Lemma 4.1). The patent holder offers license rates that make the downstream firms indifferent between contract acceptance and patent infringement. The main difference is that the downstream firms have an expected profit from the contract acceptance of

$$(1-\theta)\gamma\left(\pi(0,0) - \frac{L^{\mathcal{C}}}{n}\right) + (1-(1-\theta)\gamma)(\pi(r,r) - F), \tag{4.12}$$

[27] For instance, for $v = 1/4$, $\gamma = 1/2$, linear demand defined in Equation 4.1, with $\sigma = 1/2$, and zero litigation costs $L^{\mathcal{I}} = L^{\mathcal{C}} = 0$, we have $\theta_V^{NC} = 0$ and $\tilde{\theta} \approx 0.12$.

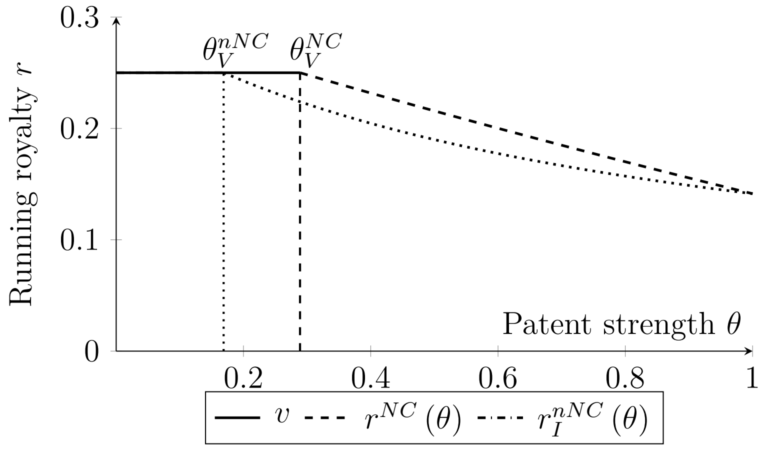
instead of the certain profit of $\pi(r,r) - F$ with a no-challenge clause (Equation (4.4)). We find that this difference leads to weakly lower running royalties in equilibrium absent a no-challenge clause. The patent holder's incentive to reduce the value of the downstream firms' outside options by means of low running royalties is stronger in the case of challenge-acceptance pricing than in the case with a no-challenge clause because high running royalties increase the patent holder's payoff only if the validity of the patent is not challenged. This yields

Proposition 4.3. *A ban of a no-challenge clause leads to (weakly) lower running royalties and consumer prices if the patent holder practices challenge-acceptance pricing absent a clause.*

Proof. See Appendix A. □

The result of Proposition 4.3 shows that a ban of no-challenge clauses increases consumer surplus if the patent is sufficiently strong. The probability that a wrongly-granted patent is challenged and invalidated in court increases from zero to $(1-\theta)\gamma$. In this case licensees therefore fulfill the important public role of *permitting full and free competition of ideas which are in reality a part of the public domain (Lear vs. Adkins).* A no-challenge clause effectively ensures that licensees do not challenge the validity of patents even if they would have had an incentive to challenge the patent absent this clause. Even if the patent goes unchallenged, the running royalties and consumer prices are lower than with a no-challenge clause, reducing deadweight loss. If the litigation costs $L^{\mathcal{C}}$ for challenging the patent are not too high then also social welfare also increases.

Figure 4.3 illustrates Proposition 4.3.



Equilibrium running royalties $r^{NC}(\theta)$ and $r_I^{nNC}(\theta)$ depending on θ for $n = 2$ licensees competing in prices. Marginal costs of the old technology: $v = 1/4$; signal probability: $\gamma = 6/10$; litigation costs: $L^{\mathcal{C}} = L^{\mathcal{I}} = 0$. Demand is defined in Equation (4.1), with $\sigma = 1/2$.

Figure 4.3: Comparison of running royalties $r^{NC}(\theta)$ and $r_I^{nNC}(\theta)$ (Proposition 4.3).

4.3.3 Profitability of a No-Challenge Clause

Patent Holder. Next, we establish that a patent holder always benefits from the inclusion of a no-challenge clause in the license contract, both for patents where otherwise challenge-acceptance pricing or challenge-avoidance pricing is optimal.

Proposition 4.4. *Implementing a no-challenge clause is strictly profitable for the patent holder for any patent strength $\theta \in (0, 1)$.*

Proof. See Appendix A □

The proof establishes that it is more profitable for the patent holder to avoid patent invalidation by means of a no-challenge clause than by means of sufficiently favorable license fees. The reason for this result is that preventing patent challenges through challenge-avoidance pricing is costly for the patent holder. By implementing a no-challenge clause the patent holder can reduce the downstream profits from the level $\pi(0, 0) - L^{\mathcal{C}}$, which is required to avoid invalidation challenges absent a no-challenge clause (see Equation (4.3)), to the expected profit of infringing the patent in Equation (4.5).

For strong patents where—absent a no-challenge clause—the patent holder practices challenge-acceptance pricing, the logic of the proof is as follows: The patent holder's profit is higher with no challenge clause as (i) the invalidation frequency drops to zero and (ii) the running royalty is (weakly) higher than without a no-challenge clause, which increases the total profit per downstream firm $T(r)$. Both aspects increase the industry profit and ultimately result in higher profit for the patent holder.

Licensees. Gal and Miller (2017) argue that licensees would have a strong incentive to agree to no-challenge clauses, as the patent holder and licensee can benefit from externalizing the monopolistic harm onto consumers. This is true in our model for the case in which the patent gets challenged upon receiving the invalidity signal, which happens only for strong patents. Recall that the running royalty $r^{NC}(\theta)$ is weakly larger than $r_I^{nNC}(\theta)$ (Proposition 4.3). A downstream firm's expected profit from infringing the patent (see Equation (4.5)), which is the equilibrium profit in this scenario, is therefore smaller absent a no-challenge clause, because its outside option to infringe the patent is worse at smaller running royalties.

If the patent holder, however, engages in challenge-avoidance pricing absent a no-challenge clause, the downstream firms realize lower profits from the introduction of such a clause. In the absence of a no-challenge clause downstream firms obtain relatively attractive licensing terms to prevent them from challenging the patent's validity even after receiving the invalidity signal. This changes if the patent holder can insist on the inclusion of a no-challenge clause, in which case the licensees obtain a smaller share of the total profit because of a weaker outside option. The downstream firms, therefore, do not benefit from the inclusion of a no-challenge clause. This may explain the frequent disagreement between patent holders and licensees about the inclusion of no-challenge clauses in a license contract.[28] If it was in their mutual interest to include no-challenge clauses—as stipulated in Gal and Miller (2017)—we would expect such clauses to be silently included in the contracts and would accordingly expect less legal debate about their legitimacy between patent holders and licensees. We summarize this in

Corollary 1. *The downstream firms' expected profit from accepting the license contract is larger with a no-challenge clause if the patent holder practices challenge-acceptance pricing absent a no-challenge clause. Otherwise, the profit decreases with a no-challenge clause.*

Proof. Omitted. □

4.3.4 Consumer Surplus and Welfare

The effect of a no-challenge clause on consumer surplus also depends on the patent strength. More specifically, consumers benefit from no a challenge-clause when the downstream firms suffer – and vice versa. First, consider the case of strong patents in which a licensee challenges the patent upon receiving the invalidity signal, such that there is a positive probability of patent invalidation in equilibrium. A no-challenge clause thus decreases the chance of the successful invalidation of an invalid patent and increases the running royalties. In turn, consumer prices are higher with no-challenge clauses. In this situation, consumer surplus is thus higher absent a no-challenge clause.

In stark contrast to this finding, with challenge-avoidance pricing, a ban of no-challenge clauses leaves the probability of patent invalidation at zero. Even worse, a ban of a no-challenge clause additionally changes the outside option for the downstream firms and thereby(weakly) increases the running royalty. A ban thus can increase the consumer prices, such that consumers are worse off. We summarize in

Corollary 2. *Consumer surplus is (weakly) smaller with a no-challenge clause if the patent holder practices challenge-acceptance pricing absent a no-challenge clause. Otherwise, a no-challenge clause increases consumer surplus.*

Proof. Omitted. □

This finding on consumer surplus is in contrast to Miller and Gal (2015) who argue that the difference in welfare effects between contracts with and without a no-challenge boils down to the probability of a challenge. In fact, we find that a ban of a no-challenge clause can adversely affect consumer surplus and social welfare, especially if the probability of a challenge remains constant.

[28] See, for instance, Harris (2015) documenting that Qualcomm Inc. conditioned the supply of baseband chips on a licensee's acceptance of no-challenge clauses.

4.4 Extensions

In this section, we study the substantial change in license negotiations brought by the Supreme Court judgment *MedImmune, Inc. vs. Genentech, Inc.*. Moreover, we analyze the case in which the patent holder is restricted from offering linear royalties (where $F = 0$).

4.4.1 MedImmune vs. Genentech

The Supreme Court ruled in the landmark case *MedImmune vs. Genentech* that a non-repudiating licensee is allowed to challenge a patent's validity. Prior to the judgment, a licensee in good standing was typically barred from challenging a patent's validity. Instead, it was necessary for a licensee to create an *actual controversy* in the form of terminating the license contract or withholding the royalty payments before an invalidation process was possible (see *Genprobe vs. Vysis*). Challenging a patent therefore carried the risk of ending up with worse license terms than before the challenge if the court did not invalidate the patent.[29] By also allowing also a non-repudiating licensee to challenge a patent's validity, the Supreme Court effectively removed this potential downside from challenging the patent. If a patent is held valid, a licensee can continue to rely on the initial contract. Hence, Dreyfuss and Pope (2009) claim that the invalidation decision and bargaining position between patent holder and licensee has substantially changed (Dreyfuss and Pope, 2009). Moreover, they interpret the judgment as extending the rationale of *Lear vs. Adkins* in order to ensure that licensees have the ability to challenge the validity of a licensed patent.

In this extension, we show that the judgment may, however, not improve the invalidation frequency of wrongly-granted patents and can even lead to less patent challenges than before. In particular, we find that despite the fact that prospects of challenging the patent substantially improved after *MedImmune vs. Genentech*, the patent holder still has the incentive and the ability to avoid a patent challenge by means of favorable contract terms if the patent is weak. This challenge-avoidance pricing has the same detrimental effects on the invalidation frequency and consumer surplus as in the main analysis in Section 4.3. Our theory predicts that the range of patents where challenge-avoidance pricing occurs can increase as well because the judgment makes it more risky for a patent holder to engage in challenge-acceptance pricing.

The Supreme Court decision in *MedImmune* does not affect the licensing game between the patent holder and licensees if the contract includes a no-challenge clause. Hence, we obtain the same equilibrium outcome as in Lemma 4.1. For the case of contracts without a no-challenge clause, we consider the following timing:

[29] This is the main reason why licensees without an invalidity signal have no incentive to challenge the patent in the main model. See Lemma 4.3 in Appendix A.

1. Contract acceptance/rejection.
2. A randomly-drawn licensee gets the invalidity signal with probability $(1-\theta)\gamma$ and can decide to challenge the patent.
3. A randomly-drawn licensee without an invalidity signal can decide to challenge the patent.
4. Payoffs realize.

The timing allows us to study the effects of the *MedImmune* judgment in a simple environment. The timing gives priority in the challenging decision to the licensee with superior knowledge about the patent's validity. Moreover, it ensures that only one licensee can decide to challenge the patent at a time. This simplifying assumption ensures consistency to the main part in which, also, only at most one licensee has an incentive to challenge the patent. Note that this timing is equivalent to the timing of the model in Section 4.3 if a challenge is only feasible with contract termination because, in this case, an uninformed licensee never decides to challenge the patent in Stage 3. For simplicity, we assume that licensees with and without an invalidity signal face the same litigation costs $L^{\mathcal{C}}$. Moreover, we replace Assumption 4.2 and impose

Assumption 4.5. $L^{\mathcal{C}} < \frac{(1-\gamma)(1-\theta)\theta}{1-\gamma(1-\theta^2)}\left(\pi\left(0,0\right)-\pi\left(v,v\right)\right).$

in order to ensure that a patent challenge can be a relevant decision for the licensees after they have accepted the contract. For higher litigation costs, the patent holder's problem is essentially the same as in the main model because licensees without a signal do not challenge the patent: either the licensee with a signal challenges the patent or no licensee does so.

There are three relevant cases to distinguish:

1. Complete challenge-avoidance pricing: the patent holder offers a contract such that no licensee has an incentive to challenge the patent.
2. Partial challenge-acceptance pricing: the patent holder offers a contract such that licensees without an invalidity signal have no incentive to challenge the patent, but a licensee with a signal challenges the patent.
3. Complete challenge-acceptance pricing: the patent holder offers a contract such that every licensee has an incentive to challenge the patent after contract acceptance.

As ruled in *MedImmune vs. Genentech,* we assume that a challenging licensee can keep the initial contract if a challenge is not successful.

Complete Challenge-Avoidance Pricing. First, note that the patent holder has to offer a contract such that

$$\pi(r,r) - F \geq \pi(0,0) - L^{\mathcal{C}}, \tag{4.13}$$

in order to completely avoid a patent challenge. This is the same constraint as in Lemma 4.5 and therefore also gives rise to the same contract offer.

Partial Challenge-Acceptance Pricing. Second, we consider the case of partial challenge-acceptance pricing. This is the case in which only an informed licensee with an invalidity signal has an incentive to challenge the patent. Suppose that all downstream firms accept the contract and that in Stage 2 of the game no licensee challenges the patent. In Stage 3, an uninformed licensee without an invalidity signal is randomly drawn in order to decide whether to challenge the patent or not. This licensee has no incentive to challenge the patent if

$$\begin{aligned} \pi(r,r) - F &\geq \frac{\theta}{\theta + (1-\theta)(1-\gamma)} (\pi(r,r) - F) + \left(1 - \frac{\theta}{\theta + (1-\theta)(1-\gamma)}\right) \pi(0,0) - L^{\mathcal{C}} \\ \Rightarrow F &\leq \pi(r,r) - \pi(0,0) + \frac{(1 - \gamma(1-\theta)) L^{\mathcal{C}}}{(1-\theta)(1-\gamma)}. \end{aligned} \tag{4.14}$$

If the licensee decides to challenge, it incurs litigation costs of $L^{\mathcal{C}}$. As the patent was not challenged in Stage 2, the licensee updates its belief that the patent is valid to $\theta / (\theta + (1-\theta)(1-\gamma))$. In this event, the licensee continues to rely on the initial contract with profit $\pi(r,r) - F$. In contrast, if the patent is invalidated by the court (with the complimentary probability), all licensees can use the new technology without royalty payments and obtain profits of $\pi(0,0)$. By Assumption 4.5 on the litigation costs in this section, licensees also find it profitable to accept the contract offer (instead of rejecting and infringing the patent) if the condition in Equation (4.14) holds.

