# The Impact of Market Regulation on Investment and Innovation

Inaugural-Dissertation

zur Erlangung des Grades
Doctor oeconomiae publicae (Dr. oec. publ.)
an der Ludwig-Maximilians-Universität München

2012

vorgelegt von

Dominik Ruderer

| | |
|---|---|
| Referentin: | Prof. Dr. Monika Schnitzer |
| Korreferent: | Prof. Tobias Kretschmer, Ph.D. |
| Promotionsabschlussberatung: | 07.11.2012 |

# Acknowledgements

First and foremost I would like to thank my supervisor Monika Schnitzer, not only for her continuous advice and support over the last four years, but also for encouraging me to take up this academic endeavor. I also would like to thank Tobias Kretschmer who agreed to serve as the second supervisor to my dissertation and Fabian Herweg for completing the doctoral committee.

I am grateful to David Newbery and the University of Cambridge for hosting me as a Visiting Researcher at the Electricity Policy Research Group in the first half of 2011. This stay and David's vast knowledge on energy economics have benefitted my research and my understanding of current energy policy immensely.

I am indebted to Gregor Zöttl for acting as a co-author for the first chapter in this thesis. His rigorous technical approach has taught me a lot about modeling in state-of-the-art energy economics. Moreover, I am thankful to Michal Masika for co-authoring the third paper of this dissertation. His patience and perseverance were a great motivator. Furthermore, I would like to thank Georg Gebhardt, Ilja Rudyk and Martin Watzinger for their comments and ideas on my work.

I am grateful to my office mates at the Max Planck Institute, Arul Scaria and Moritz Lichtenegger, who made my daily life at the office more entertaining and diverse. They have become two of my most valued friends over the last years. Moreover, I would like to thank my colleagues at the Seminar for Comparative Economics for their helpful comments and suggestions as well as the nice working environment.

I would like to thank the German Research Foundation (GRK 801) and the Max Planck Institute for Intellectual Property and Competition Law for the generous financial support who made this thesis possible.

Finally, I would like to thank May and my family for their continuous support, their trust in me and wiping away any doubts about this project.

Munich, June 17th 2012 Dominik Ruderer

# Contents

# List of Figures

# Introduction

Promoting investment and innovation is a key component in many countries' long term economic strategies. For example, the European Commission's 'Lisbon Strategy' and its successor 'Europe 2020' mainly focus on how to improve the conditions for investment and innovation in the European Union. Moreover, the U.S. Government has issued a 'Strategy for American Innovation' for the same purpose.[1] This is not surprising as investment and innovation have long been identified as key factors for economic growth (see, e.g., Romer, 1990, Aghion and Howitt, 1992, 1998, and Grossman and Helpman, 1989, 1991, 1994).

Since Adam Smith (1776) economists have seen markets as a powerful tool to promote investment and innovation (compare, e.g., Olley and Pakes, 1996, Ng and Seabright, 2001, and Fabrizio et al., 2007, for empirical evidence). This understanding is reflected in the shift of public policy from state control to deregulation during the last 40 years. Beginning with the oil shocks of the 1970s, which were accompanied with a slow down in economic growth and a contraction of public budgets, a huge change from state ownership towards reliance on market guidance could be witnessed in the western world. Moreover, the collapse of the communist block in 1989 has led to massive privatization and deregulation programs in the Eastern European countries (see, e.g., Newbery, 2000, and Alesina et al., 2005).[2]

However, deregulation is no panacea. Problems associated with market failure might make it difficult to reap the full benefits markets possibly provide.[3] This makes market regulation necessary. While it can take many forms, this dissertation focuses on two specific kinds of market regulation: Sector-specific regulation and competition policy. Sector-specific regulation relies on ex-ante regulation of business conduct, such as control of prices or revenues by sector-specific regulatory authorities. Competition policy, however,

[1] Compare European Commission (2005, 2010) for the European programs and National Economic Council (2009, 2011) for the U.S. programs.

[2] For example, a study on deregulation in the US shows a steady decline in the share of US GDP produced under heavy regulation from 11.52% in 1977 to 2.96% in 2006 (see Crandall, 2007). Moreover, according to the World Bank 238 market reforms were introduced in 175 countries between 2003 and 2007. 213 of these reforms in 112 economies make it easier to do business (compare World Bank, 2006). Further evidence on deregulation in the OECD countries can be found in Nicoletti and Scarpetta (2003).

[3] For a thorough definition of market failure see, e.g., Ledyard (2008).

operates ex-post and is basically harm-based. That is, policy makers establish general guidelines that are enforced ex-post by a generalist antitrust authority which is in charge of all industries. While competition policy is applied to the whole economy, sector-specific regulation is generally applied only when the underlying industry exhibits properties of a natural monopoly, posing hurdles for competition (see, e.g., Rey, 2003, and Motta, 2004).

It is essential to use regulatory instruments carefully and adequately as insufficient regulation or ill-designed markets might lead to inefficient and harmful outcomes. In particular, in industries that crucially depend on investment and innovation or undergo a period of technological change with high investment needs, it is essential to take the dynamic dimension of regulation and competition policy into account (see, e.g., Evans and Schmalensee, 2002, Segal and Whinston, 2007, and Gilbert and Newbery, 1994). Two prominent examples for failed regulatory policies are the initial privatization of the British railway system in 1993 (see Economist, 1999, 2000, 2001) and the Californian electricity crisis following market restructuring in 2000/01 (see Borenstein, 2002).

This dissertation contributes to the understanding of the dynamic aspects of market regulation. The following three chapters analyze different topics in market regulation and its implications on investment and innovation. The first two chapters deal with the sector-specific regulation of network industries which exhibit features of natural monopolies. In particular, both chapters were inspired by institutional characteristics of the electricity sector and hence, contribute to the discussion on its regulation. The first chapter considers the impact of different pricing methods of scarce transmission resources on investment in generation and transmission capacities. The second chapter investigates the impact of different regulation-imposed 'investment regimes' in network industries on downstream process innovation. This is specifically interesting in light of recent advances in electricity metering technology. The third chapter studies the equilibrium incentives of producers to market their products exclusively via a single retailer, the effect of such behavior on competition and the necessity for regulation of such behavior. Thus, it is mostly related to the competition policy literature. This chapter was motivated by observations on the marketing of handsets in the telecommunications industry.

In the remainder of this introduction, we present a brief overview of the three chapters and highlight their main contributions. Each chapter is self-contained and can be read independently.

In Chapter 1, 'On Investment Incentives in Network Industries', we study the effect of different allocation methods for scarce transmission resources on investment incentives in generation and transmission capacity in network industries.[4] When a good is sold through a network, either a uniform market price in the whole network is charged or market prices differ among locations in the network. Locationally differentiated market prices are able to

[4]This chapter is based on joint work with Gregor Zöttl.

take potential network congestion directly into account. A uniform market price, however, makes a mechanism outside the market necessary to alleviate congestion.

A prominent example for such a problem is the management of network transmission capacity in electricity markets. In the U.S., seven regional electricity markets have implemented locationally differentiated prices, where transmission constraints are directly taken into account at the spot market. In contrast, most European electricity markets continue to use uniform pricing systems, where a single price per market exists and transmission constraints are resolved by the network operator after the spot market has taken place. Nevertheless, intense debates about shifting towards locationally differentiated prices are ongoing in Europe (compare, e.g., European Parliament, 2009, European Council, 2011, Acer, 2011, and Electricity Regulatory Forum, 2011).

We analyze the impact of these two different transmission management regimes on investment in regulated transmission and unregulated generation facilities. First, in line with the related literature, we find that locationally differentiated prices lead to the socially optimal investment outcome. Second, we find that a uniform market price leads to over-investment in generation and transmission capacity. Finally, we are able to show that a uniform market price also distorts the generation technology mix.

Many contributions have extensively analyzed the impact of different transmission management regimes. However, they basically focus on short run market performance, leaving aside long run aspects such as investment incentives in transmission and generation facilities. Experts and policy makers have emphasized the importance of long run investment incentives for the proper functioning of electricity markets (compare, e.g., Baldick et al., 2011, and European Parliament, 2009). This chapter is the first study which explicitly analyzes the effect of transmission management on these long run investment incentives in generation and transmission capacity.

This chapter also contributes to the literature on the impact of different regulatory measures on transmission investment. Yet, this literature takes the generation stock as given and ignores potential interdependencies between generation and transmission capacities. Sauma and Oren (2006) show that this leads to significantly distorted predictions. We take this critique into account by assuming the generation stock to be endogenous, while transmission investment is regulated optimally. Thus, we are able to correct for potential distortions in our results.

Finally, this chapter extends the peak load pricing literature, which has investigated generation investment incentives under fluctuating and potentially uncertain demand and emphasized the effect of the spot market design. Yet, this literature completely abstracts from the presence of a transmission network. We use a model framework inspired by the peak load pricing literature and explicitly consider the impact of the transmission network on investment incentives.

In Chapter 2, ‘Regulating Investments in Vertically Related Industries’, we study the influence of diverse regulation-imposed ‘investment regimes’ on downstream process innovation in network industries. Many network industries, such as utilities, are characterized through their vertical structure with a monopolistic upstream and a competitive downstream segment. In order to dampen the market power stemming from the upstream segment, utilities are usually subject to partial or full vertical separation. If new technological opportunities arise in such an industry, it is often not clear which segment of the industry should invest on these new technologies. In these situations the regulator decides who should be responsible for the investment, that is, the ‘investment regime’.

An example for such a scenario is the emerging ‘smart metering technology’ in electricity distribution networks. Electricity suppliers need metering technology to measure their customers’ consumption in order to bill them. Traditional electricity metering technology can only measure the delivered quantity over a specified period of time, while the emerging smart metering technology has higher functionality and accuracy. Investment in this new metering technology is technically not linked to a distinct segment in the vertically related electricity industry. National regulators have chosen different approaches regarding investment in new metering technology. While in Italy the regulated upstream network is in charge of the investment, in Germany the unregulated downstream electricity suppliers are supposed to undertake these investments.

This chapter compares investment by a regulated upstream monopolist to investment by downstream competitors in downstream process innovation. We show that in order to enhance investment in this new technology, the regulator should carefully take the specific characteristics of the industry under regulation into account, when determining the ‘investment regime’. In particular, the optimal investment regime depends on the specific vertical ownership structure, the mode of competition and on the capital intensity of the upstream segment.

A substantial literature has extensively analyzed the impact of different regulatory measures on infrastructure investment. Though this literature considers different kinds of investment, it does not consider that an investment in one and the same technology could be undertaken by different investors. As our leading example shows, this is a highly relevant case to be investigated. In addition, this chapter is the first study comparing different regulation-imposed ‘investment regimes’ with respect to their performance. Moreover, several contributions have analyzed the impact of modern electricity metering technologies on competition, generation capacities and welfare. This chapter, however, is the first contribution to investigate how to best incentivize the initial investment in these new technologies.