The patent holder sets the fixed fee such that the condition in Equation (4.14) holds with equality. Inserting the fixed fee in the patent holder's profit function yields

$$G^{nNC}_{PCAc}(r,\theta) = (\theta + (1-\theta)(1-\gamma)) \left(T(r) - \pi(0,0) + \frac{(1 - \gamma(1-\theta)) L^{\mathcal{C}}}{(1-\theta)(1-\gamma)} \right), \tag{4.15}$$

where $PCAc$ stands for partial-challenge acceptance. The patent holder receives a positive profit only if no licensee receives the invalidity signal, which occurs with probability $(\theta + (1-\theta)(1-\gamma))$. By the same arguments as in Section 4.3.2, the patent holder sets the resulting running royalty r in order to maximize the total profit per downstream firm $T(r)$ as the remaining part of the objective function does not depend on r. This implies $r^{nNC}_{PCAc} = v$ and thereby that the same running royalty and consumer prices emerge as in Lemma 4.4.

Complete Challenge-Acceptance Pricing. Next, suppose that the patent holder sets the contract terms such that the condition in (4.14) is not fulfilled. All downstream firms accept the offer in equilibrium, anticipating that the patent will be challenged after contract acceptance. The best alternative to contract acceptance is to use the old technology and anticipate that a licensee will challenge the patent (see Section 4.2), yielding an expected profit from using the old technology of $\theta\pi(v,r) + (1-\theta)\pi(0,0)$. A downstream firm that anticipates that all remaining downstream firms will accept the contract therefore does the same if

$$\begin{aligned} \theta(\pi(r,r) - F) + (1-\theta)\pi(0,0) - \frac{L^{\mathcal{C}}}{n} &\geq \theta\pi(v,r) + (1-\theta)\pi(0,0) \qquad (4.16) \\ \Rightarrow \pi(r,r) - F - \frac{L^{\mathcal{C}}}{\theta n} &\geq \pi(v,r) \\ \Rightarrow F &\leq \pi(r,r) - \pi(v,r) - \frac{L^{\mathcal{C}}}{\theta n}. \end{aligned}$$

Again, the patent holder makes the downstream firms indifferent to their outside option by setting the fixed fee such that the condition in Equation (4.16) holds with equality. The resulting expected profit of the patent holder is

$$\begin{aligned} G^{nNC}_{CCAc}(r) &= \theta \cdot (r \cdot x(r,r) + F) \qquad (4.17) \\ &= \theta \cdot (T(r) - \pi(v,r)) - \frac{L^{\mathcal{C}}}{n}, \end{aligned}$$

where $CCAc$ stands for complete challenge-acceptance pricing. The corresponding first-order condition is $T_1(r) - \pi_2(v,r) = 0$. Denote the corresponding running royalty r^{nNC}_{CCAc} which is the same as with no-challenge clauses reported in Lemma 4.5 if the patent strength converges to $\theta \to 1$.

We summarize the results on the contracts absent a no-challenge clause in

Proposition 4.5. *Suppose that a licensee can continue to rely on the initial contract if a patent challenge is unsuccessful (MedImmune).*

- *If the patent holder wants to completely avoid a challenge, it optimally offers the licensees a contract with* $r^{nNC}_{NI} = v$ *and* $F^{nNC}_{NI} = \pi(v,v) - \pi(0,0) + L^{\mathcal{C}}$.
- *In the case of partial challenge-acceptance pricing, the patent holder sets* $r^{nNC}_{PCAc} = v$ *and* $F^{nNC}_{PCAc} = \pi(v,v) - \pi(0,0) + \frac{(1-(1-\theta)\gamma)L^{\mathcal{C}}}{(1-\gamma)(1-\theta)}$.
- *In the case of full challenge-acceptance pricing, it optimally offers a contract with* $r^{nNC}_{CCAc}(1)$ *and* $F^{nNC}_{CCAc} = \pi\left(r^{nNC}_{CCAc}(1), r^{nNC}_{CCAc}(1)\right) - \pi\left(v, r^{nNC}_{CCAc}(1)\right) - \frac{L^{\mathcal{C}}}{\theta n}$.

Proof. See the derivations above. □

In the cases of both challenge-avoidance pricing and partial challenge-acceptance pricing, we obtain that the patent holder sets the running royalty as high as possible, that is at v, the cost savings of the new technology. The only difference between the cases is that the patent holder charges a different fixed fee.[30] If the patent holder decides on either of these pricing strategies we therefore obtain the same result, that running royalties and consumer prices are higher than with a no-challenge clause given that the patent is not invalidated.

Based on the parametric example of Figure 4.2, we find that the patent holder prefers to engage in challenge-avoidance pricing if the patent strength is $\theta < 0.57$.[31] Recall that the threshold value for the model analyzed in Section 4.3 (see Figure 4.2) is around $\tilde{\theta} \approx 0.5$, which means that *MedImmune vs. Genentech* leads to higher incentives for a patent holder to avoid a challenge. The reason is that the patent holder knows with certainty that the patent will be challenged under complete challenge-acceptance pricing, which is the patent holder's second best alternative for small litigation costs $L^{\mathcal{C}}$. As long as this is the case, the range in which the patent holder completely avoids a patent challenge even further increases up to $\theta \approx 0.63$. The reason for this increase in the threshold value is that the patent holder's profit increases in L^C with complete challenge-avoidance pricing whereas the profit decreases in L^C in the case of complete challenge-acceptance pricing (see F^{nNC}_{CCAc} in Proposition 4.5).[32] We summarize these findings of the parametric example in The *MedImmune vs. Genentech* judgment can increase the range in which the patent holder strategically avoids a patent challenge because the risk of patent invalidation makes this strategy more profitable. We conclude that even if the licensees' prospects of a patent challenge have substantially increased since the *MedImmune vs. Genentech* judgment, the patent holder can avoid a patent challenge in the same fashion as prior to *MedImmune vs. Genentech.* Moreover, this strategy has the same adverse effects on consumer prices as before. Contrary to the goals of the judgment, the patent holder might adopt this strategy for an even larger range of patent strengths, leading to the unintended result that *MedImmune vs. Genentech* may reduce the frequency of successful patent challenges.

One natural way for the patent holder to restore the situation before *MedImmune vs. Genentech* in our model is to include a so-called termination clause into the license contract. A termination clause grants the patent holder the right to terminate the license contract with a licensee if it challenges the validity of the patent (see Dreyfuss and Pope 2009, and Cheng, 2015, for discussions of termination clauses). If the court holds the patent valid, the challenging licensee needs to negotiate for a new license with the patent holder. As the patent is undoubtedly valid in this case, the outside option profit that the

[30] Inspecting yields that F^{nNC}_{PCAc} and F^{nNC}_{NI} only differ in how they are affected by the litigation costs $L^{\mathcal{C}}$, and for $L^{\mathcal{C}} = 0$ these two cases are equivalent.

[31] The specification involves $v = 1/10$, $\sigma = 3/4$, and $L^{\mathcal{C}} = 0$.

[32] For higher litigation costs, the relevant comparison is between complete challenge-avoidance and partial challenge-acceptance pricing. In this range, the threshold value decreases in $L^{\mathcal{C}}$ up to the point that the constraint on the litigation costs in Assumption 4.5 binds. In the current specification the threshold value at the highest admissible litigation costs $L^{\mathcal{C}}$ is $\theta \approx 0.58$, which is approximately the same threshold value as in the main model at this amount of litigation costs.

challenging licensee obtains in these negotiations is $\pi(v, r)$. Hence, in our model, when *the MedImmune vs. Genentech* rules are in place, a termination clause re-introduces the same downsides for a challenging licensee as prior to *MedImmune vs. Genentech.*

4.4.2 Linear License Contracts

In this extension, we analyze the effects of no-challenge clauses when the license tariffs are restricted to being linear (this implies $F = 0$). We call the running royalties "pure" in this case. This analysis is also instructive for the case of two-part tariffs for which the fixed fee is sunk at the contract acceptance stage. The proofs as well as a parametric illustration based on the linear demand specification in Equation 4.1 are in Appendix B.

As in the main analysis (Section 4.3), a licensee has to terminate the license contract in order to challenge the patent. Similar to the case with two-part tariffs, we demonstrate that even if it is feasible to challenge the patent (i.e., absent a no-challenge clause), there may be no challenges of weak patents in equilibrium. Moreover, we show that the main result of Section 4.3, that a ban of a no-challenge clause can lead to higher consumer prices, can also emerge if the fixed fee does not affect the challenge decision.

If all downstream firms use the patented technology and pay a running royalty s (but no fixed fee), the patent holder generates the following profit per downstream firm:

$$\begin{aligned} R(s) &= s \cdot x(s, s) \\ &= T(s) - \pi(s, s). \end{aligned} \tag{4.18}$$

Analog to Assumption 4.4, we impose

Assumption 4.6. $R(s)$ is strictly concave on the relevant range.

Define the pure running royalty that maximizes the patent holder's profit in Equation (4.18) as $s^* = \arg\max_s R(s)$. We establish first that the unconstrained royalty rate s^* cannot be part of an equilibrium.

Lemma 4.2. *With linear tariffs, the optimal unconstrained running royalty s^* is above the monopoly level: $s^* > m \geq v$.*[33]

Proof. See Appendix B. □

Intuitively, if the patent holder only has the running royalty s available as an instrument to generate profits, it charges higher variable license terms than with two-part tariffs, leading to double-marginalization. The downstream firms do not accept pure running royalties that exceed the cost savings of the new technology ($s > v$) as they would prefer to infringe the patent or to use the old technology. Together with Lemma 4.2, this

[33] Recall that $m = \arg\max_r T(r)$.

implies that the patent holder cannot set the unconstrained pure running royalty s^* that maximizes the profit in Equation (4.18). The patent holder therefore optimally sets the highest feasible running royalty, which is at the level at which each downstream firm is indifferent to the outside option. As with two-part tariffs, this outside option is determined by the minimum profit level which either ensures contract acceptance alone or ensures contract acceptance and, in addition, avoids a patent challenge (see the derivation at the beginning of Section 4.3).

Risk of Invalidation. As with two-part tariffs, absent a no-challenge clause the patent holder has to decide between either low license fees (challenge-avoidance pricing) or high license fees with the risk of a patent challenge (challenge-acceptance pricing). We characterize the equilibrium challenge decision depending on the patent strength θ in

Proposition 4.6. *Suppose the patent holder is restricted to a linear license tariff without a no-challenge clause. The equilibrium challenge decision post contract acceptance depends on the patent strength θ as follows:*

1. *For $\theta \in (0, \underline{\theta}]$ (with $\underline{\theta}$ defined in Lemma 4.6), a licensee does not challenge the patent as this would yield a lower profit than the minimum profit level under the contract.*
2. *For $\theta \in \left(\underline{\theta}, \tilde{\theta}^s\right]$ (with $\tilde{\theta}^s < 1$ defined in Equation (4.86)), the patent holder engages in challenge-avoidance pricing. The interval $\left(\underline{\theta}, \tilde{\theta}^s\right]$ is nonempty if the litigation costs for a patent challenge are sufficiently high: $L^{\mathcal{C}} > \underline{L}^{\mathcal{C}}$ (with $\underline{L}^{\mathcal{C}}$ defined in Equation (4.85)).*
3. *For $\theta > \max\left\{\underline{\theta}, \tilde{\theta}^s\right\}$, the patent holder engages in challenge-acceptance pricing.*

Proof. See Appendix B. □

Similar to the case of two-part tariffs, we find that a patent will only be challenged in equilibrium if it is sufficiently strong. If the patent is weak, the licensees may not challenge the patent for one of two reasons.

- First, in the interval $\theta \in (0, \underline{\theta}]$, the profit from a patent challenge is lower than the profit from contract acceptance.[34] The threshold value $\underline{\theta}$ is the level of the patent strength at which the expected profit from patent infringement equals the profit of a patent challenge upon receiving the invalidity signal. In this interval, a licensee does not find it profitable to challenge the patent after contract acceptance. Hence, there is no trade-off for the patent holder and the license outcome is as if the contract contains a no-challenge clause.

[34]Note that we exclude this case in the main analysis in Section 4.3 by Assumption 4.2. We relax this assumption in this section because, in contrast to the case of two-part tariffs, the prevalence of challenge-avoidance pricing here depends more directly on the litigation costs for a patent challenge ($L^{\mathcal{C}}$).

- Second, if the profit from a patent challenge upon receiving the invalidity signal exceeds the profit of contract acceptance (for patents with $\theta > \underline{\theta}$), there exists a range of patent strengths $\theta \in \left(\underline{\theta}, \tilde{\theta}^s\right]$ in which the patent holder engages in challenge-avoidance pricing, provided that the litigation costs $L^{\mathcal{C}}$ are sufficiently large. The patent holder is indifferent between avoiding a patent challenge (NI) and not avoiding it (I) at $\theta = \tilde{\theta}^s$ (defined in Equation (4.86)). Only if the patent is sufficiently strong $\left(\theta > \tilde{\theta}^s\right)$ will the patent holder accept a positive invalidation risk for the benefit of giving a smaller share of the total profits to the licensees.