In Chapter 3, 'Exclusive Retailing', we study firms' retail strategies in markets for new and complex consumer products.[5] In such markets it can be often observed that a manufacturer markets its products exclusively via a single retail company. In particular, this behavior can be frequently found in the mobile phone industry, where new handsets are often sold exclusively via a single mobile carrier. A very prominent example for such an 'exclusive retailing' arrangement is the introduction of the 'iPhone' by Apple Inc. in 2007, where marketing efforts were undertaken exclusively via one mobile carrier per country. In this chapter, we study the equilibrium incentives of a manufacturer to market its products via an exclusive retailing arrangement. Thereby, we consider the effect of exclusivity arrangements on market conduct and welfare. In addition, we investigate the scope for regulatory intervention.

Exclusive retailing arrangements have been a matter of intense debate (see, e.g., Dobson et al., 2008). Supporters of these arrangements argue that exclusive retailing serves as a pro-competitive device to incentivize retail marketing investment in complex consumer products. Such products may be produced by firms without efficient marketing technologies to conduct this marketing on their own. Thus, exclusive retailing arrangements might incentivize product development in the long run. Critics, however, argue that exclusive retailing arrangements are established out of market power considerations and distort competition. This chapter integrates both views and derives conditions when exclusivity is anti-competitive and when it is pro-competitive.

Prior contributions have extensively investigated exclusivity arrangements, where the selling party restricts the buying party in establishing alternative trading relationships. However, pointing to the mobile phone industry, it can be often observed that the selling party restricts itself to trade only with one of the buyers. To the best of our knowledge, this study is the first contribution investigating such behavior.

Moreover, a major part of the literature on vertical restraints analyzes only 'triangular' market structures, where either the upstream or the downstream segment is characterized by the absence of competition. While this raises the tractability of these models, it ignores potential feedback effects stemming from competition in both segments. Whinston (2006, p. 176) argues that triangular market structures are too simplistic and hence, developing models with competition in both segments is of high priority. In this study we acknowledge this critique and explicitly analyze the effect from competition in both segments.

[5] This chapter is based on joint work with Michal Masika.

# Chapter 1

# On Investment Incentives in Network Industries

## 1.1 Introduction

When a good is sold through a network, one of the important questions to be answered is whether locationally differentiated prices or a uniform market price should be charged. Locationally differentiated market prices take potential network congestion directly into account. A uniform market price, however, 'enlarges' the market, but makes a mechanism outside the market necessary to alleviate potential congestion. A prominent example for such a problem is given by the management of transmission capacity in liberalized electricity markets. In the U.S., seven regional electricity markets have implemented locational marginal pricing, where prices can differ among locations in the same market and thus, implicitly price transmission constraints directly at the spot market.[6] In contrast, most European electricity markets continue to use redispatch systems, where a single price per market exists and transmission constraints are solved by the system operator after the spot market has taken place. However, intense debates about shifting towards locational marginal pricing are ongoing in the U.K., Germany as well as at the wider European level.[7]

Many contributions have extensively analyzed the impact of different transmission man-

[6]For a description of the regional electricity markets in the U.S. compare, e.g., http://www.ferc.gov/.

[7]Compare, e.g., Ofgem (2010) and Redpoint Energy (2011) for the British discussion, Frontier (2011) for the discussion in Germany and European Parliament (2009), European Council (2011), Acer (2011) and Electricity Regulatory Forum (2011) for efforts on the European level.

agement regimes.[8] However, all these articles typically focus on short run market performance, leaving aside long run aspects such as investment incentives in transmission and generation facilities. Recently, experts as well as policy makers have increasingly emphasized that for the proper functioning of electricity markets not only short run efficiency but also long run incentives are of central importance.[9] Moreover, a detailed analysis of the long run perspective seems to be of particular importance in the light of the ongoing debate on insufficient incentives in liberalized electricity markets to provide generation investment.[10] Till date this debate has entirely abstracted from issues arising due to a transmission network.

This study sheds light on the relationship between transmission management and long term investment in (unregulated) generation and (regulated) transmission capacity. Thus, we develop a network model with endogenous generation and transmission capacities. Competitive firms invest in two different generation technologies, which allow production at different levels of demand. Transmission investment is assumed to be optimally determined, anticipating subsequent generation investment. The capacity of the transmission line limits the amount of physical trade that can take place. As transmission constraints might potentially exist in this network, a mechanism for transmission allocation is needed. Our benchmark case is given by *simultaneous market clearing* ('locational marginal pricing'), where separate spot market prices exist at the different nodes in the network. Whenever the level of demand and hence, the amount of trade is high, such that a transmission line is constrained, the spot market prices at the two ends of the constrained line diverge from each other. This leads to an efficient allocation and the spot market is directly cleared. With *sequential market clearing* ('redispatch system'), a single spot market price exists in the whole network. Whenever the level of demand is high, such that the transmission line is constrained, the spot market outcome becomes physically infeasible. In order to achieve market clearing, an adjustment market has to be run, where the system operator engages in counter-trading. That is, the system operator acts as a seller at the exporting side of the constrained line and as a buyer at the importing side of the constrained line. These additional transactions reduce the level of trade between the two nodes to a physically feasible level.[11]

[8]Compare Joskow and Tirole (2000) and Gilbert et al. (2004) who analyze the effect of different transmission allocation mechanisms on generation spot market conduct and Green (2007) who estimates the short run welfare loss due to sequential market clearing compared to simultaneous market clearing.

[9]Compare, e.g., Baldick et al. (2011) for an expert opinion and European Parliament (2009) for a policy viewpoint.

[10]See, e.g., Oren(2005), Hogan (2005), Cramton and Stoft (2006), Joskow (2007) or Cramton and Ockenfels (2011) on the 'missing money discussion'.

[11]The expressions counter-trading and (market-based) redispatch are used interchangeably in this study. Both expressions describe methods to alleviate transmission congestion outside the spot market. Under both methods, the system operator makes market transactions against the 'direction' of trade at the spot market in order to reduce the traded quantity over the transmission line until the congestion is eliminated.

First, our benchmark case with simultaneous market clearing produces the socially optimal investment outcome.[12] Simultaneous market clearing ensures that generation is priced at its locational marginal value. This gives competitive firms the efficient price signals for generation investment and hence, given the optimal generation capacity, transmission investment is also conducted efficiently.

Second, sequential market clearing, on the other hand, leads to overinvestment in total generation and transmission capacity. Sequential market clearing disentangles the price signal from the location of production and hence, from its locational marginal value. This leads to higher generation scarcity rents and therefore, to exaggerated investment incentives in generation. As we show, the transmission capacity matches the generation capacity. Thus, there is also overinvestment in the corresponding transmission line.

Finally, we find that with simultaneous market clearing the socially optimal technology mix is reached. In contrast, with sequential market clearing the technology mix is distorted towards more peakload and less baseload generation capacity.

The central message of our findings is that policy makers should be aware that switching from a system of sequential market clearing to a system of simultaneous market clearing leads to a reduction of investment incentives. In a setting like ours, without any market distortions, this is desirable as it leads to the socially optimal investment outcome. However, if investment incentives in a specific market are already perceived as too low, a change of the transmission management regime might then further aggravate these problems. Inadequate investment incentives might be a result of market imperfections and institutional constraints in electricity markets, such as price caps, which suppress electricity prices below the efficient level. Hence, generation revenues might be insufficient to provide adequate generation capacity (compare the 'missing money discussion', e.g., Oren, 2005, Hogan, 2005, Cramton and Stoft, 2006, Joskow, 2007, and Cramton and Ockenfels, 2011). Policy makers should then be aware of the potentially increased necessity to adopt appropriate measures to enhance firms' investment activities. However, in this study we abstract from any of these market imperfections. Notice that our results should not be understood as a justification for the introduction or the retention of sequential market clearing as a proper mechanism to enhance firms' investment activity in a specific electricity market.

This work is related to the literature on the regulation of electricity transmission. Bushnell (1999), Joskow and Tirole (2000), and Gilbert et al. (2004) analyze different transmission capacity allocation methods and how these affect the spot market outcomes in markets with simultaneous market clearing. Wolak (2011) measures the benefits from introducing simultaneous market clearing in the Californian electricity market and Green (2007) cal-

[12]This result is in line with the previous literature on locational marginal pricing (see, e.g., Hogan, 1999).

culates the welfare loss associated with sequential market clearing relative to simultaneous market clearing in England and Wales. However, these articles do not take any long term aspects like investment in generation or transmission capacities into account. Another strand in the literature explicitly considers the impact of different regulatory measures on transmission investment. Léautier (2000), Vogelsang (2001), Bushnell and Stoft (1997), Hogan (1992), Joskow and Tirole (2005), Sauma and Oren (2009), and Hogan et al. (2010) analyze different regulatory instruments to incentivize transmission investment. As compared to our work, however, these articles do not consider the impact of different transmission management systems. Moreover, we also analyze a potential change in the generation stock.[13] To the best of our knowledge, this study is the first one to derive the impact of the transmission management system on investment incentives in generation and transmission facilities.

Last but not least, this study is related to the peak load pricing literature, that has investigated generation investment incentives under fluctuating and potentially uncertain demand and emphasized the effect of the spot market design. A good overview of the literature is provided by Crew et al. (1995). Boom (2009) and Fabra et al. (2011) analyze the effect of auctions at the spot market. Reynolds and Wilson (2000) and Fabra and de Frutos (2011) analyze the case of Bertrand spot markets. Gabszewicz and Poddar (1997), Murphy and Smeers (2005), and Zöttl (2011) analyze strategic investment prior to Cournot competition. All these contributions completely abstract from the problem of a transmission network.

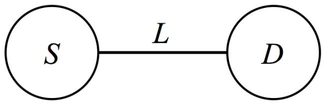
The next Section presents our model. In Section 1.3 we analyze simultaneous market clearing. In Section 1.4 we analyze sequential market clearing and compare the results. In Section 1.5 we relate our work to the current discussion on transmission management in the electricity sector. In Section 1.6 we discuss an extension and generalize our results in a $n$-node star network. In Section 1.7 we put forward some concluding remarks.

## 1.2 The Model

We consider a network as described in Figure 1.1 where consumption takes place at a 'demand node', denoted by $D$, and production takes place at a 'supply node', denoted by $S$. Both nodes are connected via a transmission line. Trade between consumers at the demand node and producers at the supply node is limited by the transmission line's capacity $L$.