Comparison of Linear Royalty Rates. We compare the royalties in a contract with a no-challenge clause $\left(s^{NC}(\theta)\right)$ to the royalties absent a no-challenge clause, for the case both with positive $\left(s_I^{nNC}(\theta)\right)$ and with zero invalidation risk $\left(s_{NI}^{nNC}\right)$. The contracts for each case are characterized in the Lemmas 4.7, 4.8, and 4.9 in Appendix B. The royalty rates $s_I^{nNC}(\theta)$ and s_{NI}^{nNC} are only defined for $\theta \geq \underline{\theta}$.

Proposition 4.7. *Suppose the patent holder is restricted to a linear license tariff. For weak enough patents ($\theta < \underline{\theta}$, see Lemma 4.6), a no-challenge clause does not affect the license outcome. For stronger patents, the following holds: If absent a no-challenge clause*

- *challenge-acceptance pricing prevails, the equilibrium royalty is higher than with a no-challenge clause:* $s_I^{nNC}(\theta) > s^{NC}(\theta)$.
- *If challenge-avoidance pricing prevails, the equilibrium royalty is independent of θ and smaller than with a no-challenge clause:* $s_{NI}^{nNC} < s^{NC}(\theta)$.

Proof. See Appendix B. □

Compared to the contract with a no-challenge clause, the patent holder charges a lower royalty if it avoids a patent challenge (NI). In contrast, if it accepts a positive invalidation risk (I), it charges a higher royalty.

Effects on Welfare. The results of Propositions 4.6 and 4.7 imply ambiguous welfare effects of a no-challenge clause in the case of linear license contracts. If, absent a no-challenge clause, a patent holder engages in patent-acceptance pricing, then such a clause clearly reduces the invalidation probability (bad for welfare, as an invalid patent remains unchallenged) but royalty rates and hence consumer prices are lower in the case where no invalidation occurs (good for welfare).

In contrast, under challenge-avoidance pricing by means of a low royalty rate, a no-challenge clause reduces welfare because it leads to a higher royalty rate and thus consumer prices while leaving the invalidation frequency unaffected (at zero).

Effects on Profits. With linear license contracts, the patent holder always benefits from a no-challenge clause (as with two-part tariffs). The downstream firms do not benefit from the introduction of a no-challenge clause. This is in contrast to the case of two-part tariffs where downstream firms benefit from a no-challenge clause if the patent holder engages in challenge-acceptance pricing absent the clause. This result reinforces the conclusion that licensees do not prefer the inclusion of a no-challenge clause in many cases. Again, this contrasts Gal and Miller (2017) who argue that licensees have a strong incentive to accept such clauses (see the discussion of Corollary 1 in Section 4.3 for the case of two-part tariffs).

To illustrate these results, consider first the case of challenge-avoidance pricing absent a no-challenge clause. Without a no-challenge clause, the licensees receive a high profit that incentivizes them to not challenge the patent. A no-challenge clause allows the patent holder to offer a lower profit level to the downstream firms and keeps the frequency of patent challenges at zero. In this case, a no-challenge clause is therefore clearly beneficial for the patent holder to the detriment of the downstream firms.

Second, the same qualitative result holds when the patent holder accepts a positive invalidation risk in equilibrium. The licensees' profit decreases for two reasons. To see this, recall that their profit in this case is

$$(1-\theta)\,\gamma\left(\pi\,(0,0)-L^{\mathcal{C}}/n\right)+\left(1-(1-\theta)\,\gamma\right)\left(\theta\pi\,(v,s)+(1-\theta)\,\pi\,(0,0)-L^{\mathcal{I}}\right). \quad (4.19)$$

First, a no-challenge clauses reduces the probability of a patent challenge from $((1-\theta)\,\gamma)$ to zero. The licensees' thus do not realize the expected profit of $\pi\,(0,0)-L^{\mathcal{C}}/n$ with certainty. Second, recall that the expected profit from patent infringement, $\theta\pi\,(v,s)+(1-\theta)\,\pi\,(0,0)-L^{\mathcal{I}}$, increases in the royalty rate s. As $s_I^{nNC}(\theta)>s^{NC}$, the expected profit of patent infringement is lower with a no-challenge clause. The licensees' profit is therefore lower with a no-challenge clause. For the same reasons, the patent holder benefits from a no-challenge clause: the patent cannot be challenged and the downstream firms' outside option is worse than without a no-challenge clause.

4.5 Conclusion

We analyze the effects of a ban of a no-challenge clause on the probability that licensees challenge a wrongly-granted patent and the license terms. Our results emphasize that a patent holder can avoid a patent challenge even absent a no-challenge clause. This strategy is particularly profitable for the patent holder in the case of weak patents, where the probability that the patent is invalidated if challenged in court is high. For such patents, there is arguably a large public interest in the successful invalidation. Our theory, however, predicts that a ban of a no-challenge clause may not increase the frequency with which these weak patents are challenged.

The hope expressed in court judgments, such as *Lear, Inc. vs. Adkins,* that licensees would have incentives to identify and challenge invalid patents and thereby serve the public interest, is thus not necessarily warranted. We show under different pricing assumptions (in particular, we study both linear royalty rates as well as two-part tariffs), the patent holder accepts patent challenges only if the patent is sufficiently strong. In contrast, it finds profitable to avoid a challenge by means of favorable license terms if the patent is relatively weak.

If the patent holder engages in this form of challenge-avoidance pricing, a no-challenge clause can be beneficial for consumers. In particular, for the case of two-part license contracts, the running royalties and hence consumer prices can be higher than in a contract with a no-challenge clause. A ban of no-challenge clauses in this setting is therefore welfare-decreasing.

The analysis focuses on the case in which the patent holder and a licensee cannot privately settle a patent challenge. As private settlements might prevent the public invalidation of the patent, our approach therefore captures the case in which the ban of a no-challenge clause has the potential to have a strong effect on the public invalidation of wrongly-granted patents, as articulated in *Lear vs. Adkins.* Our results emphasize that, even in such a case, the ban of a no-challenge clause is not necessarily effective and can be socially detrimental. We expect that incorporating the possibility of private settlements in the analysis further diminishes the effectiveness of banning no-challenge clauses in order to identify and invalidate wrongly-granted patents.

Finally, we also analyze the implications of the court judgment *MedImmune vs. Genentech.* This judgment is meant to substantially improve the prospects of challenging a patent by allowing licensees to challenge without first terminating the license contract. This is supposed to remove a major potential downside of a patent challenge because a licensee can continue to rely on the initial contract if the patent challenge is not successful. Maybe surprisingly, our analysis reveals that the basic trade-off for the patent holder remains essentially the same. For weak patents, it is profitable to avoid a patent challenge by means of favorable contract terms for the licensees and, again, this has the same price effects of increasing running royalties and consumer prices compared to a contract with no-challenge clauses. Moreover, as this judgment increases the risk of a patent challenge for the patent holder, the range of patent strengths in which challenge-avoidance pricing occurs can be substantially larger. By taking into account the patent holder's reaction to the judgment in its license terms, we therefore show that *MedImmune vs. Genentech* may have the unintended effect of even reducing the number of patent challenges.

In summary, our results cast doubt on the repeatedly expressed hope that licensees fill the important role of identifying and challenging wrongly-granted patents. Our theory therefore contributes to the discussion of whether a prohibition of no-challenge clauses under antitrust law, as it is expressed in Gal and Miller (2017), is socially optimal. As our analysis reveals, the ban of a no-challenge clause can lead to lower consumer surplus and social welfare. This indicates that a general prohibition of no-challenge clauses may not be optimal.

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Appendix

Appendix A: Proofs of Section 4.3

Proof of Proposition 4.1

We prove the result of Proposition 4.1 as follows:.

1. We derive as an auxiliary result that only a licensee with an invalidity signal can have an incentive to challenge the patent (Lemma 4.3).
2. We derive the patent holder's contract offers for the cases in which it
   (a) avoids a patent invalidation by means of financial incentives for the licensees (Lemma 4.4);
   (b) accepts that a licensee challenges the patent upon receiving the invalidity signal (Lemma 4.5).
3. We compare the profit for the patent holder under the two scenarios and derive that the former contract offer dominates the latter if the probability of the invalidity signal $(1-\theta)\gamma$ is large.

Lemma 4.3 (Step 1)**.** *Suppose all downstream firms accepted the license contract. A licensee with the invalidity signal can have an incentive to challenge the patent. Any licensee without the invalidity signal does not challenge the patent.*

Proof of Lemma 4.3. We derive the result of Lemma 4.3 in two steps. First, we analyze the incentives of a licensee with an invalidity signal and second the incentives of a licensee without a signal.

First, suppose licensee D_i has received the invalidity signal yielding conclusive evidence that the patent is invalid. Recall that a court will invalidate the patent with certainty in light of this evidence. Hence, the licensee D_i knows that a patent challenge yields the profit of $\pi(0,0) - L^{\mathcal{C}}$ as stated in Equation (4.3). Hence, for every contract offer $\{F, r\}$ yielding a lower profit for the licensee, the licensee will challenge and thereby invalidate the patent. For instance, if the patent holder offers license terms that make licensees indifferent between contract acceptance and patent infringement at the contract acceptance stage, a licensee will challenge the patent if it receives the invalidity signal. Recall from Equation (4.5) that the expected profit from infringing the patent is

$$\theta \cdot \pi(v, r) + (1 - \theta) \cdot \pi(0, 0) - L^{\mathcal{I}}. \tag{4.20}$$

Under Assumption 4.2, it holds that this expected profit is lower than the profit from challenging the patent with certainty about the patent invalidity in Equation (4.3).

Second, the case for a licensee without the invalidity signal is different. Recall that the contract offer has to grant a minimum expected profit (Equation (4.20)) in order to ensure contract acceptance. For a lower expected profit a licensee is not willing to accept the contract. If a licensee does not receive the invalidity signal, it rationally updates its belief about the patent strength and expects the patent to be valid with a probability larger than θ. According to Bayes rule, the conditional probability that the patent is valid if a downstream firm does not receive the invalidity signal is

$$\begin{aligned} P(\text{valid}|i \text{ receives no signal}) &= \frac{P(i \text{ receives no signal}|\text{valid}) \cdot P(\text{valid})}{P(i \text{ receives no signal})} \qquad (4.21) \\ &= \frac{1 \cdot \theta}{1 \cdot \theta + (1 - \theta)\gamma \frac{n-1}{n} + (1 - \theta)(1 - \gamma)} \\ &= \frac{\theta}{1 - (1 - \theta)\frac{1}{n}\gamma} > \theta. \end{aligned}$$

The denominator is smaller than one. Recall that a licensee has to terminate the license contract in order to challenge the patent. Hence, the expected profit of challenging the patent without an invalidity signal is

$$\frac{\theta}{1 - (1 - \theta)\frac{1}{n}\gamma} \cdot \pi(v, r) + \left(1 - \frac{\theta}{1 - (1 - \theta)\frac{1}{n}\gamma}\right) \cdot \pi(0, 0) - L^{\mathcal{CU}}. \tag{4.22}$$

Given that $L^{\mathcal{CU}} \geq L^{\mathcal{I}}$ and the updated beliefs about the patent's validity, this yields a lower expected profit than the expected profit in Equation (4.20), which is the minimal profit level to ensure contract acceptance. Recall that a licensee without additional evidence is assumed to have the same litigation costs $L^{\mathcal{I}}$ as an infringing downstream firm. Hence, whenever a licensee has accepted the contract offer but has not received the invalidity signal, it has no incentive to challenge the patent. This establishes the result. □

Lemma 4.4 (Step 2(a)). *Suppose there is no no-challenge clause. If challenge-avoidance pricing prevails, the patent holder optimally charges the running royalty* $r_{NI}^{nNC} = v$ *and the fixed fee* $F_{NI}^{nNC} = \pi(v, v) - \pi(0, 0) + L^{\mathcal{C}}$ *for all* $\theta \in (0, 1)$.

Proof of Lemma 4.4. Let the superscript nNC indicate that the license contract does not contain a no-challenge clause and let the subscript NI indicate that licensees have financial incentives to not challenge and thereby invalidate the patent even upon receiving the invalidity signal. The patent holder maximizes its profit per downstream firm $G_{NI}^{nNC} = r \cdot x(r,r) + F$ under the constraints that all downstream firms accept the contract:

$$\pi(r,r) - F \geq \theta\pi(v,r) + (1-\theta)\pi(0,0) - L^{\mathcal{I}}, \tag{4.23}$$

and no licensee finds it profitable to challenge the patent even if it gets the invalidity signal:

$$\pi(r,r) - F \geq \pi(0,0) - L^{\mathcal{C}}. \tag{4.24}$$

By Assumption 4.2, Condition (4.24) implies Condition (4.23). This implies that the patent holder's problem is to

$$\begin{aligned} \max_{\{F,r\}} G_{NI}^{nNC} &= r \cdot x(r,r) + F \\ s.t \quad & \pi(r,r) - F \geq \pi(0,0) - L^{\mathcal{C}}. \end{aligned} \tag{4.25}$$

The latter constraint yields an optimal fixed fee of

$$F_{NI}^{nNC} = \pi(r,r) - \pi(0,0) + L^{\mathcal{C}}, \tag{4.26}$$

which makes each licensee indifferent between relying on the license contract and challenging the patent upon receiving the invalidity signal. Inserting the fixed fee from Equation (4.26) in Equation (4.25) yields the following reduced maximization problem for the patent holder:

$$\max_{r} G_{NI}^{nNC} = T(r) - \pi(0,0) + L^{\mathcal{C}}. \tag{4.27}$$

Under Assumption 4.4, G_{NI}^{nNC} is strictly concave in r. As in the above expression only $T(r)$ depends on the running royalty r, this implies that the patent holder sets the running royalty such that it attains the highest possible total profit per downstream firm. According to Assumption 4.4 and the restriction $r \leq v \leq m$, this implies that the ensuing running royalty is $r_{NI}^{nNC} = v$. Inserting $r_{NI}^{nNC} = v$ in Equation (4.26) yields $F_{NI}^{nNC} = \pi(v,v) - \pi(0,0) + L^{\mathcal{C}}$. This establishes the result. □

Lemma 4.5 (Step 2(b)). *Suppose there is no no-challenge clause. If challenge-acceptance pricing prevails, a licensee that receives the invalidity signal challenges the patent. The patent holder optimally sets the running royalty*

$$r_I^{nNC}(\theta) = \begin{cases} v & \text{if } \theta < \theta_V^{nNC}, \\ \bar{r}_I^{nNC}(\theta) & \text{if } \theta \geq \theta_V^{nNC}, \end{cases} \tag{4.28}$$

where the royalty $\bar{r}_I^{nNC}(\theta)$ is implicitly defined by the first-order condition

$$T_1\left(\bar{r}_I^{nNC}(\theta)\right) - \frac{\theta\pi_2\left(v, \bar{r}_I^{nNC}(\theta)\right)}{1-(1-\theta)\gamma} = 0, \tag{4.29}$$

and it decreases in $\theta \in \left(\theta_V^{nNC}, 1\right)$. The threshold value θ_V^{nNC} is defined in Equation (4.38).