[13] Our work explicitly considers investment in transmission and generation. Sauma and Oren (2006) show in their paper that analyzing transmission investment, taking the generation capacity in the market as given, leads to significantly distorted predictions. Rious et al. (2010) extend the analysis by Sauma and Oren by assuming that anticipation is costly.

Figure 1.1: Two-node network




Competitive firms at the supply node can invest in production capacity. This allows these firms to produce at a spot market with variable levels of demand at the demand node. Production takes place given the constraints by transmission and generation capacities. Inverse demand is given by the function $P(Q,\theta)$, which depends on output $Q \in \mathbb{R}^+$, and the variable $\theta \in \mathbb{R}$ which captures the different levels of demand. The frequencies of all different levels of demand are denoted by $f(\theta)$, their support is given by $[\underline{\theta}, \overline{\theta}]$ and their cumulative distribution is denoted by $F(\theta)$. We normalize $F(\theta)$ such that $F(\underline{\theta}) = 0$ and $F(\overline{\theta}) = 1$. Throughout this chapter we refer to the different levels $\theta$ of spot market demand simply as to 'spot market $\theta$'.[14] The firms are assumed to be price takers and the spot market is perfectly competitive.

We analyze the case of two different production technologies, which are available at the supply node, production technology $B$ (for 'baseload') and technology $P$ (for 'peakload'). Technology $B$ $(P)$ comes with production cost $c_1$ $(c)$ and the cost of capacity investment is given by $k_1$ $(k)$, with $c_1 < c$ and $k_1 > k$.[15] We denote the equilibrium industry investment by $(X, X_1)$, where $X$ represents total investment and $X_1$ represents baseload investment. Peakload investment is given by the difference of total and baseload investment $(X - X_1)$.

Investment in the transmission line is taking place optimally, given subsequent generation investment. A natural and realistic interpretation of this assumption would be that transmission line investment is determined by a welfare maximizing regulator. The transmission line is assumed to be operated by a (independent) system operator and transmission capacity is fully utilized. The nominal line size is denoted by $L$ and the marginal cost of investment in the transmission line by $t$. For the main part of this chapter we

[14]Notice that at the time of investment firms do not necessarily need to know the demand levels at all spot markets. In order to keep notation to a minimum, we do not explicitly disentangle demand fluctuations occurring at spot markets in several periods from uncertainty regarding the precise pattern of those fluctuations. Notice, however, that the parameter $\theta \epsilon [\underline{\theta}, \overline{\theta}]$ of our model is suited to capture both phenomena. Moreover, it is noteworthy that the demand fluctuations are central to our analysis, as only then the different market clearing mechanisms begin to matter. An analysis without demand fluctuations would thus not generate any useful insights for the design of liberalized electricity markets. We discuss the implications stemming from the demand fluctuations in detail in Section 1.4.

[15]In the case of the electricity sector, nuclear-, lignite-, coal-, and gas-fired power plants are usually used by energy companies. Nuclear power plants have very high investment costs but a low cost of production, while gas-fired power plants have relatively low investment cost and a high cost of reduction. Hence, nuclear power plants can be interpreted as baseload plants and gas-fired power plants as peakload plants. Lignite- and coal-fired power plants have a cost structure that locates them somewhere in between nuclear- and gas-fired plants.

assume that investment in additional transmission capacity is less costly than investment in peakload capacity, $t < k$. This reflects the situation in the electricity sector, where transmission expansion is considerably cheaper than generation expansion.[16] In Section 1.6 we relax this assumption in order to discuss its relevance for our results. Generators know their production capacities, the nominal line capacity as well as the spot market demand at the time of making their production decision. Hence, produced quantities are contingent on the demand scenarios $\theta \in [\underline{\theta}, \overline{\theta}]$. However, the exact transmission capacity is only known after spot market production decisions have been made. This assumption is needed in order to establish an equilibrium and is explained in detail in Section 1.3. We abstract from any cost of transmission operation like line losses or other system services.

We consider two different mechanisms for transmission pricing in this study. Under *simultaneous market clearing* the operation of the network is governed by a system of optimal nodal prices, that is, a price at the supply node and a price at the demand node. These nodal prices adjust in such a way that the market is always cleared. If transmission capacity is abundant, trade between the two nodes leads to identical prices at both nodes. However, if transmission capacity is scarce, trade between the two nodes is restricted and prices at the two nodes diverge. At the demand node a high price occurs, while at the supply node competition among generators leads to a low price. The price differences between the two nodes in the case of a congested transmission line ('congestion rents') can be used by the regulator to finance transmission investment.

Under *sequential market clearing* the operation of the network is governed by a single spot market price in the whole network. In case the transmission capacity is scarce, trade at the spot market takes place as if no congestion occurs, though this might lead to physically infeasible spot market outcomes. After the spot market has taken place and the de facto transmission capacities are realized, the system operator assures whether or not the spot market outcome is feasible, that is, production is not larger than transmission capacity. If this is not the case, the system operator runs an adjustment market. In this market the system operator engages as a seller at the demand node and as a buyer at the supply node, such that the production volume just matches the transmission capacity. Notice that in the adjustment market the price at the demand node always lies above the price at the supply node. Hence, it is costly for the system operator to run the adjustment market. The adjustment market as well as transmission investment are financed via a transmission fee raised from the generators.

The timing is as follows: 1.) The optimal transmission investment decision is made. 2.) Generators decide upon generation capacity investments. 3.) The system operator runs the spot market: ($i$) Spot market realization $\theta$ is determined. ($ii$) Generators set

[16] An overview of investment costs for different generation and transmission technologies can be found in Schaber, Steinke and Hamacher (2012).

production quantities. (*iii*) Transmission line uncertainty is revealed. (*iv*) If necessary, in a system with sequential market clearing, the system operator runs the adjustment market.

## 1.3 Simultaneous Market Clearing

In this section, we analyze the effect of a spot market design with simultaneous market clearing on industry investment in generation capacity and the optimal transmission capacity investment. With simultaneous market clearing, spot market prices at the two nodes in the network diverge from each other when the transmission line is constrained. This system allows to directly take transmission constraints into account at the spot market.

We provide a short description of the spot market, in order to understand the concept of simultaneous market clearing: For given generation and transmission capacities and demand realizations, competitive generators want to produce until marginal cost equals the market price. The marginal cost is either given by the characteristics of the baseload or the peakload production units. Moreover, generators are constrained by their capacity in their production decision. The latter is denoted by $Q'(\theta)$. Demand is restricted by the transmission capacity $L$, which is needed to transport the electricity from the supply to the demand node. As long as the transmission capacity exceeds the generation production decision ($Q'(\theta) < L$) trade takes place without limitations. However, if the generation production decision exceeds the transmission capacity ($Q'(\theta) > L$) prices at the two nodes have to diverge to clear the market. The price at the supply node is kept down at marginal cost through competition among generators. The price at the demand node, however, rises above the price at the supply node, such that consumers just demand a quantity equal to the transmission capacity $L$.

In order to establish an equilibrium under simultaneous market clearing, a small technical assumption has to be made. When the production decision equals the transmission capacity ($Q'(\theta) = L$) an arbitrarily small amount of uncertainty for the overall size of transmission capacity is needed: The transmission line is subject to some uncertainty, that is, the de facto transmission capacity, denoted by $T$, is slightly different from the nominal line size and given by $T = L + \varepsilon$.[17] The support $[-\epsilon, +\epsilon]$ of the random shock $\varepsilon$ can be deliberately small (i.e., $\epsilon \to 0$). We denote the density of $T$ by $g(T)$ and its

[17] Notice that this assumption is in line with the technical properties of electricity transmission. De facto transmission capacities usually depend on environmental conditions and operational actions in the transmission network. For example, 'the import capacity of Path 15 (connecting Northern and Southern California) varies between about 2600 MW and 3950 MW depending upon the ambient temperature and remedial action schemes that are in place to respond to unanticipated outages of generating plants and transmission lines.' (see Joskow and Tirole (2005), fn. 20)

distribution by $G(T)$. For simplicity, if $|L - Q'(\theta)| < \varepsilon$ holds, we refer to $Q'(\theta) = L$ in the remainder of this chapter. This implies that peakload generation units can only earn positive scarcity rents, if the de facto line capacity exceeds the total generation capacity $(T \geq X)$.

The following Lemma characterizes investment under a system with simultaneous market clearing.

**Lemma 1.1.** *[Generation and Transmission Investment - Simultaneous Market Clearing] Under a system with simultaneous market clearing, industry investment in generation* $\left(\hat{X}, \hat{X}_1\right)$ *is uniquely characterized by*

$$\hat{X}: \left\{\left(1 - G\left(\hat{X} - \hat{L}\right)\right) \int_{\theta^X}^{\bar{\theta}} \left(P\left(\hat{X}, \theta\right) - c\right) dF(\theta) = k\right\}$$

$$\hat{X}_1: \left\{\int_{\theta^{\underline{X_1}}}^{\theta^{\overline{X_1}}} \left(P\left(\hat{X}_1, \theta\right) - c_1\right) dF(\theta) + \int_{\theta^{\overline{X_1}}}^{\bar{\theta}} (c - c_1) \, dF(\theta) = k_1 - k\right\}.$$

*The optimal line* $\left(\hat{L} = \hat{X}\right)$*, given industry investment, is uniquely characterized by*

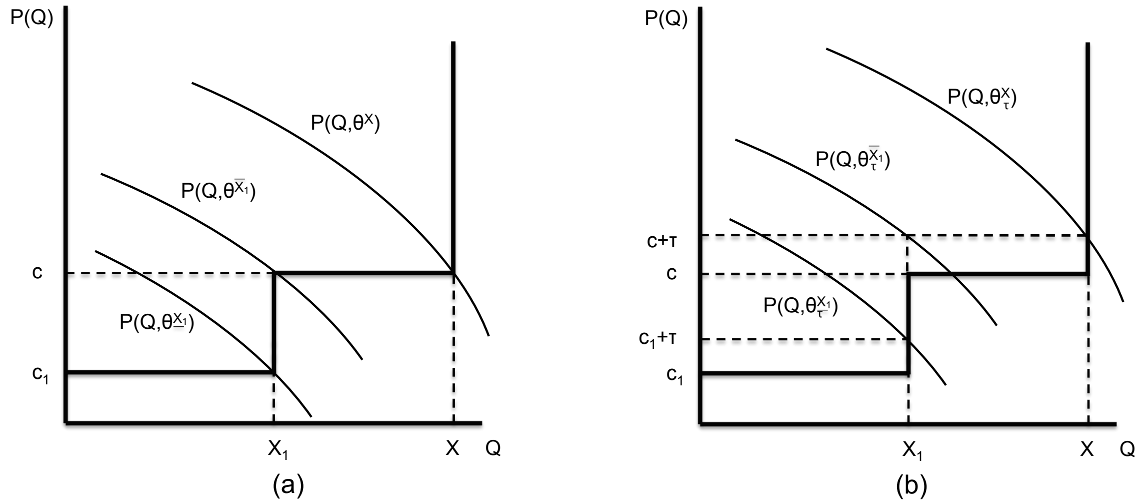
$$\hat{L}: \left\{G\left(\hat{X} - \hat{L}\right) \int_{\theta^X}^{\bar{\theta}} \left(P\left(\hat{L}, \theta\right) - c\right) dF(\theta) = t\right\}.$$

$\theta^{\underline{X_1}}$ *is the spot market scenario beyond which baseload investment is binding,* $\theta^{\overline{X_1}}$ *is the spot market scenario beyond which firms produce at the marginal cost of the peak load technology* $c$ *and* $\theta^X$ *is the spot market scenario beyond which total investment is binding.*

*Proof.* See Appendix. ■

The critical spot market scenarios are illustrated in graph $(a)$ of Figure 1.2. Notice that $\theta^{\underline{X_1}}$, $\theta^{\overline{X_1}}$ and $\theta^X$ are defined by the respective spot market conditions, that is: At $\theta^{\underline{X_1}}$ and quantity $X_1$ marginal revenue equals the marginal cost of baseload production $c_1$. At $\theta^{\overline{X_1}}$ and quantity $X_1$ marginal revenue equals the marginal cost of peakload production $c$. At $\theta^X$ and quantity $X$ marginal revenue is equal to the marginal cost of peakload production $c$.