The fixed fee is

$$\begin{aligned} F_I^{nNC} &= \pi\left(r_I^{nNC}(\theta), r_I^{nNC}(\theta)\right) \\ &\quad - \frac{\theta\pi\left(v, r_I^{nNC}(\theta)\right) + (1-\theta)(1-\gamma)\pi(0,0) - L^{\mathcal{I}} + (1-\theta)\frac{\gamma}{n}L^{\mathcal{C}}}{1-(1-\theta)\gamma}. \end{aligned} \tag{4.30}$$

Proof of Lemma 4.5. Together with Assumption 4.2, the lemma's requirement that the downstream firms are indifferent between contract acceptance and patent infringement implies that a licensee challenges (and thereby invalidates) the patent upon receiving the invalidity signal. Formally, this implies that the patent holder is only bound by the downstream firms' contract-acceptance constraints and Equation (4.23) holds with equality. Under the same reasoning as above, the condition in Equation (4.24) is therefore violated. We denote the equilibrium outcomes in this case with subscript I. The patent holder's problem is thus:

$$\max_{\{F,r\}} G_I^{nNC} = (1-(1-\theta)\gamma)(r \cdot x(r,r) + F) \tag{4.31}$$

$$\begin{aligned} s.t. \quad & \theta\pi(v,r) + (1-\theta)\pi(0,0) - L^{\mathcal{I}} \\ = \quad & \underbrace{(1-\theta)\gamma\left(\pi(0,0) - L^{\mathcal{C}}/n\right)}_{D_i \text{ exp. profit if patent challenged}} + \underbrace{(1-(1-\theta)\gamma)(\pi(r,r) - F)}_{D_i \text{ exp. profit if patent not challenged}}. \end{aligned} \tag{4.32}$$

If the patent remains valid, which occurs with probability $(1-(1-\theta)\gamma)$, the patent holder realizes a positive profit of $r \cdot x(r,r) + F$. With the complementary probability $(1-\theta)\gamma$, the patent is invalid, one licensee D_i receives the invalidity signal, and the patent is invalidated in court. In this event, the patent holder realizes a profit of zero. The right-hand side of Equation (4.32) contains a licensee's expected profit from accepting the contract. In equilibrium, a licensee is indifferent to its outside option of patent infringement (left-hand side of Equation 4.32).

Suppose a downstream firm expects the other $n-1$ downstream firms to accept the contract offer. The fixed fee that solves Condition (4.32) is

$$F_I^{nNC} = \pi(r,r) - \frac{\theta\pi(v,r) + (1-\theta)(1-\gamma)\pi(0,0) - L^{\mathcal{I}} + (1-\theta)\frac{\gamma}{n}L^{\mathcal{C}}}{1-(1-\theta)\gamma}. \tag{4.33}$$

Inserting F_I^{nNC} in Equation (4.31) yields the patent holder's reduced problem to maximize $G_I^{nNC}(r,\theta)$ with respect to r, where

$$G_I^{nNC}(r,\theta) = (1-(1-\theta)\gamma)\left(T(r) - \frac{\theta\pi(v,r) + (1-\theta)(1-\gamma)\pi(0,0) - L^{\mathcal{I}} + (1-\theta)\frac{\gamma}{n}L^{\mathcal{C}}}{1-(1-\theta)\gamma}\right). \tag{4.34}$$

Under Assumptions 4.3 and 4.4, $G_I^{NC}(r,\theta)$ is strictly concave in r. The first-order condition characterizes the running royalty $\bar{r}_I^{nNC}(\theta)$ that maximizes G_I^{nNC}:

$$G_{I,1}^{nNC}(r,\theta) = T_1\left(\bar{r}_I^{nNC}(\theta)\right) - \frac{\theta}{1-(1-\theta)\gamma}\pi_2\left(v,\bar{r}_I^{nNC}(\theta)\right) = 0, \tag{4.35}$$

which is the term reported in Equation (4.29) in the lemma.

Totally differentiating Equation (4.35) yields

$$\frac{d\bar{r}_I^{nNC}(\theta)}{d\theta} = \frac{(1-\gamma)\pi_2\left(v,\bar{r}_I^{nNC}(\theta)\right)}{(1-(1-\theta)\gamma)^2 G_{I,11}^{nNC}} \leq 0. \tag{4.36}$$

The change of $\bar{r}_I^{nNC}(\theta)$ with respect to θ is weakly negative as (i) $\pi_2(v,r) \geq 0$ under Assumption 4.3 (the inequality is strict if $\pi_2(v,r) > 0$), and (ii) the second-order derivative of the patent holder's profit with respect to the running royalty, $G_{I,11}^{nNC}(r,\theta)$, is negative at $\bar{r}_I^{nNC}(\theta)$ due to Assumptions 4.3 and 4.4.

For a small enough θ, it is possible that the running royalty $\bar{r}_I^{nNC}(\theta)$ implied by Equation 4.35 exceeds the cost savings from the new technology v. Due to the restriction that the running royalty cannot exceed v, there exists a threshold value on the patent strength below which the running royalty equals v, and above which it is determined by the first-order condition in Equation (4.35). The threshold value θ_V^{nNC} is thus defined by

$$T_1(v) - \frac{\theta_V^{nNC}\pi_2(v,v)}{1-(1-\theta_V^{nNC})\gamma} = 0. \tag{4.37}$$

Rearranging yields

$$\theta_V^{nNC} \equiv \frac{(1-\gamma)T_1(v)}{\pi_2(v,v) - \gamma T_1(v)}. \tag{4.38}$$

If the patent strength is below θ_V^{nNC}, the patent holder optimally charges a running royalty equal to the cost savings of the new technology (v). We therefore define the equilibrium running royalty as

$$r_I^{nNC}(\theta) = \begin{cases} v & \text{if } \theta < \theta_V^{nNC}, \\ \bar{r}_I^{nNC}(\theta) & \text{if } \theta \geq \theta_V^{nNC}. \end{cases} \tag{4.39}$$

Inserting the equilibrium running royalty from Equation (4.39) into Equation 4.33 yields the equilibrium fixed fee reported in the lemma. □

Proof of Proposition 4.1 (Step 3). Based on Lemma 4.4 and Lemma 4.5, we compare the profitability of both contract offers for the patent holder. If the patent holder avoids a patent challenge (subscript NI), it offers the contract $r_{NI}^{nNC} = v$ and $F_{NI}^{nNC} = \pi(v, v) - \pi(0, 0) + L^{\mathcal{C}}$ (Lemma 4.4) and its (certain) profit is

$$\begin{aligned} G_{NI}^{nNC} &= vx(v, v) + \pi(v, v) - \pi(0, 0) + L^{\mathcal{C}} \\ &= T(v) - \pi(0, 0) + L^{\mathcal{C}}, \end{aligned} \tag{4.40}$$

which is independent of the patent strength θ and the signal probability γ. Moreover, it holds that this profit is strictly positive as

$$T(v) - \pi(0, 0) + L^{\mathcal{C}} \;>\; T(0) - \pi(0, 0) + L^{\mathcal{C}} = L^{\mathcal{C}} \geq 0, \tag{4.41}$$

where the first inequality follows from the fact that $T(r)$ increases in the interval $[0, v]$, and the equality follows from $T(0) = \pi(0, 0)$ as there is no double marginalization at $r = 0$.

The expected profit that the patent holder obtains if it does not disincentivize a patent challenge when a downstream firm learns about the invalidity (subscript I, see Equation (4.34) in Lemma 4.5) is

$$\begin{aligned} & G_{I}^{nNC}\left(r_{I}^{nNC}(\theta), \theta\right) \\ =\; & (1 - (1 - \theta)\gamma) T\left(r_{I}^{nNC}(\theta)\right) \\ -\; & \left(\theta\pi\left(v, r_{I}^{nNC}(\theta)\right) + (1 - \theta)(1 - \gamma)\pi(0, 0) - L^{\mathcal{I}} + (1 - \theta)\frac{\gamma}{n}L^{\mathcal{C}}\right). \end{aligned} \tag{4.42}$$

The equilibrium profit $G_{I}^{nNC}\left(r_{I}^{nNC}(\theta), \theta\right)$ in Equation (4.42) changes in θ according to

$$\underbrace{\frac{\partial G_{I}^{nNC}\left(r_{I}^{nNC}(\theta), \theta\right)}{\partial r_{I}^{nNC}(\theta)} \frac{\partial r^{nNC}(\theta)}{\partial \theta}}_{=0} + \frac{\partial G_{I}^{nNC}\left(r_{I}^{nNC}(\theta), \theta\right)}{\partial \theta}. \tag{4.43}$$

Note that the first term $\left(\partial G_{I}^{nNC}\left(r_{I}^{nNC}(\theta), \theta\right) / \partial r_{I}^{nNC}(\theta)\right)$ is equal to zero, whenever the equilibrium running royalty $r_{I}^{nNC}(\theta)$ is determined by the patent holder's first-order condition, as is the case for $\theta > \theta_{V}^{nNC}$. Moreover, the second term $\left(\partial r_{I}^{nNC}(\theta) / \partial \theta\right)$ is zero for $\theta \leq \theta_{V}^{nNC}$ as then the running royalty is invariant to θ and equal to v. Hence, the total change of G_{I}^{nNC} in θ is given by the partial derivative

$$\begin{aligned} & \frac{\partial G_{I}^{nNC}\left(r_{I}^{nNC}(\theta), \theta\right)}{\partial \theta} \\ =\; & \gamma\left(T\left(r_{I}^{nNC}(\theta)\right) - \pi(0, 0)\right) + \pi(0, 0) - \pi\left(v, r_{I}^{nNC}(\theta)\right) + \frac{\gamma}{n}L^{\mathcal{C}}, \end{aligned} \tag{4.44}$$

which is larger than zero for all $\theta \in (0,1)$. To see this note that (i) $T\left(r_I^{nNC}(\theta)\right) - \pi(0,0) = T\left(r_I^{nNC}(\theta)\right) - T(0) > 0$, (ii) $\pi(0,0) > \pi\left(v, r_I^{nNC}(\theta)\right)$, and (iii) $L^{\mathcal{C}} \geq 0$. Hence, the patent holder's profit $G_I^{nNC}\left(r_I^{nNC}(\theta), \theta\right)$ increases in θ.

Toward establishing which contract offer is optimal for the patent holder, note from the above that:

- $G_I^{nNC}\left(r_I^{nNC}(\theta), \theta\right)$ increases monotonically in θ, and
- G_{NI}^{nNC} is constant in θ.

Given the monotonicity of $G_I^{nNC}\left(r_I^{nNC}(\theta), \theta\right)$, there is at most one intersection in the relevant range $\theta \in (0,1)$. We show that there are two cases to be distinguished:

1. $G_I^{nNC}\left(r_I^{nNC}(\theta), \theta\right)$ is larger than G_{NI}^{nNC} for all $\theta \in (0,1)$.
2. $G_I^{nNC}\left(r_I^{nNC}(\theta), \theta\right)$ and G_{NI}^{nNC} intersect once in $\theta \in (0,1)$. Call the intersection $\tilde{\theta}$. This implies that $G_I^{nNC}\left(r_I^{nNC}(\theta), \theta\right) < G_{NI}^{nNC}$ for $\theta < \tilde{\theta}$, and greater otherwise.

We first establish that it is profitable to avoid a patent challenge for weak patents ($G_{NI}^{nNC} > G_I^{nNC}$ for $\theta \to 0$). For $\theta \to 0$, Equation (4.42) becomes

$$G_I^{nNC}\left(r_I^{nNC}(0), 0\right) = (1-\gamma)\left(T(v) - \pi(0,0)\right) + L^{\mathcal{I}}. \tag{4.45}$$

Recall that $r_I^{nNC}(0) = v$ and $L^{\mathcal{C}} = 0$ due to Assumption 4.2. At $\theta \to 0$, the condition $G_{NI}^{nNC} > G_I^{nNC}$ implies

$$\gamma > \frac{L^{\mathcal{I}}}{T(v) - \pi(0,0)}. \tag{4.46}$$

Next, we show that for $\theta \to 1$ it is never profitable for the patent holder to offer the contract G_{NI}^{nNC}. First note that, for $\theta \to 1$, it must be that $L^{\mathcal{I}} = 0$ as otherwise patent infringement is not the relevant outside option (Assumption 4.1). Equation (4.42) therefore becomes

$$G_I^{nNC}\left(r_I^{nNC}(1), 1\right) = T\left(r_I^{nNC}(1)\right) - \pi\left(v, r_I^{nNC}(1)\right).$$

With $\theta \to 1$, the condition $G_I^{nNC} > G_{NI}^{nNC}$ holds if

$$\begin{aligned} & T(v) - \pi(0,0) + L^{\mathcal{C}} < T\left(r_I^{nNC}(1)\right) - \pi\left(v, r_I^{nNC}(1)\right) \\ \Rightarrow \quad & \left[T(v) - \pi(v,v)\right] + L^{\mathcal{C}} < \left[T\left(r_I^{nNC}(1)\right) - \pi\left(v, r_I^{nNC}(1)\right)\right] + \left[\pi(0,0) - \pi(v,v)\right], \end{aligned} \tag{4.47}$$

where the second line follows from subtracting $\pi(v,v)$ on both sides of Equation (4.47). We compare the terms on both sides of the inequality and note that it holds for the following reasons:

- As $r_I^{nNC}(1) \in \arg\max_r \; T(r) - \pi(v,r)$ it holds that $T(v) - \pi(v,v) < T\left(r_I^{nNC}(1)\right) - \pi\left(v, r_I^{nNC}(1)\right)$ if $r_I^{nNC}(1) < v$. Note that the last inequality holds if $\pi_2(v,r) > 0$.
- By Assumption 4.2, the litigation costs $L^{\mathcal{C}}$ are smaller than $\pi(0,0) - \pi(v,v)$.