Figure 1.2: Illustration of the critical spot market scenarios for given investment decisions $(X, X_1, L)$, with $X = L$. $(a)$ critical spot market scenarios in the absence of a transmission fee $\tau$. $(b)$ critical spot market scenarios when a transmission fee $\tau$ exists.




The characterization of the investment outcome in the lemma is rather intuitive.

First, generation and transmission capacity are of equal size $\left(\hat{X} = \hat{L}\right)$: The optimal transmission line capacity does not exceed the generation capacity built by investors $\left(\hat{L} \leq \hat{X}\right)$ as capacity is costly and the exceeding capacity would never be utilized. In addition, peakload generators can only earn positive scarcity rents at the spot market, when they constitute the constraining element in the market $\left(\hat{X} \leq \hat{T}\right)$. Hence, generation capacity does not exceed the transmission capacity $\left(\hat{X} \leq \hat{L}\right)$. As neither generation nor transmission capacity is larger than the other in equilibrium, it has to hold that both are of equal size $\left(\hat{X} = \hat{L}\right)$.

Second, consider total generation capacity. In equilibrium, the scarcity rents earned by generators beyond spot market $\theta^X$, when the transmission line is not congested, are equal to the marginal cost of investment $k$. As the nominal transmission capacity $\hat{L}$ differs from the de facto transmission capacity $\left(\hat{T} = \hat{L} + \varepsilon\right)$ the transmission line is uncongested with probability $1 - G\left(\hat{X} - \hat{L}\right)$. Notice that investment in generation capacity is solely determined by the peakload generation characteristics. Due to the higher production cost, the peakload generation units are employed in the spot market only after baseload generation units have been fully utilized, that is, beyond demand realization $\theta^{\overline{X_1}}$. Hence, the characteristics of these 'marginally' employed generation units are decisive for total capacity investment. Additional capacity is only valuable at the marginal demand levels, when capacity is scarce, that is, beyond demand realization $\theta^X$, when total capacity is met and the spot market price rises above the peakload production cost $c$.

Third, consider transmission capacity. In equilibrium, the marginal value of transmission capacity, namely, the scarcity rents when the transmission line is congested beyond spot market $\theta^X$, is equal to the marginal cost of investment $t$. Congestion only occurs beyond spot market $\theta^X$ with probability $G\left(\hat{X}-\hat{L}\right)$. Notice that the price differences occurring between the supply and the demand node just equal the transmission investment costs. Hence, no additional revenue for financing the transmission line is necessary and no extra transmission fee is needed. The identical result can also arise as the outcome in a transmission merchant investment model, where financial transmission rights are issued to investors to determine and finance the transmission capacity (see also Joskow and Tirole, 2005).

Fourth, the most intuitive way to describe baseload capacity investment $\hat{X}_1$ is as a replacement trade-off. Replacing a unit of baseload generation with a unit of peakload generation causes higher investment costs by $k_1 - k$ as the former is more expensive to build than the latter. However, the baseload unit has cheaper production costs. Therefore, at all spot markets when peakload generation is used, that is, beyond $\theta^{\overline{X_1}}$, substituting peakload with baseload generation creates a gain equal to the difference in production cost $c - c_1$. Moreover, the baseload unit is already profitable to run at lower spot markets as the peakload unit, that is, before $\theta^{\overline{X_1}}$, and earns additional scarcity rents whenever baseload capacity is constrained but peakload generation is not profitable to run yet, that is, at all spot markets $\theta \epsilon \left[\theta^{\underline{X_1}}, \theta^{\overline{X_1}}\right]$.

The following remark compares the investment performance under simultaneous market clearing with the socially optimal investment outcome which is denoted by $(X^*, X_1^*, L^*)$.

**Remark 1.1.** *[Generation and Transmission Investment - Simultaneous Market Clearing] The solution obtained under a system with simultaneous market clearing gives rise to the socially optimal investment, in total generation investment* $\left(\hat{X} = X^*\right)$*, in the baseload technology* $\left(\hat{X}_1 = X_1^*\right)$ *as well as in the transmission line* $\left(\hat{L} = L^*\right)$*.*

*Proof.* See Appendix. ■

This result is in line with the previous literature on locational marginal pricing (see, e.g., Hogan, 1999, and Joskow and Tirole, 2005). Since generation investors behave perfectly competitive, firms invest in additional generation capacity up to the point when the generation scarcity rents equal the investment cost and the marginal profit from investment is zero. With simultaneous market clearing, these scarcity rents at each spot market realization just reflect the locational marginal value of generation at each node and provide the efficient signal for investment. Hence, the generation investment outcome corresponds to the socially optimal solution.

## 1.4 Sequential Market Clearing

This section analyzes industry investment in generation capacity and optimal investment in transmission capacity under sequential market clearing. Subsequently, we compare the outcome to the results from Section 1.3. With sequential market clearing only a single spot market price for the whole network exists. This single spot market price is insufficient to take transmission constraints into account and might lead to infeasible spot market outcomes. Therefore, if necessary, the system operator runs an adjustment market to finally achieve market clearing after the spot market has taken place and when the actual transmission capacity is known.

In order to understand the concept of sequential market clearing, we provide a short description of the spot market: For given capacities, competitive generators want to produce until marginal cost equals the market price. The marginal cost is either given by the characteristics of the baseload or the peakload production units. The resulting spot market production decision, denoted by $Q\text{'}(\theta)$, is constrained by the generators capacity. Moreover, trade is physically restricted by the de facto transmission capacity $T$. However, with sequential market clearing, trade at the spot market takes place as if this transmission constraint did not exist. Thus, the generators' production decision at the spot market might even exceed the transmission capacity ($Q\text{'}(\theta) > T$). Yet, such a spot market outcome is physically infeasible. In order to ensure market clearing in this case, the system operator runs an adjustment market after the spot market has taken place. At the adjustment market, the system operator engages as a buyer of the 'exceeding' quantity $Q\text{'}(\theta) - T$ at the demand node and as a seller of equal quantity at the supply node, such that the market outcome becomes feasible. This produces prices at the adjustment market, which are equal to the spot market prices at the different nodes with simultaneous market clearing, though the trade volume at the adjustment market is less. Notice that in contrast to simultaneous market clearing, where revenues are generated through the price differences, running a market with sequential market clearing is costly. The reason is that the system operator has to engage as a buyer at the 'expensive' demand node and as a seller at the 'inexpensive' supply node.

The following Lemma characterizes investment in generation and transmission under a system with sequential market clearing.

**Lemma 1.2.** *[Generation and Transmission Investment - Sequential Market Clearing] Under a system with sequential market clearing, industry investment in generation* $\left(\tilde{X}, \tilde{X}_1\right)$ *is uniquely characterized by*

$$\tilde{X} : \left\{ \int_{\theta_\tau^X}^{\bar{\theta}} \left(P\left(\tilde{X}, \theta\right) - \tau - c\right) dF\left(\theta\right) = k \right\}$$

$$\tilde{X}_1 : \left\{ \int_{\underline{\theta_\tau^{X_1}}}^{\theta_\tau^{\overline{X_1}}} \left( P\left(\tilde{X}_1, \theta\right) - \tau - c_1 \right) dF\left(\theta\right) + \int_{\theta_\tau^{\overline{X_1}}}^{\bar{\theta}} \left( c - c_1 \right) dF\left(\theta\right) = k_1 - k \right\}.$$

*The optimal line* $\left(\tilde{L} = \tilde{X}\right)$*, given industry investment, is uniquely characterized by*

$$\tilde{L} : \left\{ \int_{\theta_\tau^L}^{\bar{\theta}} \left( P\left(\tilde{L}, \theta\right) - c \right) dF\left(\theta\right) \geq t \right\}.$$

$\tau$ *is a transmission fee the regulator charges in order to compensate the transmission investment expenses.* $\theta_\tau^{\underline{X_1}}$ *is the spot market scenario beyond which baseload investment is binding,* $\theta_\tau^{\overline{X_1}}$ *is the spot market scenario beyond which firms produce at the marginal cost of the peak load technology c,* $\theta_\tau^X$ *is the spot market scenario beyond which total investment is binding and* $\theta_\tau^L$ *is the spot market scenario beyond which the transmission capacity is binding.*

*Proof.* See Appendix. ■

The critical spot market scenarios are illustrated in graph $(b)$ of Figure 1.2. $\theta_\tau^{\underline{X_1}}$, $\theta_\tau^{\overline{X_1}}$, $\theta_\tau^X$ and $\theta_\tau^L$ are defined by the respective spot market conditions, that is: At $\theta_\tau^{\underline{X_1}}$ and quantity $X_1$ marginal revenue is equal to the marginal cost of baseload production plus the transmission fee, $c_1 + \tau$. At $\theta_\tau^{\overline{X_1}}$ and quantity $X_1$ marginal revenue is equal to the marginal cost of peakload production plus the transmission fee, $c+\tau$. At $\theta_\tau^X$ and quantity $X$ marginal revenue is equal to the marginal cost of peakload production $c$ plus the transmission fee, $c + \tau$. Again, the characterization of the investment outcome in the Lemma is rather intuitive. We discuss the investment outcome in detail in the following paragraphs.

First, generation capacity is built as if transmission constraints did not exist. In equilibrium, the total generation scarcity rents, that is, beyond spot market realization $\theta_\tau^X$, are equal to the peakload generation investment cost $k$, regardless of potential transmission congestion. However, notice that the generation scarcity rents are reduced by the transmission fee $\tau$. As the transmission fee increases the generators' perceived production cost above the actual production cost, the generators produce less quantity at all spot markets when capacity constraints are not met and capacity constraints are only reached at higher spot markets. That is, generators earn scarcity rents only at spot markets beyond $\theta_\tau^X$. An illustration of these distortions can be found in graph $(b)$ of Figure 1.2.

Second, consider transmission capacity. In equilibrium, the marginal value of transmission capacity is equal to the marginal cost of investment $t$. Notice that, as generation investment takes place regardless of the existence of sufficient transmission capacity, the marginal value of transmission capacity is equal to the full scarcity rents beyond spot market $\theta_\tau^L$ for $\tilde{L} \leq \tilde{X}$. Furthermore, since $t < k$, the marginal value of transmission capacity is larger than the marginal revenue of generation capacity. Hence, the optimal transmission capacity is never smaller than the generation capacity. As the optimal transmission capacity also never exceeds the generation capacity, the transmission capacity again just matches the generation capacity $\left(\tilde{L} = \tilde{X}\right)$. Finally, observe that since $\tilde{L} = \tilde{X}$ there is no trading volume at the adjustment market and no extra cost for running the adjustment market occurs.

Third, the baseload generation investment outcome can again be best understood in a replacement context as in Section 1.3, under simultaneous market clearing. Replacing a peakload by a baseload generation unit causes higher investment costs. However, it also decreases the production cost, whenever it is profitable for a peakload unit to produce. In addition, production becomes profitable at spot market realizations, when peakload units would still be unprofitable to run.

Now we can state our main result, which compares investment under sequential market clearing with investment under simultaneous market clearing.

**Proposition 1.1.** *[Generation and Transmission Investment] If demand is inelastic, $|\eta| \leq 1$, the solution obtained under a system with sequential market clearing gives rise to*

*(i)* *higher investment in total generation capacity $\left(\tilde{X} > \hat{X}\right)$,*

*(ii)* *lower investment in baseload capacity $\left(\tilde{X}_1 < \hat{X}_1\right)$ and*

*(iii)* *higher investment in total transmission capacity $\left(\tilde{L} > \hat{L}\right)$*

*compared to investment under a system with simultaneous market clearing.*

*Proof.* See Appendix. ■

Let us provide an intuition for this result. Regardless of the specific market design, the cost of transmission investment has to be fully recouped from the market participants. Under simultaneous market clearing, the transmission congestion rents are sufficient for financing the transmission line. These price differences only occur at the 'marginal' spot markets, that is, beyond $\theta^X$, when generators potentially earn scarcity rents which determine the generation capacity. Under sequential market clearing, no such price differences occur. A linear transmission fee is levied on the generators' usage of the transmission line at all spot market realizations. This implies that the cost of transmission investment is partly recouped at the 'inframarginal' spot market realizations, that is, before $\theta_\tau^X$, which are irrelevant for the investment decision. Therefore, the transmission fee is lower than it would be if it was only collected at the marginal spot market realizations. Thus, the transmission fee is also lower at all spot market realizations beyond $\theta_\tau^X$, and consequently, the scarcity rents earned by generators' are larger compared to a system with simultaneous market clearing. With larger scarcity rents, investment becomes more profitable and more generation capacity is built.

However, notice that the spot market distortions caused through the transmission fee have the reverse effect on investment. Hence, the result in Proposition 1.1 only holds if demand is inelastic ($|\eta| \leq 1$). Most studies find price elasticities of demand in the electricity sector of $0.1 - 0.5$ in the short run and $0.3 - 0.7$ in the long run. See, e.g., Lijsen (2006) for an overview of recent contributions on that issue. This implies that the introduction of the transmission fee does not cause too severe spot market distortions. That is, the spot market quantities are not distorted too much, and hence, the critical spot market realizations are not too different from those without a transmission fee.

The result for baseload investment is contrary to that for total investment. Under simultaneous market clearing, firms' replacement decisions are independent of the level of transmission capacity (as long as we have an interior solution with positive peakload investment). Hence, the replacement decision is independent of the cost of the transmission line. In principle, this also obtains under sequential market clearing, that is, the transmission fee $\tau$ has no impact on the replacement decision. An exception is given, however, by those spot market realizations, where baseload is binding, as scarcity rents in those cases are reduced. In total, this leads to lower baseload investment compared to simultaneous market clearing. Eventually, as the transmission capacity just matches the generation capacity, the transmission capacity is also larger compared to simultaneous market clearing.

Finally, it is noteworthy that the assumption on fluctuating demand is central for our results. Only then the different market clearing mechanisms begin to matter. As explained in this section, investment differs between sequential and simultaneous market clearing, as the generation scarcity rents are different. This is due to the fact that under sequential market clearing the cost of transmission investment is partly recouped at the 'inframarginal' spot market realizations before $\theta_\tau^X$. Hence, the transmission fee is lower at all spot market realizations beyond $\theta_\tau^X$, and consequently, the scarcity rents earned by generators are larger compared to a system with simultaneous market clearing. Without demand fluctuations, this distinction could not be made, as only a single spot market realization exists. An analysis without demand fluctuations would thus not generate any useful insight on the impact of different transmission management regimes on firms' investment incentives as analyzed in the present framework.

## 1.5 Policy Implications

The allocation of scarce transmission capacity in electricity markets is an intensively debated topic. In the U.S., seven regional electricity markets have introduced simultaneous market clearing: The PJM electricity market in 1998, the New York (NYISO) market in 1999, the New England market (ISO-NE) in 2003, the Midwest market (MISO) in 2005, the California market (CAISO) and the Southwest Power Pool (SPP) in 2007 and the Texas market (ERCOT) in 2010.[18] In contrast, most European electricity markets continue to use sequential market clearing. To this date, simultaneous market clearing has only been introduced in the Polish electricity market in 2011. However, the rapid and regionally concentrated increase in new low-carbon generation as well as the retirement of old generation in Europe puts pressure on the existing transmission grid. Old and new generation facilities are typically not located at the same production site. This creates the need for efficient transmission management.[19] This development has led to intense debates about shifting towards simultaneous market clearing in the U.K. as well as in Germany. The British electricity regulator *Ofgem* is currently reviewing the electricity transmission charging arrangements as part of its 'Project TransmiT' (compare Ofgem, 2010, and Redpoint Energy, 2011). The German electricity regulator *Bundesnetzagentur* has recently commissioned a study on the introduction of locational pricing (see Frontier, 2011). Moreover, the debate in Germany has gained pace after the decision in 2011 to phase out nuclear power, which has put the transmission grid under pressure (see Bundesnetzagentur, 2011). Also, the European authorities exert strong pressure towards an approach using locational pricing between regional markets on the European level. Transmission congestion management is seen as a key element in the efforts by the *European Commission* to establish a fully functioning electricity market in Europe until 2014 (see, e.g., European Parliament, 2009, and European Council, 2011). For this purpose the European energy regulator *Acer* has developed 'Framework Guidelines on Capacity Allocation and Congestion Management for Electricity' (see Acer, 2011) and the *Electricity Regulatory Forum*, which was established by the *European Commission* to promote an internal market for energy, has proposed a 'Target Model for Capacity Allocation and Congestion Management' (see Electricity Regulatory Forum, 2011).[20]

Many contributions have extensively analyzed the impact of the different transmission management regimes. Compare, e.g., Joskow and Tirole (2000) and Gilbert et al. (2004) who analyze the effect of different transmission allocation mechanisms on generation spot market conduct. Moreover, Wolak (2011) and Green (2007) estimate the short run welfare

[18]Compare also, e.g., O'Neill et al. (2006, 2008).

[19]Neuhoff et al. (2011a, 2011b) show that the introduction of simultaneous market clearing might lead to substantial operational cost savings as well as a reduction in marginal power prices in the majority of the European countries.

[20]To the Electricity Regulatory Forum it is also regularly referred as the 'Florence Forum'.

loss due to non-locational pricing in California resp. England and Wales. However, all these articles typically focus on short run spot market conduct, leaving aside long run aspects such as investment incentives in transmission and generation facilities. Recently, experts[21] as well as policy makers[22] have increasingly emphasized that for the proper functioning of electricity markets not only short run efficiency, but also long run incentives are of central importance. Moreover, a detailed analysis of the long run perspective seems to be of particular importance in the light of the ongoing debate on insufficient incentives in liberalized electricity markets to provide generation investment (see for the 'missing money discussion', Oren, 2005, Hogan, 2005, Cramton and Stoft, 2006, Joskow, 2007, and Cramton and Ockenfels, 2011). Till date, this debate has entirely abstracted from issues arising due to the presence of transmission networks. As we show, in a system with sequential market clearing, investment incentives turn out to be higher than in systems with simultaneous market clearing. As a central message of our findings, policy makers should thus be aware that switching from a system of sequential market clearing to a system of simultaneous market clearing probably has a negative impact on firms' investment incentives. This is desirable in a setting like ours, where no market distortions exist. However, if investment incentives in a specific market are already perceived as too low, as indicated in the literature on missing money, a change in the transmission management regime might then further aggravate these problems. This leads to an increased need for adequate measures to overcome these problems.

As pointed out throughout our analysis, the investment outcome closely depends on the structure of transmission financing. So far our analysis of sequential market clearing has only considered a linear transmission fee. However, in some electricity markets non-linear elements in the transmission fee can be found. The effect of such non-linearities critically depends on their specific structure. In the remainder of this section, we discuss the impact of two common non-linearities in the transmission fee.

First, the transmission fee is raised as a lump sum payment per generator.[23] Then the effect on total generation and transmission investment is even stronger compared to a linear transmission tariff. However, investment in baseload capacity is undistorted. With a lump sum transmission fee, no spot market distortion occurs and generation scarcity rents are even larger. Hence, more investment takes place in generation capacity and also the transmission line. Notice that overinvestment in transmission capacity always occurs,

[21] Baldick et al. (2011) argue that 'the energy sector is now facing an unprecedented investment challenge driven by the need to connect large amounts of new generation to the electricity networks to meet climate change targets, while continuing to provide value for money for consumers and security of supply.'

[22] The 2009 EU directive states that 'undistorted market prices would provide an incentive for cross-border interconnections and for investments in new power generation', compare European Parliament (2009).