The left-hand side of the condition in Equation (4.47) is thus strictly smaller than the right-hand side. It follows that for $\theta \to 1$, $G_I^{nNC} > G_{NI}^{nNC}$.

Returning to the case distinction, we conclude that the first case $G_I^{nNC} > G_{NI}^{nNC}$, $\theta \in (0,1)$ applies if the condition in Equation (4.46) is violated. In contrast, if the condition in Equation (4.46) holds, the second case applies. In the second case, there exists a threshold value $\tilde{\theta} \in (0,1)$ such that the patent holder profitably avoids a patent challenge if $\theta < \tilde{\theta}$. The threshold value is defined by

$$G_I^{nNC}\left(r_I^{nNC}\left(\tilde{\theta}\right), \tilde{\theta}\right) = G_{NI}^{nNC}. \tag{4.48}$$

Note that the condition in Equation (4.46) is reported in Proposition 4.1. This establishes the result. □

Proof of Lemma 4.1

Proof. We prove that the running royalty $r^{NC}(\theta)$ weakly decreases in θ in the range $\theta > \theta_V^{NC}$, where the running royalty is defined by the first-order condition in Equation (4.9). The remaining results of the lemma are derived in the main text above the lemma.

Total differentiation of Equation (4.9) yields the comparative static

$$\frac{dr^{NC}(\theta)}{d\theta} = \pi_2\left(v, r^{NC}(\theta)\right) / G_{11}^{NC}\left(r^{NC}(\theta), \theta\right) \leq 0. \tag{4.49}$$

In the range $\theta > \theta_V^{NC}$, the change of $r^{NC}(\theta)$ with respect to θ is negative as (i) $\pi_2(v,r) \geq 0$ under Assumption 4.3, and (ii) the second-order derivative of the patent holder's profit with respect to the running royalty, $G_{11}^{NC}(r,\theta)$, is negative at $r^{NC}(\theta)$ due to Assumptions 4.3 and 4.4. This establishes the result. □

Proof of Proposition 4.3

Proof. We prove the result by separating the range of $\theta \in (0,1)$ in three intervals.

1. First, for a small $\theta \in \left(0, \theta_V^{nNC}\right]$, both running royalties, with and without a no-challenge clause, are equal to the cost savings of the new technology: $r_I^{nNC}(\theta) = r^{NC}(\theta) = v$.

2. Second, there exists an intermediate interval $\theta \in \left(\theta_V^{nNC}, \theta_V^{NC}\right]$ of patent strengths θ in which $r_I^{nNC}(\theta) < r^{NC}(\theta) = v$.

3. Third, for a large θ, both running royalties are strictly smaller than v, but it still holds that $r_I^{nNC}(\theta) < r^{NC}(\theta)$.

The **first step** is to show that $r_I^{nNC}(\theta) = r^{NC}(\theta) = v$ in the interval $\theta \in \left(0, \theta_V^{nNC}\right]$. The threshold value θ_V^{nNC} is defined in Equation (4.29) in Lemma 4.5, and for $\theta < \theta_V^{nNC}$, it holds that $r_I^{nNC} = v$. We verify that $\theta_V^{nNC} < \theta_V^{NC}$ for $\gamma > 0$. This argument has three steps.

1. Note that θ_V^{NC} is constant in γ (Equation (4.10)).

2. We show that $\theta_V^{nNC} = \theta_V^{NC}$ at the endpoint of $\gamma = 0$.

3. We show that θ_V^{nNC} decreases monotonically in $\gamma \in (0, 1)$.

From the first-order condition in Equation (4.29) in Lemma 4.5, the threshold value θ_V^{nNC} is defined by

$$T_1(v) - \frac{\theta_V^{nNC} \pi_2(v, v)}{1 - \left(1 - \theta_V^{nNC}\right)\gamma} = 0. \tag{4.50}$$

Rearranging yields the expression

$$\theta_V^{nNC} = \frac{(1-\gamma)\, T_1(v)}{\pi_2(v, v) - \gamma T_1(v)}, \tag{4.51}$$

which is also reported in Equation (4.38).

Note that for $\gamma = 0$, the threshold value equals the one from the case with a no-challenge clause, that is, $\theta_V^{nNC} = \theta_V^{NC} = T_1(v) / \pi_2(v, v)$ (Equation (4.10)). The derivative of $\theta_V^{nNC}(\gamma)$ with respect to γ is

$$\begin{aligned} \frac{\partial \theta_V^{nNC}(\gamma)}{\partial \gamma} &= \frac{-T_1(v)\left(\pi_2(v, v) - \gamma T_1(v)\right) - (1-\gamma)\, T_1(v)\left(-T_1(v)\right)}{\left(\pi_2(v, v) - \gamma T_1(v)\right)^2} \\ &= \frac{T_1(v)\left(T_1(v) - \pi_2(v, v)\right)}{\left(\pi_2(v, v) - \gamma T_1(v)\right)^2} < 0. \end{aligned} \tag{4.52}$$

The derivative is negative because $T_1(v) < \pi_2(v, v)$, which follows from the first-order condition in Equation (4.35). The fact that the derivative is negative implies that $\theta_V^{nNC}(\gamma)$ decreases monotonically in γ.

The **second step** applies to the intermediate interval of $\theta \in \left(\theta_V^{nNC}, \theta_V^{NC}\right]$. In this interval, under the definition of θ_V^{NC} (Equation (4.10)) and θ_V^{nNC} (Equation (4.38)), the running royalty $r_I^{nNC}(\theta)$ is strictly below v and $r^{NC}(\theta)$ is equal to v. This implies that $r_I^{nNC}(\theta) < r^{NC}(\theta) = v$ for $\theta \in \left(\theta_V^{nNC}, \theta_V^{NC}\right]$.

The **last step** applies to the case of patents with strength $\theta \in \left(\theta_V^{NC}, 1\right)$. In this range, both running royalties $r_I^{nNC}(\theta)$ and $r^{NC}(\theta)$ are determined by the patent holder's respective first-order condition (Equations (4.9) and (4.29)):

$$\begin{aligned} T_1\left(r^{NC}(\theta)\right) & -\theta \cdot \pi_2\left(v, r^{NC}(\theta)\right) = & 0, \qquad (4.53)\\ (1-(1-\theta)\gamma)\cdot T_1\left(r_I^{nNC}(\theta)\right) & -\theta \cdot \pi_2\left(v, r_I^{nNC}(\theta)\right) = & 0. \qquad (4.54)\end{aligned}$$

Note that the first-order condition in Equation (4.54), evaluated at the running royalty r^{NC} that solves Equation (4.53), collapses to $-(1-\theta)\cdot\gamma\cdot T_1\left(r_I^{nNC}(\theta)\right) < 0$. Hence, the patent holder has an incentive to charge a lower running royalty than r^{NC} absent a no-challenge clause. Together with Assumption 4.3, which ensures a unique solution to the patent holder's maximization problem, we conclude that $r_I^{nNC}(\theta) < r^{NC}(\theta)$ in the interval $\theta \in \theta_V^{NC}(0,1)$. This establishes the result. □

Proof of Proposition 4.4

Proof. We verify that it is always profitable for the patent holder to insert a no-challenge clause in the license contract if possible. To this end, we compare the patent holder's equilibrium contract for the cases with and without a no-challenge clause. For the interval $\theta \in \left(0, \theta^{nNC}\right]$, we have $r^{NC}(\theta) = r_I^{nNC}(\theta) = r_{NI}^{nNC}(\theta) = v$. The patent holder's profit without a no-challenge clause is

$$T(v) - \left(\pi(0,0) - L^{\mathcal{C}}\right), \qquad (4.55)$$

if it prevents patent invalidation and

$$(1-(1-\theta)\gamma)\,T(v) - \left(\theta\pi(v,v) + (1-\theta)\,\pi(0,0) - L^{\mathcal{I}}\right), \qquad (4.56)$$

if it does not. If the contract specifies a no-challenge clause, the patent holder's profit is

$$T(v) - \left(\theta\pi(v,v) + (1-\theta)\,\pi(0,0) - L^{\mathcal{I}}\right). \qquad (4.57)$$

The profit level in (4.57) is larger than the profit levels in Equations (4.55) and (4.56). First note that $\pi(0,0) - L^{\mathcal{C}} > \theta\pi(v,v) + (1-\theta)\,\pi(0,0) - L^{\mathcal{I}}$ by Assumption 4.2 which implies that the profit in (4.57) is larger than the one in (4.55). Second, the only difference between the profit levels in Equations (4.56) and (4.57) is the invalidation probability $(1-\theta)\,\gamma$ and hence the patent holder realizes a higher profit in (4.57) than in (4.56).

Next, consider the interval $\theta \in \left(\theta^{nNC}, 1\right)$. Suppose first that it is profitable for the supplier to restrict invalidation of the patent absent a no-challenge clause. If the patent holder can implement a no-challenge clause, its profit is

$$T\left(r^{NC}(\theta)\right)-\left(\theta\pi\left(v,r^{NC}(\theta)\right)+(1-\theta)\pi(0,0)-L^{\mathcal{I}}\right). \tag{4.58}$$

By revealed preferences, the patent holder prefers to charge a running royalty of $r^{NC}<v$ instead of v and its profit is thus larger than $T(v)-\left(\theta\pi(v,v)+(1-\theta)\pi(0,0)-L^{\mathcal{I}}\right)$. Moreover, the latter profit is larger than $T(v)-\left(\pi(0,0)-L^{\mathcal{C}}\right)$, which is the profit from preventing invalidation by means of licensing fees.

Second, suppose that it is not profitable for the supplier to restrict invalidation of the patent. Recall that in this interval $r_I^{nNC}(\theta)<r^{NC}(\theta)\leq v$. Then, the profit without a no-challenge clause is

$$\begin{aligned}&(1-(1-\theta)\gamma)\,T\left(r_I^{nNC}(\theta)\right)\\-\;&\left(\theta\pi\left(v,r_I^{nNC}(\theta)\right)+(1-\theta)\pi(0,0)-L^{\mathcal{I}}-(1-\theta)\gamma\left(\pi(0,0)-L^{\mathcal{C}}\right)\right).\end{aligned} \tag{4.59}$$

Note that a no-challenge clause corresponds to $\gamma=0$ and that this changes the patent holder's profit to

$$T\left(r_I^{nNC}(\theta)\right)-\left(\theta\pi\left(v,r_I^{nNC}(\theta)\right)+(1-\theta)\pi(0,0)-L^{\mathcal{I}}\right), \tag{4.60}$$

holding the running royalty fixed at $r^{nNC}(\theta)$. This change increases the profit by $(1-\theta)\gamma T\left(r_I^{nNC}(\theta)\right)$ and decreases the profit by $(1-\theta)\gamma\left(\pi(0,0)-L^{\mathcal{C}}\right)$. Due to the fact that

$$T\left(r_I^{nNC}(\theta)\right)>T(0)=0\cdot x(0,0)+\pi(0,0)\geq\pi(0,0)-L^{\mathcal{C}}, \tag{4.61}$$

it holds that the increase in profit outweighs the decrease. Moreover, by revealed preferences to charge a running royalty of r^{NC} instead of $r_I^{nNC}(\theta)$ and it thus holds that

$$\begin{aligned}&T\left(r^{NC}(\theta)\right)-\left(\theta\pi\left(v,r^{NC}(\theta)\right)+(1-\theta)\pi(0,0)-L^{\mathcal{I}}\right)\\>\;&T\left(r_I^{nNC}(\theta)\right)-\left(\theta\pi\left(v,r_I^{nNC}(\theta)\right)+(1-\theta)\pi(0,0)-L^{\mathcal{I}}\right).\end{aligned} \tag{4.62}$$

Hence, we conclude that the patent holder prefers to insert a no-challenge clause in the license contract for any patent strength $\theta\in(0,1)$. This establishes the result. □

Appendix B: Linear License Contracts

Proof of Lemma 4.2

Proof. Recall that the patent holder's objective function is $R^{NC}(s) = s \cdot x(s,s) = T(s) - \pi(s,s)$. The pure running royalty that maximizes the unconstrained maximization problem of the patent holder solves the first-order condition

$$R_1^{NC}(s) = T_1(s) - (\pi_1(s,s) + \pi_2(s,s)) = 0. \tag{4.63}$$

Denote with s^* the optimal pure running royalty implicitly defined by Equation (4.63). Note that the first derivative of R^{NC}, evaluated at the monopoly running royalty m, is

$$R_1^{NC}(m) = -(\pi_1(m,m) + \pi_2(m,m)) > 0, \tag{4.64}$$

which is positive under the assumption that $\pi_1(a,a) + \pi_2(a,a) < 0$. Due to the fact that $R^{NC}(s)$ is single-peaked, this implies that $s^* > m$, which establishes the result. □

Proof of Proposition 4.6

We prove Proposition 4.6 in five steps. In the section with linear tariffs, it is necessary to allow for litigation costs for a patent challenge $L^{\mathcal{C}}$ that violate Assumption 4.2. The reason is that the prevalence of challenge-avoidance pricing depends more directly on the litigation costs for a patent challenge $L^{\mathcal{C}}$ than in the main model with two-part tariffs. Moreover, we will characterize both potential best alternatives to contract acceptance: (i) infringement and (ii) using the old technology.

1. As a preliminary result, we first characterize the range of patent strengths θ for which the introduction of a no-challenge clause changes the license outcome. The range depends on $L^{\mathcal{C}}$.

2. We characterize the optimal contract offer for which licensees do not challenge the patent. This occurs either because litigation costs for a patent challenge $L^{\mathcal{C}}$ are prohibitively large or because the license contract includes a no-challenge clause.