[23] This might be the case when the transmission fee is levied on generators in a way uncorrelated to the system demand. This is, for example, the case with a fee for network connection as the sole source of transmission financing.

that is even for $t > k$. Baseload investment takes place efficiently again, as long as the lump sum fee is levied on generators regardless of the generation technology used.
Second, the transmission fee can be conditioned on the spot market outcome.[24] In such a system the transmission fee is calculated on the basis of the generators' individual contribution to market output during demand peak. This implies that the transmission fee is implicitly conditioned on the spot market realization $\theta$. If the transmission fee is perfectly set, the net revenue a generator receives, that is, the market price minus the transmission fee, is equal to the revenue in a system with simultaneous market clearing. Hence, such a system can lead to the socially optimal investment outcome.

## 1.6 Extensions

**Expensive Transmission.** Our analysis so far was based on the assumption $t < k$. This assumption implies that the transmission capacity matches the generation capacity under sequential market clearing. If we relax this assumption, the transmission capacity can also be smaller than the generation capacity, $\tilde{L} < \tilde{X}$. Nevertheless, all results established in Lemmata 1.1 and 1.2 and Proposition 1.1 (*i*) and (*ii*) remain valid. While our results with respect to generation investment do not change, there is not necessarily overinvestment in transmission capacity. The regulator faces two effects when deciding how much transmission capacity to build, that is, a *sunk cost effect* and a *spot market distortion effect*. The *sunk cost effect* captures the fact that generation investment does not depend on the available transmission capacity under sequential market clearing. When expanding transmission capacity, the regulator does not have to take the additional cost of generation investment into account as it is already sunk. The *spot market distortion effect* captures the distortion at the spot market caused by the transmission fee and is detrimental to the *sunk cost effect*. Technically, the effects are given by

$$\underbrace{-\int_{\theta^L}^{\theta_\tau^L} \left(P\left(L,\theta\right)-c\right) dF\left(\theta\right)}_{Spot\, Market\, Distortion\, Effect} + \underbrace{k}_{Sunk\, Cost\, Effect} .$$

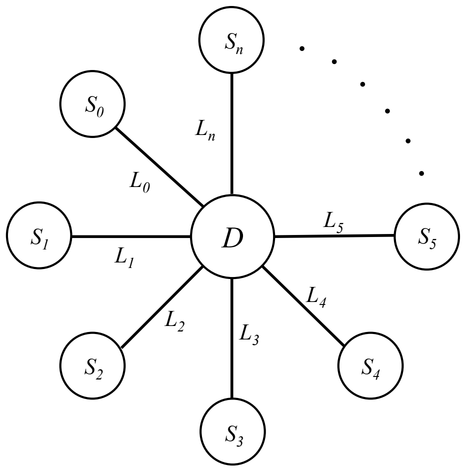
Notice that both effects are independent from each other. Hence, one or the other effect can be larger. If the *sunk cost effect* exceeds the *spot market distortion effect*, the transmission capacity is smaller than under simultaneous market clearing $\left(\tilde{L} < \hat{L}\right)$ otherwise

[24]E.g., in the British electricity market, one element in the calculation of the transmission fee (i.e., the Transmission Network Use of System or TNUoS charges) is based on the so called 'triad demand'. According to National Grid 'Triad Demand is measured as the average demand on the system over three half hours between November and February (inclusive) in a financial year. These three half hours comprise the half hour of system demand peak and the two other half hours of highest system demand which are separated from system demand peak and each other by at least ten days.' (see http://www.nationalgrid.com/uk/Electricity/SYS/glossary/#tri and http://www.ofgem.gov.uk/Networks/Trans/ElecTransPolicy/Charging/Pages/Charging.aspx)

it is larger $\left(\tilde{L} > \hat{L}\right)$. Notice that the *sunk cost effect* is clearly larger than the *spot market distortion effect* for $t < k$, and hence, overinvestment in transmission capacity $\left(\tilde{L} > \hat{L}\right)$ occurs.

**Complex Networks.** In this section, we show that our results from Section 1.4 for a two-node network can be easily generalized to more complex networks. In principle, our findings hold for any star-network with an arbitrarily large number of nodes. An example for such a network with $n$ nodes is presented in Figure 1.3. We illustrate this generalization in the simplest possible star-network with one demand and two supply nodes.[25]

Figure 1.3: $n$-node star network




We assume that the cost of transmission investment $t$ is identical for both transmission lines. Moreover, we denote the capacity of the transmission line connecting the 'baseload node' with the demand node by $L_1$ and the sum of transmission line capacities by $L$. The capacity of the transmission line connecting the 'peakload node' with the demand node is given by $L - L_1 = L_0$. Thus, the only difference between the three-node network and the two-node network lies in the fact that the baseload generators are connected to the demand node via a separate line, where congestion can occur independently of the peakload line. In the subsequent analysis we focus on why this is irrelevant and does not change our results.

With simultaneous market clearing - as before -, both transmission line capacities exactly

[25] Since the use of different generation technologies is often restricted to certain geographical locations or nodes in the network, we consider a situation, where all the baseload generation is located at one of the two supply nodes, while all the peakload generation is located at the other supply node. Wind turbines or solar panels can only be used at sufficiently windy or sunny locations, gas-fired power plants require access to a gas pipeline, lignite-, coal- and nuclear-fired plants need access to large quantities of water. Moreover, the transport of lignite and coal is rather costly, so that access to transport facilities is required and the location of nuclear-fired plants has to fulfill certain safety regulations.

match the generation capacities at the respective supply nodes $\left(\hat{L}=\hat{X},\, \hat{L}_1=\hat{X}_1\right)$. Moreover, though both generation technologies are connected via different transmission lines, which can be congested independently from each other, baseload investment can again be expressed as a replacement trade-off independent from the cost of transmission. In other words, under simultaneous market clearing, the contribution of a generation unit to transmission financing is independent of the generation technology used. Replacing a peakload unit with a baseload unit makes additional baseload transmission capacity necessary. However, the same amount of transmission capacity becomes superfluous at the peakload node. Hence, the total transmission capacity in the network remains unchanged. Notice that in equilibrium the marginal value of transmission has to be equal for both lines as the marginal cost of transmission investment $t$ is the same for both lines. This implies that both transmission lines are built such that the resulting total scarcity rents at each line times the probability of congestion are identical. Since the total scarcity rents from the baseload technology are higher than those from the peakload technology, it has to hold that the baseload line is less often congested relative to the peakload line.

The following remark compares the investment performance under simultaneous market clearing with the socially optimal investment outcome which is denoted by $(X^*, X_1^*, L^*, L_1^*)$.

**Remark 1.2.** *[Generation and Transmission Investment - Simultaneous Market Clearing] The solution obtained under a system with simultaneous market clearing gives rise to the socially optimal investment in the base load technology* $\left(\hat{X}_1=X_1^*\right)$*, in total generation investment* $\left(\hat{X}=X^*\right)$ *as well as in the transmission lines* $\left(\hat{L}=L^*,\, \hat{L}_1=L_1^*\right)$.

This remark resembles the result stated in remark 1.1. Hence, simultaneous market clearing also gives efficient investment signals in more complex star-networks.

With sequential market clearing, again, both transmission line capacities exactly match the generation capacities at the respective supply nodes $\left(\tilde{L}=\tilde{X},\, \tilde{L}_1=\tilde{X}_1\right)$. However, as in a two-node network, the subsequently built generation capacity does not depend on the existence of the transmission capacity. Hence, the size of the transmission lines is solely determined by the generation capacity. This implies that the marginal value of transmission capacity is not necessarily equal among both transmission lines as it was the case under simultaneous market clearing. In the following, we state our main result for the three-node network, which compares industry investment in generation and optimal transmission investment under sequential market clearing with investment under simultaneous market clearing.

**Proposition 1.2.** *[Generation and Transmission Investment - Star Network] If demand is inelastic,* $|\eta|\leq 1$*, the solution obtained under a system with sequential market clearing in a star-network with* 3 *nodes gives rise to the identical investment outcome as described* *in Proposition 1.1. That is, sequential market clearing leads to (i) higher total investment,* $\tilde{X} > \hat{X}$, *(ii) lower investment in baseload generation capacity,* $\tilde{X}_1 < \hat{X}_1$, *as well as (iii) higher transmission capacity,* $\tilde{L} > \hat{L}$, *compared to investment under simultaneous market clearing.*

*Proof.* See Appendix. ■

This Proposition supports the results in Proposition 1.1 for the two-node network and shows that our findings from Section 1.4 can be easily generalized to more complex star-networks.

## 1.7 Conclusion

Market design is important in network industries as potential congestion between different locations can create a significant barrier to trade. In this regard, there are two competing approaches: Either, the whole network is designed as a single market with only one price, where potential network congestion is treated through an alternative mechanism outside the market, or different prices are introduced at different locations, which can take potential congestion into account. A prominent example for such a problem is given by the management of transmission capacity in liberalized electricity markets. In the U.S. most markets already implemented simultaneous market clearing, but in Europe sequential market clearing is still used in the vast majority of electricity markets. However, the rapid replacement of old carbon intense power plants by new and low carbon generation puts the transmission grid under pressure. Old and new generation facilities are typically not located at the same production site, as different production technologies often have different locational requirements. That is, e.g., gas-fired power plants need access to gas pipelines, while solar plants are only efficient to use in sunny areas. This creates the need for an efficient utilization of the existing transmission capacity. While many contributions exist on the short run effects on transmission management, experts and policymakers have highlighted the need for the proper long run investment incentives in generation and transmission capacity for the efficient functioning of the electricity sector. This study sheds light on the long run effects of different transmission management rules by introducing a network model with endogenous generation and transmission capacities. We analyze the impact of two regularly used market designs - simultaneous and sequential market clearing - on generation and transmission capacities as well as on the generation technology mix in the market.

First, we find that simultaneous market clearing leads to the socially optimal generation and transmission capacity as well as to the optimal technology mix. This confirms results from the previous literature (see, for example, Joskow and Tirole, 2005).

Second, we find that sequential market clearing leads to overinvestment in total generation and transmission capacity. Sequential market clearing disentangles the price signal from the location of production and hence, from its locational marginal value. This leads to exaggerated investment incentives.

Third, we find that under sequential market clearing the technology mix is distorted, that is, overinvestment in peakload capacity and underinvestment in baseload capacity takes place. This is because baseload generators contribute more to financing the transmission network than peakload generators and hence, investment in baseload becomes less lucrative.

The central message of our findings is that policy makers should be aware that switching from a system of sequential market clearing to a system of simultaneous market clearing probably has a negative impact on firms' investment incentives. This in turn aggravates potential investment problems stemming from market imperfections and institutional constraints in electricity markets, which have been identified in the literature on missing money. This might lead to an increased need for adequate measures to overcome those problems.

# Chapter 2

# Regulating Investments in Vertically Related Industries

## 2.1 Introduction

Vertically related monopolistic industries such as utilities (e.g., the electricity, gas, telecommunications or railway industry) are often under broad regulatory supervision. This usually includes the regulation of the monopolist's wholesale price and vertical separation. Under vertical separation the monopolistic upstream component is restricted from being active on the competitive downstream market. These measures are supposed to help avoid anticompetitive effects resulting from a monopolistic upstream segment.[26] However, if new technological opportunities arise in such an industry, it is often not clear which segment of the industry (upstream monopolist or downstream competitors) should conduct the investment on these new technologies. In such situations the regulator decides who should be responsible for the investment.

This study compares two different investment regimes in order to determine which regime provides the best possible investment incentives from a welfare perspective. Under an *upstream investment regime* the monopolist is responsible for a specific investment in the industry, while under a *downstream investment regime* the investment is 'liberalized' and the downstream firms may invest in the respective technology. We focus on how investment incentives in the different regimes are influenced by the nature of downstream competition (*Bertrand*- vs. *Cournot competition*) and the vertical structure of the industry, that is, *vertical separation (VS)* and *vertical integration (VI)*.

[26] Regulators generally refer to the 'disaggregated approach to regulation' according to which only the monopolistic component of an industry is subject to regulation, while all other components are left unregulated.

An example for such an investment scenario is the recently emerging smart meter technology in electricity distribution networks. Metering technology is needed by electricity suppliers to measure their customers' consumption in order to bill them. Traditional electricity metering technology (so called electromechanical induction meters) can only measure the delivered quantity over a specified period of time. With the newly emerging smart metering technology it has become possible to obtain a much higher functionality and accuracy, as compared to traditional technologies. These new features include two-way communication over power lines and the mobile phone network. This allows the use of flexible retail tariffs ('real-time pricing'), makes estimated readings and bills due to remote reading superfluous, avoids the need for profile estimation and improves information on network losses (compare, e.g., Frontier Economics, 2006). Responsibility for investment in this new metering technology is per se not linked to a distinct segment in the vertically related electricity industry. Studies show that the biggest benefits from installing smart meters do not arise at the (upstream) network segment, but at the (downstream) production and retail segment. A study on the British electricity market estimates the benefits from modern meter technology at £8.2bn for the downstream segment and at £0.3bn for the upstream segment (see Frontier Economics, 2009).[27] National regulators have chosen different approaches regarding investment in new meter technology. While in most of continental Europe the network owner is responsible for the investment (e.g. Italy), in the UK and Germany this responsibility falls on the downstream segment or is 'liberalized', that is, anybody except the network owner is allowed to invest.[28]

Our model analyzes a vertically related industry where the upstream good is provided by a regulated monopolist. For downstream firms the upstream good is an essential input to offer products to customers. These products are offered by a differentiated duopoly that competes either in quantities or in prices. Throughout the first part of the chapter, the industry is vertically separated (VS), that is, the upstream monopolist is not allowed to be active on the downstream market. Subsequently, we consider a setting with vertical integration (VI), where the monopolist is partially integrated into the downstream market. Before competition takes place, an investment opportunity for downstream process innovation arises. This investment lowers the marginal costs of the downstream firms. As the investment may possibly be conducted by both sectors of the industry, it is ultimately the regulator who decides which segment is responsible for the investment. Moreover, it is assumed that the investment cannot be undertaken by both

[27] Moreover, there is an undetermined externality on the environment (compare Frontier Economics, 2009). Another study argues that the particular needs of a heterogeneous customer base can be more easily taken into account under a downstream investment regime (compare Frontier Economics, 2011).

[28] Among regulators, the fear was expressed that a lock-in effect from investment in smart meter technology might exist resulting in the fragmentation of the downstream electricity market. This would render regulation of the access to meter equipment necessary. We abstract in our model from such effects. See, for example, Dow Jones Energy Weekly, 19, 2008, p.7-8.

sectors jointly.[29,30] The actual investment decision is taken after the investment regime is determined and for a given regulated wholesale price, but before firms supply products competitively to consumers. An interpretation of this assumption is that the investment is non-verifiable. Thus, the wholesale prices cannot be conditioned on the investment. We consider linear wholesale prices which are set in order to allow the upstream monopolist to fully recover its fixed costs. Linear wholesale prices are typical for regulated industries as regulators mostly do not allow for two-part tariffs as access price schemes. These are under suspicion to provide scope for misuse by the regulated monopolist.[31]

It is noteworthy that downstream process innovation has similar properties to our leading example: Smart metering technology includes functionality that makes real-time pricing possible. Real-time pricing allows generators to give their consumers time dependent price signals reflecting their cost of production. This leads to a lower average electricity generation cost given generation cost curves are convex and demand varies over time. Both assumptions are fulfilled in the electricity sector. Thus, downstream process innovation can be understood as a stylized way to model the effect of real-time pricing in a one period model.

Our main results are as follows: First, we show that in a vertically separated industry the optimal investment regime depends on the mode of competition and on the capital intensity of the upstream segment. Under Cournot competition, the downstream investment regime is always superior from a welfare perspective. Under Bertrand competition, however, the upstream investment regime is superior if the capital intensity of the upstream segment is sufficiently high.

Second, we show that the vertical ownership structure of the industry influences the optimal investment regime. While different investment regimes are optimal under vertical separation, under vertical integration, the downstream investment regime always outperforms the upstream investment regime, regardless of the mode of competition and the upstream capital intensity.

Our results have implications for policy making. They justify sector-specific approaches to regulatory decisions regarding the treatment of investments in network industries. Besides considering the specific characteristics of an investment, the nature of competition and the ownership structure of the industry should also be taken into account when the

[29]This assumption reflects reality as negotiations between the upstream monopolist and the downstream competitors might result in coordination failure. Moreover, regulators often prevent collaboration between the upstream monopolist and downstream competitors as they fear anticompetitive effects.

[30]We are abstracting from the question which industry segment actually wants to conduct the investment. This might arise when the investment is associated with high enough fixed costs, so that only one of the two segments is willing to invest. As we assume a convex investment cost function in our model, any segment would invest at least a bit when allowed to do so.

[31]Non-linear tariffs are under suspicion to make discrimination of the downstream competitors possible (see, e.g., European Commission, 2007, part 1, p. 58).

regulator determines the investment regime. These findings are particularly relevant for industries that are undergoing rapid technological changes, as is witnessed in the electricity industry.[32]

It has become a common notion in the literature to interpret different natures of competition as a manifestation of the importance of capacity constraints.[33] This interpretation allows us to derive the following tentative implications for regulatory policy: In sectors where capacity constraints play an important role on the downstream market (Cournot industries), the regulator should opt for the downstream investment regime, as it provides superior investment incentives. In contrast, when capacity constraints are inconsequential (Bertrand industries), upstream fixed costs in an industry are high (which might be the case in industries where the initial upstream investment has taken place recently) and the industry is vertically separated, the regulator should opt for the upstream investment regime, as this would provide the superior investment performance. A similar setting is often given just after rate-of-return regulation has been abandoned in an industry.[34]

This study contributes to the literature on investment behavior in vertically related industries. Buehler (2005) and Buehler et al. (2004, 2006) explore the issue of potential underinvestment in infrastructure. They investigate the effects of partial vertical integration as well as vertical separation on investment. Cremer et al. (2006) and Höffler and Kranz (2011a, 2011b) study whether legal unbundling, as an intermediate structure between vertical integration and vertical separation, can deliver a superior investment performance through combining the benefits of both vertical structures. They find a weakly positive impact on investments. However, all of these models solely investigate the effect of upstream investment activity, while we compare investment incentives by the upstream monopolist and by the downstream competitors for identical investment technologies. Banerjee and Lin (2003), Brocas (2003) and Buehler and Schmutzler (2008) also consider the impact of the vertical structure on downstream process innovation. However, in their work the downstream firms are always in charge of the investment, while in this study we also investigate investment by the upstream firm.

Moreover, this study relates to the literature on the nature of competition and its effect on investment behavior. Singh and Vives (1984) are the first to compare market outcomes of Bertrand and Cournot competition in a duopoly with differentiated goods. In our study, we use a framework similar to theirs to model downstream competition. Bester and Petrakis (1993) and Qui (1997) also use similar frameworks to model process innovation

[32]Detailed reports on new technological opportunities in the electricity industry can be found in Economist (2009a, 2009b).

[33]As Tirole (1988), p. 219, points out, "[...] what we mean by quantity competition is really a choice of scale that determines the firm's cost functions and thus determines the conditions of price competition. This choice of scale can be a capacity decision, [...]". Another reference is Kreps and Scheinkman (1983).

[34]Rate-of-return regulation is often associated with overinvestment in capacity (compare, e.g., Averch and Johnson, 1962).

and derive welfare comparisons among the different modes of competition.

Recently, several contributions have emerged, considering the impact of vertical ownership structures under different modes of competition on market conduct and investment. Arya et al. (2008) model different modes of competition in a vertical structure with an upstream monopoly. They investigate the price setting behavior of a vertically integrated monopolist owning the source of an essential input good with downstream competition. They partly contradict the findings of Singh and Vives (1984). But they do not consider pre-competition investments as we do. Chen and Sappington (2010) compare the incentives of an upstream monopolist to invest into upstream cost reduction and upstream product design for different vertical structures and modes of competition. They find that under Cournot competition VI always increases investment incentives, while under Bertrand competition VI might lead to a decrease. Mandy and Sappington (2007) model the incentives of a vertically integrated monopolist to sabotage downstream competitors by providing an inferior quality or raising their costs under different modes of competition.[35] Although these actions harm economic efficiency whereas investments improve it, the underlying incentives resemble those considered in our study. Finally, Chen and Sappington (2009) analyze the optimal regulation of wholesale prices in order to stimulate downstream process innovation considering different vertical structures as well as different modes of competition.

In the next Section we present our model. In Section 2.3 we derive our results for a vertically separated industry. In Section 2.4 we present the results for a vertically integrated industry. In Section 2.5 we relate this study to the current discussion on the implementation of smart metering technology in electricity distribution networks and provide some concluding remarks.

## 2.2 The Model

We consider an industry that consists of an upstream monopolist and a competitive downstream segment. The monopolist $U$ provides a good, which is an essential input required for producing the final product downstream. The provision of the upstream good involves a fixed cost $F > 0$, which is incurred whenever the monopolist decides to produce. In addition, each unit of the input good comes at a constant marginal cost, which we normalize to be 0. The upstream industry, thus, exhibits economies of scale which explains the monopolistic industry structure.