The next steps focus on contracts without a no-challenge clause:

3. We characterize the contract for which a licensee that obtains the invalidity signal challenges the patent (challenge-avoidance pricing).

4. We characterize the contract that financially ensures that no licensee has the incentive to do so (challenge-acceptance pricing).

5. We compare the patent holder's profits with both challenge-avoidance and challenge-acceptance pricing to derive the threshold value on the patent strength above which the patent holder prefers to accept a positive invalidation risk.

Lemma 4.6 (Step 1)**.** *If the patent strength θ satisfies*

$$\theta \;>\; \underline{\theta} = \frac{L^{\mathcal{C}} - L^{\mathcal{I}}}{\pi(0,0) - \pi(v,s)}, \tag{4.65}$$

a patent challenge yields higher profit than the expected profit from patent infringement. For $\theta \leq \underline{\theta}$, licensees do not have an incentive to challenge the patent after contract acceptance and Assumption 4.2 is violated.

Proof of Lemma 4.6. For given litigation costs $L^{\mathcal{C}}$ and $L^{\mathcal{I}}$, there can exist a range of patent strengths θ for which a patent challenge yields a lower profit than the minimum profit level that ensures contract acceptance. In particular, a patent challenge yields lower profit than patent infringement if

$$\pi(0,0) - L^{\mathcal{C}} \;\leq\; \theta\pi(v,s) + (1-\theta)\,\pi(0,0) - L^{\mathcal{I}}. \tag{4.66}$$

The condition holds for

$$\theta \leq \underline{\theta} = \frac{L^{\mathcal{C}} - L^{\mathcal{I}}}{\pi(0,0) - \pi(v,s)}. \tag{4.67}$$

If $\underline{\theta} < 0$, a patent challenge yields higher profit than the (expected) profit from patent infringement for all $\theta \in (0,1)$. For $\underline{\theta} > 1$, the litigation costs for a patent challenge $L^{\mathcal{C}}$ are prohibitively high, such that patent infringement yields higher profit than a patent challenge independent of how strong the patent is. Assumption 4.2 is violated in the interval $\theta \in (0, \underline{\theta}]$. This establishes the result. □

Lemma 4.7 (Step 2)**.** *Suppose the patent holder is restricted to a linear license tariff and includes a no-challenge clause (or the costs of a patent challenge $L^{\mathcal{C}}$ are prohibitively high). The optimal running royalty is*

$$s^{NC}(\theta) = \begin{cases} \bar{s}^{NC}(\theta) & \text{if } \theta < \tilde{\theta}_V^{NC}, \\ v & \text{if } \theta \geq \tilde{\theta}_V^{NC}, \end{cases} \tag{4.68}$$

where $\bar{s}^{NC}(\theta)$ is implicitly defined in Equation (4.69) and increases in θ. The threshold value $\tilde{\theta}_V^{NC}$ is defined in Equation (4.71).

Proof of Lemma 4.7. Suppose that a patent challenge is not feasible or is prohibitively costly after contract acceptance. We characterize the contract for both potential outside options at the contract acceptance stage: patent infringement and using the old technology. Denote by $\bar{s}^{NC}(\theta)$ the pure running royalty that makes a downstream firm indifferent between contract acceptance and its outside option of patent infringement:

$$\pi\left(\bar{s}^{NC}(\theta), \bar{s}^{NC}(\theta)\right) = \theta\pi\left(v, \bar{s}^{NC}(\theta)\right) + (1-\theta)\pi(0,0) - L^{\mathcal{I}}. \tag{4.69}$$

Implicit differentiation of Equation (4.69) yields

$$\frac{d\bar{s}^{NC}(\theta)}{d\theta} = -\frac{\pi(0,0) - \pi\left(v, \bar{s}^{NC}(\theta)\right)}{\pi_1\left(\bar{s}^{NC}(\theta), \bar{s}^{NC}(\theta)\right) + \pi_2\left(\bar{s}^{NC}(\theta), \bar{s}^{NC}(\theta)\right) - \theta\pi_2\left(v, \bar{s}^{NC}(\theta)\right)} > 0. \tag{4.70}$$

The denominator is negative due to the assumptions that $\pi_2(a,b) > 0$ and $\pi_1(a,a) + \pi_2(a,a) < 0$. The nominator is positive as $\pi(0,0) > \pi\left(v, \bar{s}^{NC}(\theta)\right)$. Taken together, these observations imply that the running royalty $\bar{s}^{NC}(\theta)$ increases in θ if it is implicitly defined by (4.69).

We now characterize the running royalty if using the old technology instead of patent infringement is the relevant outside option. With positive litigation costs of patent infringement ($L^{\mathcal{I}}$), there exists a threshold on the patent strength such that using the old technology is the relevant outside option for the downstream firm above this threshold. Define this threshold value at which patent infringement and using the old technology yield the same (expected) profit for the downstream firms as

$$\tilde{\theta}_V^{NC} = 1 - \frac{L^{\mathcal{I}}}{\pi(0,0) - \pi(v,v)}. \tag{4.71}$$

For $\theta < \tilde{\theta}_V^{NC}$, the running royalty is implicitly defined by Equation (4.69). Otherwise, using the old technology is the relevant outside option and the patent holder sets the running royalty equal to v, the cost savings from the new technology as in this case. Define

$$s^{NC}(\theta) = \begin{cases} \bar{s}^{NC}(\theta) & \text{if } \theta < \tilde{\theta}_V^{NC}, \\ v & \text{if } \theta \geq \tilde{\theta}_V^{NC}. \end{cases} \tag{4.72}$$

This establishes the result. □

Lemma 4.8 (Step 3)**.** *Suppose the patent holder is restricted to a linear license tariff absent a no-challenge clause. If challenge-acceptance pricing prevails, the optimal running royalty is*

$$s_I^{nNC}(\theta) = \begin{cases} \bar{s}_I^{nNC}(\theta) & \textit{if } \theta < \tilde{\theta}_V^{nNC}, \\ v & \textit{if } \theta \geq \tilde{\theta}_V^{nNC}, \end{cases} \tag{4.73}$$

where $\bar{s}_I^{nNC}(\theta)$ is implicitly defined in Equation (4.75) and increases in θ. The threshold value $\tilde{\theta}_V^{nNC}$ defined in Eq. (4.77). Moreover, it holds that $\tilde{\theta}_V^{nNC} < \tilde{\theta}_V^{NC}$.

Proof of Lemma 4.8. We characterize the contract for both potential outside options at the contract acceptance stage: patent infringement and using the old technology. We focus on $\theta > \underline{\theta}$ (threshold defined in Lemma 4.6), such that a patent challenge can alter the license outcome. If a licensee challenges the patent upon receiving the invalidity signal, the patent holder obtains the expected profit

$$\begin{aligned} R_I(s) &= (1-(1-\theta)\gamma)\, s \cdot x(s,s) \\ &= (1-(1-\theta)\gamma)\,(T(s) - \pi(s,s)), \end{aligned} \tag{4.74}$$

where I stands for the case absent a no-challenge clause in which a licensee challenges and invalidates the patent upon receiving the invalidity signal. Due to the fact that the only difference to the objective function $R(s)$ in Equation (4.18) is the pre-multiplied term $(1-(1-\theta)\gamma)$, we conclude that also R_I is single-peaked in s and the unconstrained solution to the patent holder's maximization problem exceeds the monopoly running royalty, as derived in Lemma 4.2.

Suppose first that patent infringement is the relevant outside option to contract acceptance for the downstream firms. Accordingly, denote the running royalty $\bar{s}_I^{nNC}(\theta)$ that ensures that the downstream firms are willing to accept the contract offer

$$\begin{aligned} & (1-(1-\theta)\gamma)\,\pi\left(\bar{s}_I^{nNC}(\theta), \bar{s}_I^{nNC}(\theta)\right) + (1-\theta)\gamma\left(\pi(0,0) - \frac{L^{\mathcal{C}}}{n}\right) \\ = \;& \theta\pi\left(v, \bar{s}_I^{nNC}(\theta)\right) + (1-\theta)\,\pi(0,0) - L^{\mathcal{I}}, \end{aligned} \tag{4.75}$$

where the first line is the expected profit of contract acceptance and second line the outside option of patent infringement. Recall that a licensee has an incentive to challenge the patent if it receives the invalidity signal in this case as $\theta > \underline{\theta}$.

First, we show that the running royalty $\bar{s}_I^{nNC}(\theta)$ implied by Equation (4.75) increases monotonically in θ. Note that this royalty increases in $L^{\mathcal{I}}$ because it reduces the outside option, and decreases in $L^{\mathcal{C}}$ because it reduces the expected profit from contract acceptance. Moreover, implicit differentiation of Equation (4.75) yields

$$\begin{aligned} &\frac{d\bar{s}_I^{nNC}(\theta)}{d\theta} = \\ &-\frac{\gamma\pi\left(\bar{s}_I^{nNC}(\theta), \bar{s}_I^{nNC}(\theta)\right) + (1-\gamma)\,\pi(0,0) - \pi\left(v, \bar{s}_I^{nNC}(\theta)\right) + \frac{\gamma}{n}L^{\mathcal{C}}}{(1-(1-\theta)\gamma)\left(\pi_1\left(\bar{s}_I^{nNC}(\theta), \bar{s}_I^{nNC}(\theta)\right) + \pi_2\left(\bar{s}_I^{nNC}(\theta), \bar{s}_I^{nNC}(\theta)\right)\right) - \theta\pi_2\left(v, \bar{s}_I^{nNC}(\theta)\right)} > 0. \end{aligned} \tag{4.76}$$

The denominator is negative due to the assumption that $\pi_2(a,b) > 0$ and $\pi_1(a,a) + \pi_2(a,a) < 0$. The nominator is positive as the convex combination of $\pi\left(s_I^{nNC}(\theta), s_I^{nNC}(\theta)\right)$

and $\pi(0,0)$ is larger than $\pi\left(v, s^{NC}(\theta)\right)$ for all $\gamma \in (0,1)$, and the litigation costs $L^{\mathcal{C}}$ are also (weakly) positive. This implies that the pure running royalty $\bar{s}_I^{nNC}(\theta)$ increases in θ.

Next, consider that using the old technology is the relevant outside option. For $L^{\mathcal{I}} > 0$, there exists a threshold value such that patent infringement and using the old technology yield the same (expected) profit. Define this threshold as

$$\tilde{\theta}_V^{nNC} = 1 - \frac{L^{\mathcal{I}}}{(1-\gamma)(\pi(0,0) - \pi(v,v))}. \tag{4.77}$$

Below this threshold value $\left(\theta < \tilde{\theta}_V^{nNC}\right)$, the pure running royalty is implicitly defined by Equation (4.69). Otherwise, the patent holder optimally sets the pure running royalty equal to the cost savings from the new technology v as in this case using the old technology is the relevant outside option. Define

$$s_I^{nNC}(\theta) = \begin{cases} \bar{s}_I^{nNC}(\theta) & \text{if } \theta < \tilde{\theta}_V^{nNC}, \\ v & \text{if } \theta \geq \tilde{\theta}_V^{nNC}. \end{cases} \tag{4.78}$$

Last, we assess how $\tilde{\theta}_V^{nNC}$ changes in the signal probability γ. Comparing $\tilde{\theta}_V^{nNC}$ with the threshold value $\tilde{\theta}_V^{NC}$ defined in Equation (4.71) yields $\tilde{\theta}_V^{nNC} < \tilde{\theta}_V^{NC}$ for $\gamma \in (0,1)$. This establishes the result. □

Lemma 4.9 (Step 4)**.** *Suppose the patent holder is restricted to a linear license tariff absent a no-challenge clause. If challenge-avoidance pricing prevails and if $\theta > \underline{\theta}$ (defined in Lemma 4.6), the running royalty s_{NI}^{nNC} solves Equation (4.79) with equality, is independent of θ, and increases in $L^{\mathcal{C}}$.*

Proof of Lemma 4.9. As derived in Lemma 4.6, only for $\theta > \underline{\theta}$ a patent challenge can alter the license outcome. A downstream firm, which has obtained the invalidity signal, decides to not challenge the patent if

$$\pi(0,0) - L^{\mathcal{C}} \leq \pi(s,s). \tag{4.79}$$

The optimal running royalty s_{NI}^{nNC} solves (4.79) with equality and is independent of the patent strength θ. If licensees do not incur litigation costs when challenging the patent $\left(L^{\mathcal{C}} = 0\right)$, the patent holder is not able to enforce running royalties above zero. As $\pi(s,s)$ decreases in s, the equilibrium running royalty s_{NI}^{nNC} increases in $L^{\mathcal{C}}$. This establishes the result. □

Proof of Proposition 4.6 (Step 5). We characterize a licensee's challenge decision for the three intervals of θ defined in the proposition in turn.

First interval: For $\theta < \underline{\theta}$ (defined in Lemma 4.6), the patent holder optimally behaves as if the license contract contains a no-challenge clause, charges $s = s^{NC}$ as characterized in Lemma 4.7, and realizes a profit of

$$R^{NC}\left(s^{NC}(\theta)\right) = s^{NC} \cdot x\left(s^{NC}(\theta), s^{NC}(\theta)\right). \tag{4.80}$$

For $\theta \geq \underline{\theta}$, a patent challenge yields higher profits than the expected profit from contract acceptance. If $\underline{\theta} < 1$, the patent holder has to decide whether to avoid a patent challenge or not. We show that two cases can arise in this interval:

- Case 1: Challenge-avoidance pricing never occurs.
- Case 2: Challenge avoidance pricing occurs in an intermediate interval of patent strengths and for stronger patents the patent holder engages in challenge-acceptance pricing.

First, we characterize the case in which challenge-avoidance pricing never occurs. The patent holder's profit in the case of challenge avoidance is

$$R_{NI}^{nNC}\left(s_{NI}^{nNC}\right) = s_{NI}^{nNC} \cdot x\left(s_{NI}^{nNC}, s_{NI}^{nNC}\right), \tag{4.81}$$

which is independent of the patent strength θ. Moreover, the patent holder's profit from challenge-acceptance pricing

$$R_{I}^{nNC}\left(s_{I}^{nNC}(\theta);\theta\right) = \left(1-(1-\theta)\gamma\right) s_{I}^{nNC}(\theta) \cdot x\left(s_{I}^{nNC}, s_{I}^{nNC}\right), \tag{4.82}$$

which (weakly) increases in θ. This profit changes in θ according to

$$\frac{R_{I}^{nNC}\left(s_{I}^{nNC}(\theta);\theta\right)}{\partial\theta} = \gamma R^{NC}\left(s_{I}^{nNC}(\theta)\right) + \left(1-(1-\theta)\gamma\right) \frac{\partial R^{NC}\left(s_{I}^{nNC}(\theta)\right)}{\partial s_{I}^{nNC}} \frac{\partial s_{I}^{nNC}(\theta)}{\partial\theta} \geq 0. \tag{4.83}$$

The derivative in Equation (4.83) is positive due to the fact that $\partial s_{I}^{nNC}(\theta)/\partial\theta \geq 0$ (derived in Lemma 4.8) and $\partial R^{NC}\left(s_{I}^{nNC}(\theta)\right)/\partial s_{I}^{nNC} > 0$ (Lemma 4.2 together with the assumption that $s \cdot x(s,s)$ is single-peaked on the relevant range). This implies that if challenge-acceptance pricing is more profitable than challenge-avoidance pricing for at $\theta = \underline{\theta}$, it also holds for the entire range of θ that the patent holder does not engage in patent-avoidance pricing.

Formally, challenge-avoidance pricing does not occur if

$$\begin{aligned} R_{NI}^{nNC}\left(s_{NI}^{nNC}\right) &= s_{NI}^{nNC} \cdot x\left(s_{NI}^{nNC}, s_{NI}^{nNC}\right) \\ &< \left(1-(1-\underline{\theta})\gamma\right)\left(s_{I}^{nNC}(\underline{\theta}) \cdot x\left(s_{I}^{nNC}(\underline{\theta}), s_{I}^{nNC}(\underline{\theta})\right)\right) = R_{I}^{nNC}\left(s_{I}^{nNC}(\underline{\theta})\right). \end{aligned} \tag{4.84}$$

If this condition does not hold, there exists a range of patent strengths $\theta > \underline{\theta}$ such that the patent holder engages in challenge-avoidance pricing.

The case distinction depends on the litigation costs for a patent challenge ($L^{\mathcal{C}}$). Recall from Lemma 4.9 that s_{NI}^{nNC} increases in $L^{\mathcal{C}}$ as long at it is below v. In particular, Equation (4.79) shows that s_{NI}^{nNC} approaches v if $L^{\mathcal{C}} \to \pi(0,0) - \pi(v,v)$. Due to the fact that $s_{I}^{nNC}(\theta)$ can be at most equal to v (the cost savings of the new technology), we conclude that Condition (4.84) is violated for high litigation costs $L^{\mathcal{C}}$. If $s_{I}^{nNC}(\underline{\theta}) \leq s_{NI}^{nNC} = v$, it holds that $R_{NI}^{nNC}\left(s_{NI}^{nNC}\right) > R_{I}^{nNC}\left(s_{I}^{nNC}(\underline{\theta})\right)$ due to the fact there is no invalidation risk in the challenge-avoidance case and a (weakly) higher royalty rate increases the patent holder's profit. By continuity in $L^{\mathcal{C}}$, the condition also holds for a range of litigation costs of a patent challenge below $\pi(0,0) - \pi(v,v)$. Denote by $\underline{\mathrm{L}}^{\mathcal{C}}$ the smallest element in the support of $L^{\mathcal{C}}$ that fulfills Condition (4.84) with equality. As s_{NI}^{nNC} increases in $L^{\mathcal{C}}$, provided that $L^{C} < \pi(0,0) - \pi(v,v)$, and $s_{I}^{nNC}(\theta)$ (weakly) decreases in $L^{\mathcal{C}}$ (see Lemma 4.8), the threshold $\underline{\mathrm{L}}^{\mathcal{C}}$ is uniquely defined by

$$R_{NI}^{nNC}\left(s_{NI}^{nNC}\right) = R_{I}^{nNC}\left(s_{I}^{nNC}(\underline{\theta})\right). \tag{4.85}$$

Hence, we can summarize: If the litigation costs for a patent challenge are sufficiently small $L^{\mathcal{C}} < \underline{\mathrm{L}}^{\mathcal{C}}$, the patent holder engages in challenge-acceptance pricing for all $\theta > \underline{\theta}$ (Case 1). If the litigation costs are larger, there exists a range of patent strengths above $\underline{\theta}$ in which the patent holder engages in challenge-avoidance pricing (Case 2).

Next, we characterize the interval of intermediate patent strengths in which the patent holder engages in challenge-avoidance pricing if $L^{\mathcal{C}} > \underline{\mathrm{L}}^{\mathcal{C}}$. Recall from above that the patent holder's profit without challenge, R_{NI}^{nNC}, is independent of the patent strength for $\theta \in (\underline{\theta}, 1)$, and the profit with challenge-acceptance pricing R_{I}^{nNC} increases in θ.

Hence, if $L^{\mathcal{C}} > \underline{\mathrm{L}}^{\mathcal{C}}$, there exists a threshold value $\tilde{\theta}^{s}$ such that the patent holder is indifferent between avoiding a patent challenge (NI) and accepting a positive invalidation risk (I) in particular, at $\theta = \tilde{\theta}^{s}$, it holds that

$$R_{I}^{nNC}\left(s_{I}^{nNC}\left(\tilde{\theta}^{s}\right);\tilde{\theta}^{s}\right) = R_{NI}^{nNC}\left(s_{NI}^{nNC}\right). \tag{4.86}$$

For stronger patents $\theta > \tilde{\theta}^{s}$, the patent holder prefers to engage in challenge-acceptance pricing.

Last, we show that $\tilde{\theta}^{s}$ lies in the relevant interval $(\underline{\theta}, 1)$. By conditioning $L^{\mathcal{C}} > \underline{\mathrm{L}}^{\mathcal{C}}$, it holds that $\tilde{\theta}^{s} > \underline{\theta}$. Furthermore, $\tilde{\theta}^{s}$ needs to be smaller than 1 as for $\theta \to 1$, $R_{NI}^{nNC}\left(s_{NI}^{nNC}\right) < R_{I}^{nNC}\left(s_{I}^{nNC}(1)\right)$. The reason why this inequality holds is that, in both cases, the invalidation risk is zero and $s_{I}^{nNC}(1) = v$ takes the highest admissible value. This establishes the result. □

Proof of Proposition 4.7

Proof. Suppose that $\theta > \underline{\theta}$, such that a patent challenge yields higher profit than patent infringement. First, we compare the license fees $s^{NC}(\theta)$ and $s_I^{nNC}(\theta)$ (see Lemmas 4.7 and 4.8) to show that $s^{NC}(\theta) < s_I^{nNC}(\theta)$ if $\theta < \tilde{\theta}_V^{NC}$. For $\theta > \tilde{\theta}_V^{NC}$, both $s^{NC}(\theta)$ and $s_I^{nNC}(\theta)$ are equal to v, the cost savings of the new technology.

We first consider $\theta < \tilde{\theta}_V^{nNC}$, which implies that both running royalties are derived from a condition which sets each downstream firm indifferent between contract acceptance and the outside option of patent infringement instead of using the old technology (see Lemma 4.8). With a no-challenge clause, this implies

$$\theta\pi\left(v, s^{NC}(\theta)\right) + (1-\theta)\,\pi(0,0) - L^{\mathcal{I}} \;=\; \pi\left(s^{NC}(\theta), s^{NC}(\theta)\right). \tag{4.87}$$

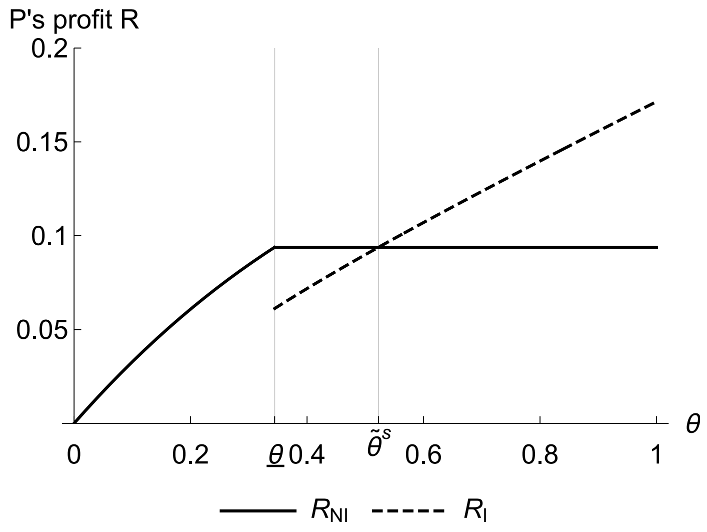
We show that, for the case a without no-challenge clause, the downstream firm's outside option is slack at the running royalty $s^{NC}(\theta)$. In this case, the expected profit from contract acceptance is

$$(1-(1-\theta)\gamma)\,\pi\left(s^{NC}(\theta), s^{NC}(\theta)\right) + (1-\theta)\gamma\left(\pi(0,0) - \frac{L^{\mathcal{C}}}{n}\right) \;>\; \pi\left(s^{NC}(\theta), s^{NC}(\theta)\right),$$

as the convex combination of $\pi\left(s^{NC}(\theta), s^{NC}(\theta)\right)$ and $\pi(0,0) - \frac{L^{\mathcal{C}}}{n}$ is larger than $\pi\left(s^{NC}(\theta), s^{NC}(\theta)\right)$ because $\pi(0,0) - \frac{L^{\mathcal{C}}}{n} > \theta\pi\left(v, s^{NC}(\theta)\right) + (1-\theta)\,\pi(0,0) - L^{\mathcal{I}}$ for $\theta > \underline{\theta}$. The latter inequality holds because $\underline{\theta}$ is defined such that for $\theta > \underline{\theta}$ the profit of a patent challenge is larger than the expected profit of patent infringement. Hence, the patent holder charges a higher running royalty rate $s_I^{nNC}(\theta)$ if it accepts a positive invalidation risk compared to the royalty rate under a no-challenge clause, that is $s^{NC}(\theta)$. As the outside option of patent infringement increases in s, the downstream firms realize a higher expected profit absent a no-challenge clause.

For $\theta \in \left(\tilde{\theta}_V^{nNC}, \tilde{\theta}_V^{NC}\right)$, we have $s_I^{nNC}(\theta) = v$ and $s^{NC}(\theta) < v$ (by definition of $\tilde{\theta}_V^{NC}$, Equation (4.71)), and, therefore, in this range it also holds that $s^{NC}(\theta) < s_I^{nNC}(\theta)$. Recall the result that $\tilde{\theta}_V^{nNC} < \tilde{\theta}_V^{NC}$ for $\gamma > 0$ (derived in Lemma 4.8). For $\theta \geq \tilde{\theta}_V^{NC}$, it holds that $s^{NC}(\theta) = s_I^{nNC}(\theta) = v$, which is the condition provided in Proposition 4.7.

Second, we compare the license contracts $s^{NC}(\theta)$ and s_{NI}^{nNC} (characterized in Lemmas 4.7 and 4.8). In both cases, the invalidation frequency is zero and the downstream firms realize with certainty $\pi\left(s^{NC}(\theta), s^{NC}(\theta)\right)$ and $\pi\left(s_{NI}^{nNC}, s_{NI}^{nNC}\right)$, respectively. The only difference is that, for $\theta > \underline{\theta}$, the downstream firms' outside option is larger absent a no-challenge clause. With linear license contracts, the only way to grant higher profits to the downstream firms is by reducing the royalty rate. Hence, we obtain $s^{NC}(\theta) < s_{NI}^{nNC}$. In this case, the downstream firms' profits are also larger absent a no-challenge clause. This establishes the result. □



The figure shows the patent holder's (expected) profit depending on the patent strength θ and depending on whether the license contract is such that a licensee challenges the patent upon receiving the invalidity signal (R_I) or not (R_{NI}) for the case of $n = 2$ licensees competing in prices. Marginal cost of the old technology: $v = 1/4$, litigation costs: $L^{\mathcal{C}} = 2/100$ and $L^{\mathcal{I}} = 0$; signal probability: $\gamma = 3/4$. The threshold $\underline{\theta}$ is defined in Lemma 4.6 and $\tilde{\theta}^s$ is defined in Eq. (4.86). Demand is defined in Equation 4.1, with $\sigma = 3/4$.

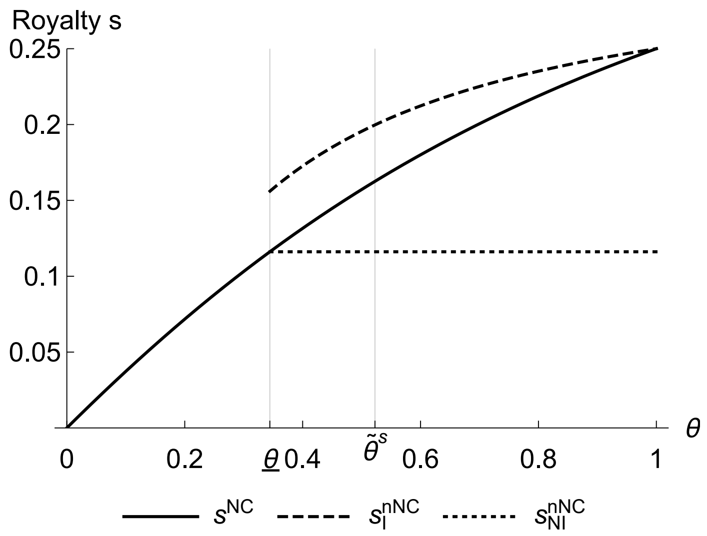
Figure 4.4: Patent holder's profit with linear tariffs in invalidation (I) and no invalidation (NI) case.

Parametric Example

Patent Holder's Profit. Figure 4.4 provides a parametric example of the results of Proposition 4.6 when the litigation costs for a patent challenge $L^{\mathcal{C}}$ exceed the threshold value $\underline{\mathrm{L}}^{\mathcal{C}}$.[35] We compare the patent holder's profit when there is no invalidation in equilibrium (R_{NI}) with the expected profit that it receives when it accepts that a licensee challenges the patent upon receiving the invalidity signal (R_I).

For weak patents ($\theta \leq \underline{\theta}$), the patent holder does not face the risk of a patent challenge and its profit R_{NI} (solid line) increases in θ due to the fact that stronger patents reduce the downstream firms' outside option of infringing the patent which permits a higher running royalty. For stronger patents ($\theta > \underline{\theta}$), the patent holder can avoid a patent challenge only by giving a sufficiently high profit of $\pi(0,0) - L^{\mathcal{C}}$ to the licensees. Accordingly, in this range of θ, R_{NI} is constant. Alternatively, the patent holder can extract a larger share of total profits but thereby accepts a positive invalidation risk. The profit R_I (dashed line) is defined for $\theta \in (\underline{\theta}, 1)$ and increases in the patent strength θ. There exists a threshold $\tilde{\theta}^s$ at which the patent holder's profit with patent-acceptance pricing R_I surpasses the profit level R_{NI} of avoiding a challenge. For very strong patents ($\theta \to 1$), the risk of patent

[35]The litigation costs $L^{\mathcal{I}}$ are set to zero in order to fulfill Assumption 4.1 for all patent strengths $\theta \in (0, 1)$ and to avoid the case distinction between the outside options of patent infringement and using the old technology.



The figure shows three different running royalties as functions of the patent strength θ: s^{NC} for a license contract with no-challenge clause; s_I^{nNC} for a contract without clause and challenge acceptance pricing; s_{NI}^{nNC} for a contract without clause and challenge avoidance pricing. Setting: two licensees compete in prices; marginal cost of the old technology: $v = 1/4$; litigation costs: $L^{\mathcal{C}} = 2/100$ and $L^{\mathcal{I}} = 0$; signal probability: $\gamma = 3/4$. The threshold $\underline{\theta}$ is defined in Lemma 4.6 and $\tilde{\theta}^s$ is defined in Eq. (4.86). Demand is defined in Eq. 4.1, we set $\sigma = 3/4$.

Figure 4.5: Pure running royalties with and without a no-challenge clause.

invalidation as well as the licensees' outside option are small whereas the profit level for the downstream firms to avoid a patent challenge $\pi(0,0) - L^{\mathcal{C}}$ remains at the same high level. As a result, the patent holder accepts a positive invalidation risk for strong patents $\theta > \tilde{\theta}^s$.

If the litigation costs for a patent challenge $L^{\mathcal{C}}$ are below the threshold value $\underline{\mathrm{L}}^{\mathcal{C}}$, the intermediate interval $\theta \in \left(\underline{\theta}, \tilde{\theta}^s\right]$, in which the patent holder strategically avoids a patent challenge, is empty. For small values of $L^{\mathcal{C}}$, the royalty rate s_{NI}^{nNC} and the corresponding profit R_{NI} are small, such that this strategy is not profitable. In this case, a patent challenge is either not profitable for the licensees after contract acceptance ($\theta \leq \underline{\theta}$) or the patent holder accepts a patent challenge with positive probability in equilibrium ($\theta > \underline{\theta}$).

License Terms. The next figure summarizes the result of Proposition 4.7 on the pure running royalties.[36] The solid line represents the pure royalty for the case with a no-challenge clause $s^{NC}(\theta)$ and is defined for all patent strengths $\theta \in (0,1)$. It increases in the patent strength because a stronger patent implies a worse outside option at the contract acceptance stage, which allows for higher royalty rates.

Absent a no-challenge clause and for $\theta > \underline{\theta}$, the patent holder has to decide whether to accept a positive invalidation risk ($s_I^{nNC}(\theta)$, dashed line) or avoid a patent challenge by means of financial incentives for the licensees (s_{NI}^{nNC}, dotted line). The figure illustrates

[36]The figure is based on the same parametrization as in Figure 4.4.

that the rate under challenge-avoidance pricing is independent of the patent strength and lower than the rate under a no-challenge clause. The reason is that, at the same invalidation risk θ, the patent holder has to give a higher share of the total profits to the licensees, which requires a lower royalty rate s.

In contrast, challenge-acceptance pricing yields a higher royalty rate than with a no-challenge clause although the licensees obtain the same expected profit level (equal to the profit from infringing the patent). Whereas licensees realize this profit with certainty in the case of a no-challenge clause, absent such a clause, they have the advantage that with some probability the patent will be invalidated. Hence, they are willing to accept a higher royalty for the event that the patent remains valid.

The vertical lines in the figure depict the same threshold values as introduced in Figure 4.4 and delineate the three intervals characterized in Proposition 4.6. Absent a no-challenge clause, the patent holder thus chooses the royalty rate as follows:

- for small patent strengths $\theta \leq \underline{\theta}$, the patent holder sets $s = s^{NC}(\theta)$,
- for intermediate patent strengths $\theta \in \left(\underline{\theta}, \tilde{\theta}^s\right]$, it charges $s = s_{NI}^{nNC}$, and
- for strong patents $\theta > \tilde{\theta}^s$, it increases the royalty to $s_I^{nNC}(\theta)$ and thereby accepts a positive invalidation risk.

Relation of a Linear License Contract to a Two-Part Tariff Where the Fixed Fee is Sunk Upon Contract Acceptance. The analysis of linear license contracts is also relevant if the patent holder uses a two-part license contract but the fixed fee F is sunk when a licensee considers challenging the patent upon receiving new information post contract acceptance. In this case, the patent holder can only use the running royalty r of the two-part tariff to make it unprofitable for a licensee to challenge the patent. It can therefore at most charge the running royalty $r = s_{NI}^{nNC}$ to avoid an invalidation lawsuit. Based on this running royalty, it sets the fixed fee in order to make the downstream firms indifferent to their outside option of contract acceptance.

As a possibility result, we provide a parametric example for which a ban of a no-challenge clause has qualitatively the same negative welfare consequences as with the assumption that the fixed fee is not sunk at the stage of the patent challenge. The example relies on high litigation costs for a patent challenge $L^{\mathcal{C}}$ (as it allows for a high running royalty s_{NI}^{nNC} that achieves the avoidance of a patent challenge) and a high probability for the invalidity signal (as this makes it beneficial for the patent holder to avoid a challenge). For linear demand defined in Equation 4.1, with $\sigma = 3/4$, $\upsilon = 1/4$, $\gamma = 3/4$, $L^{\mathcal{I}} = 0$, and $L^{\mathcal{C}} = 7/200$, the relevant range in which a patent challenge can occur is $\theta > \underline{\theta} \approx 0.88$. In this range it holds that $s_{NI}^{nNC} \approx 0.21$ is larger than $r^{NC}(\theta)$, which decreases in θ and therefore takes on the highest value at $r^{NC}(.88) \approx 0.20$. Together with the observation that the invalidation frequency does not increase if the patent holder offers the running royalty of s_{NI}^{nNC}, we find that a ban of a no-challenge clause can be welfare detrimental even in the case in which the fixed fee is sunk after contract acceptance.

Appendix C: Use of the Old Technology as the Relevant Outside Option

In this appendix, we study the case in which the use of the old technology is the relevant outside option for the downstream firms at the contract acceptance stage. We do this for the setting with two-part tariffs laid out in Section 4.3.

Using the old technology instead of infringing the patent is the relevant outside option for a downstream firms if

$$\pi(v,r) \quad > \quad \theta\pi(v,r) + (1-\theta)\,\pi(0,0) - L^{\mathcal{I}}. \tag{4.88}$$

If this condition holds, then using the old technology yields a higher profit than infringing the patent, independent of whether a downstream firm expects that another downstream firm challenges the patent or not. The condition is fulfilled for all admissible running royalties $r \in [0,v]$ if the litigation costs $L^{\mathcal{I}}$ are sufficiently high. For the purpose of this appendix, we replace Assumption 4.1 with

Assumption 4.7. $L^{\mathcal{I}} > (1-\theta)\,(\pi(0,0) - \pi(v,0))\,.$

We first analyze the case with a no-challenge clause and afterwards the case without a no-challenge clause.

No-Challenge Clause. Given Assumption 4.7, the patent holder sets the fixed fee such that the downstream firms are indifferent to their second-best alternative of using the old technology, which yields a fixed fee of

$$F^{NC} = \pi(r,r) - \pi(v,r)\,. \tag{4.89}$$

Inserting the fixed fee into the patent holder's profit function yields the reduced profit

$$G^{NC}(r,\theta) = T(r) - \pi(v,r)\,. \tag{4.90}$$

The resulting first-order condition

$$G_1^{NC}(r,\theta) = T_1(r) - \pi_2(v,r) = 0 \tag{4.91}$$

is independent of the patent strength θ. Denote the optimal running royalty implied by Equation (4.91) with r^{NC}. This equals the running royalty that the patent holder sets if infringing is the relevant outside option and the patent strength approaches one (see Equation (4.9)). We summarize in

Proposition 4.8. *Suppose the patent holder includes a no-challenge clause in the licensing contract and that Assumption 4.7 holds. The running royalty r^{NC} is independent of the patent strength θ and is implicitly defined by the first-order condition in Equation (4.91). The fixed fee is $F^{NC}\left(r^{NC}\right) = \pi\left(r^{NC}, r^{NC}\right) - \pi\left(v, r^{NC}\right)$.*

Proof. Derived in the text above. □

No No-Challenge Clause. Let us first consider *challenge-acceptance pricing* where the patent holder's problem is to

$$\max_{\{F,r\}} G_I^{nNC} = (1-(1-\theta)\gamma)(r \cdot x(r,r) + F) \tag{4.92}$$

$$s.t \quad (1-\theta)\gamma\left(\pi(0,0) - \frac{L^{\mathcal{C}}}{n}\right) + (1-(1-\theta)\gamma)(\pi(r,r) - F) \tag{4.93}$$

$$\geq \left(1 - \frac{(1-\theta)(n-1)\gamma}{n}\right)\pi(v,r) + \frac{(1-\theta)(n-1)\gamma}{n}\pi(0,0).$$

The outside option of not accepting the license contract involves a positive probability that the patent will be challenged and invalidated by other downstream firms, in which case everyone can use the new technology free of charge. Accordingly, the patent holder sets the fixed fee in order to make the downstream firms indifferent between contract acceptance and the outside option of using the old technology – and possibly even the new technology, which yields

$$F_I^{nNC} = \pi(r,r) - \frac{\left(1 - \frac{(1-\theta)(n-1)\gamma}{n}\right)\pi(v,r) - \frac{(1-\theta)\gamma}{n}\left(\pi(0,0) - L^{\mathcal{C}}\right)}{1-(1-\theta)\gamma}. \tag{4.94}$$

Inserting F_I^{nNC} in Equation (4.92) and dropping the pre-multiplied term $1-(1-\theta)\gamma$ yields the problem to

$$\max_{r} G_I^{nNC} = T(r) - \frac{\left(1 - \frac{(1-\theta)(n-1)\gamma}{n}\right)\pi(v,r) - \frac{(1-\theta)\gamma}{n}\left(\pi(0,0) - L^{\mathcal{C}}\right)}{1-(1-\theta)\gamma}. \tag{4.95}$$

The implied first-order condition is

$$G_{I,1}^{nNC} = T_1(r) - \frac{\left(1 - \frac{(1-\theta)(n-1)\gamma}{n}\right)\pi_2(v,r)}{1-(1-\theta)\gamma} = 0. \tag{4.96}$$

The running royalty $r_I^{nNC}(\theta)$ implied by the above Equation (4.96) depends on the patent strength θ. This is different to the case with a no-challenge clause. We summarize in

Proposition 4.9. *Suppose the patent holder does not insert a no-challenge clause to the licensing contract, that a licensee challenges the patent if it learns about the patent's invalidity, and that Assumption 4.7 holds. The optimal running rate $r_I^{nNC}(\theta)$ is implied by Equation (4.96), increases in θ, and approaches $r^{NC}(1)$ from below for $\theta \to 1$.*

Proof of Proposition 4.9. Implicit differentiation of Equation (4.96) yields

$$\frac{\partial r_I^{nNC}(\theta)}{\partial \theta} = -\frac{1}{\partial G_{I,1}^{nNC}/\partial r}\left(\frac{\gamma \pi_2(v,r)}{n\left(1-(1-\theta)\gamma\right)^2}\right) > 0,$$

which implies that the optimal running royalty $r_I^{nNC}(\theta)$ increases in θ. Moreover, for $\theta \to 1$, the first-order condition in Equation (4.96) approaches $T_1(r) - \pi_2(v,r) = 0$, which is implicitly solved by $r^{NC}(1)$, as defined in Equation (4.91). This establishes the result. □

Comparing the results of Propositions 4.8 and 4.9 confirms the main insight from Proposition 4.3: a ban of a no-challenge clause weakly decreases the running royalty if the patent holder does not avoid patent challenge by means of favorable license terms.

With *challenge-avoidance pricing*, the outside option at the contract acceptance stage (either patent infringement or using the old technology) does not affect the license outcome. The reason is that the patent holder leaves a profit of $\pi(0,0) - L^{\mathcal{C}}$ to each licensee, which is larger than the profit from using the old technology (Assumption 4.2). Hence, this means that the main insight of Propositions 4.1 and 4.2 extends to the case that using the old technology is the relevant outside option: if the patent holder avoids a patent challenge by means of favorable license terms, a ban of a no-challenge clause leads to (i) no increase in the probability of a patent invalidation, and (ii) an increase in the running royalty to the level that yields the highest attainable industry profit, which increases the consumer prices.

Heinrich Heine Universität Düsseldorf

Eidesstattliche Versicherung

Ich, Herr Frank Schlütter, versichere an Eides statt, dass die vorliegende Dissertation von mir selbstständig und ohne unzulässige fremde Hilfe unter Beachtung der „Grundsätze zur Sicherung guter wissenschaftlicher Praxis an der Heinrich-Heine-Universität Düsseldorf“ erstellt worden ist.

Duisburg, der 18. Mai 2021

Unterschrift