The monopolist is price regulated, that is, all units that are demanded have to be served at

[35] More on sabotage can be found in Economides (1998), Beard et al. (2001) and Sibley and Weisman (1998).

the regulated linear wholesale price $w$.[36] As the upstream marginal cost is normalized to 0, the wholesale price $w$ also represents the upstream margin. Price regulation is needed to avoid anticompetitive effects resulting from the monopolistic nature of the upstream sector. We assume that the wholesale price $w$ is set such that the upstream monopolist can just recover the fixed infrastructure cost $F$.[37] This implies that the wholesale price is always positive ($w > 0$) and, as is shown in the appendix, that it is an increasing function of the fixed cost, $w_F(F) > 0$ (see Section B.7 in the appendix).

We restrict our attention to two downstream firms, $D1$ and $D2$. These firms offer their products directly to consumers, but require the upstream good as an input. Downstream firms use a fixed proportions technology, that is, they transform one unit of the input good into one unit of the output good. The final product is differentiated and firms compete either in quantities $q_i$ or prices $p_i$, with $i \epsilon \{1, 2\}$ denoting the respective downstream firm. Following Singh and Vives (1984), we assume representative consumers with preferences described by the quadratic utility function $U(q_1, q_2) = \alpha(q_1 + q_2) - 1/2 (q_1^2 + 2\gamma q_1 q_2 + q_2^2)$. $\alpha > 0$ is the maximum willingness to pay, and $\gamma \epsilon (0, 1)$ can be viewed as a measure of product homogeneity, which increases in $\gamma$. As $\gamma$ approaches 0, the products of the two downstream firms become independent. As $\gamma$ approaches 1, the products of the firms become completely homogeneous. In the remainder we will sometimes refer to a market with rather homogenous goods as a market with tough competition. The resulting inverse market demand functions are linear and given by $p_i(q_i, q_{-i}) = \alpha - q_i - \gamma q_{-i}$, for $i$, $-i = 1, 2$, $i \neq -i$. Moreover, we denote the total quantity in the market by $Q = q_1 + q_2$.

The downstream competitors have ex-ante symmetric constant marginal costs of production, denoted by $c$. In our model, an investment opportunity in downstream process innovation exists. The investment $\Delta_i$ lowers the perceived marginal cost of providing the downstream product from $w + c$ to $w + c_i$ with $c_i = c - \Delta_i$. This investment can either be conducted by the downstream firms or by the upstream monopolist. We assume the exact amount of investment to be not verifiable for the regulator. The regulator decides ex-ante which sector is responsible for the investment. Therefore, our analysis distinguishes between two cases. Under the *upstream investment regime*, the upstream monopolist undertakes the investment. Under the *downstream investment regime*, the two downstream firms invest themselves. Regardless of which sector is undertaking the investment, it has to be done for each downstream firm separately. Hence, both industry segments have the same cost structure in investing. The investment cost is given by

[36] The assumption of linear access prices resembles the situation in many network utilities (see also footnote 31).

[37] A similar approach regarding when the wholesale price is set is used by Valletti and Cambini (2005). Though this assumption on the timing of the regulator's decision making might seem strong, the wholesale price set by the regulators provides some commitment. Valletti (2003) stresses the need, when implementing a regulatory policy, that regulators are endowed with some commitment power over time. A discussion on the commitment value of a regulator's decision can be found in Guthrie (2006) and Spiller (2005), p. 627-630.

$\frac{K}{2}\Delta_i^2$ per downstream firm, where $K$ is a parameter determining the marginal cost of investment. Moreover, we (implicitly) assume that investment is subsidized. That is, the respective investor(s) receive ex-ante a lump sum payment sufficient to cover the expected investment cost. As the investment is non-verifiable, the subsidy is paid ex-ante whether or not the investment is undertaken and hence, investment (and our remaining analysis) is independent of this subsidy. This assumption ensures that the upstream monopolist can break even, though the wholesale price only allows to recover the fixed cost $F$. There are a number of possible interpretations of this subsidy. One of them is the government's support on R&D. More on this assumption can be found at the end of Section 2.4.

The timing is as follows: At stage 1 the regulator determines the investment regime. At stage 2 the respective investor(s) take(s) the investment decision. Finally, at stage 3 competition in quantities or prices takes place.

## 2.3 Vertical Separation (VS)

We begin by considering the setting with a vertically separated industry. That is, the downstream competitors and the upstream monopolist act independently from each other. We investigate the differences in pre-competition investment activity among two different investment regimes and two modes of competition, Cournot competition and Bertrand competition.

### 2.3.1 Competition Stage

In order to gain a better understanding of how the mode of competition influences the investment incentives, we need to analyze how cost reducing investment influences competition. Therefore, we start with providing a short description of the competition stage under the two different modes of competition. Under Cournot competition, the downstream firms choose *quantities* in order to maximize

$$\max_{q_i} \pi_i = (p_i(q_i, q_{-i}) - w - (c - \Delta_i))\, q_i$$

for $i, -i \,\epsilon\, \{1,2\}$, $i \neq -i$. Under Bertrand competition, however, the downstream firms choose *prices* in order to maximize

$$\max_{p_i} \pi_i = (p_i - w - (c - \Delta_i))\, q_i\,(p_i, p_{-i})$$

for $i, -i \,\epsilon\, \{1,2\}$, $i \neq -i$. All results of the competition stage for given levels of investment are provided in detail in Section B.1 of the appendix. Notice that, except for the firms' individual marginal cost, $c_i = c - \Delta_i$, the investment regime has no influence on the competition.

Under both modes of competition a decrease in downstream firm $i$'s marginal cost $c_i$, makes a lower price (*Bertrand*) resp. a higher quantity (*Cournot*) for firm $i$ optimal. First of all, this leads to a higher industry output. Moreover, it also affects competition as the rival firm $-i$ might react to the change in output or price by firm $i$. As is well known, Cournot and Bertrand competition have different properties in this respect (see, e.g., Vives, 2001). Under Cournot competition, quantities are strategic substitutes, that is, an output increase by firm $i$ leads to a decrease in output by firm $-i$. In other words, the output increase by one firm is partly compensated by the rival firm and hence, total output is only increased modestly. Under Bertrand competition, however, prices are strategic complements, that is, a decrease in price by firm $i$ makes it optimal for firm $-i$ to also lower its price. In other words, the price decrease by one firm is amplified by the subsequent price decrease by the rival firm. This leads to a relatively large increase in total output. In sum, it holds that the output increase is larger under Bertrand competition than under Cournot competition $\left(\frac{\partial Q^C}{\partial \Delta_i} < \frac{\partial Q^B}{\partial \Delta_i}\right)$. Having this fact in mind, we can now investigate the different investment regimes.

### 2.3.2 Investment Stage

Before we analyze the differences in investment among the two modes of competition, we compare investment under the different investment regimes $\left(\Delta_{VS}^{Upstream}, \Delta_{VS}^{Downstream}\right)$ with the socially optimal investment $\left(\Delta^{Welfare}\right)$ in the following lemma.

**Lemma 2.1.** *[Investment under Vertical Separation] Under vertical separation, investment is always below the socially optimal level regardless of the investment regime and the mode of competition,* $\Delta^{Welfare} > \Delta_{VS}^{Upstream}, \Delta_{VS}^{Downstream}$.

*Proof.* See Appendix. ■

This result is rather intuitive. Private investors only take the effect of investment on their profits into account and miss out the effect on consumers and all other firms' profits. As market power exists in our model, private investment is always below the socially optimal investment. Notice that this result simplifies our subsequent analysis as we only have to determine the investment regime with the highest investment incentives in order to find the 'best' regime from a welfare perspective.

**Upstream Investment Regime.** Under the upstream investment regime, the monopolist chooses how much to invest in the cost-reduction of the downstream firms. It anticipates downstream industry demand, that is, $Q^C$ under Cournot competition respectively

$Q^B$ under Bertrand competition, and takes the wholesale price $w$ as given. Hence, the upstream monopolist maximizes

$$\max_{\Delta_i,\,\Delta_{-i}} \pi^U = wQ^*\left(\Delta_i, \Delta_{-i}\right) - \frac{K}{2}\Delta_i^2 - \frac{K}{2}\Delta_{-i}^2.$$

The first term consists of the regulated wholesale price $w$ multiplied by total industry output $Q^*$, where $Q^*\left(\Delta_i, \Delta_{-i}\right) = Q^C\left(\Delta_i, \Delta_{-i}\right)$ under Cournot competition and $Q^*\left(\Delta_i, \Delta_{-i}\right) = Q^B\left(p_i\left(\Delta_i, \Delta_{-i}\right), p_{-i}\left(\Delta_i, \Delta_{-i}\right)\right)$ under Bertrand competition. In order to improve the clarity of expression, we use similar 'reduced' notation in the remainder of this chapter. As the wholesale price is regulated and identical for all downstream firms, the monopolist only considers overall industry output, regardless of which downstream firm produces this output. The second term constitutes the cost of investment. The corresponding optimality conditions for the different modes of competition are given by:

$$\Delta_i^{Cournot} \quad : \quad \left\{w\frac{\partial Q^*\left(\Delta_i, \Delta_{-i}\right)}{\partial \Delta_i} - K\Delta_i = 0\right\} \tag{2.1}$$

$$\Delta_i^{Bertrand} \quad : \quad \left\{w\frac{\partial Q\left(p_i^*, p_{-i}^*\right)}{\partial p_i^*}\frac{\partial p_i^*\left(\Delta_i, \Delta_{-i}\right)}{\partial \Delta_i} - K\Delta_i = 0\right\} \tag{2.2}$$

Though the upstream monopolist does not directly gain from investment into downstream process innovation, it benefits indirectly. Investment lowers the marginal cost of the downstream firms and thus, increases market output. As the wholesale margin is positive ($w > 0$) an output increase is profitable for the monopolist. Notice that the upstream monopolist invests to the same extent in both downstream firms. We know from Section 2.3.1 that market output under Bertrand competition is more responsive to investment than market output under Cournot competition, $\frac{\partial Q^C}{\partial \Delta_i} < \frac{\partial Q^B}{\partial p_i}\frac{\partial p_i}{\partial \Delta_i}$. Thus, the marginal revenue of investment is higher under Bertrand relative to Cournot competition and so is the investment level.

**Downstream Investment Regime.** Under the downstream investment regime, the downstream firms choose how much to invest into the reduction of their own marginal costs. They take the access price $w$ as given and anticipate their future demand $q_i\left(\Delta_i, \Delta_{-i}\right)$ and $q_{-i}\left(\Delta_i, \Delta_{-i}\right)$ in the subsequent competition stage. Thus, the downstream competitors non-cooperatively maximize

$$\max_{\Delta_i} \pi_i = \left(p_i\left(Q^*\left(\Delta_i, \Delta_{-i}\right)\right) - w - \left(c - \Delta_i\right)\right) q_i^*\left(\Delta_i, \Delta_{-i}\right) - \frac{K}{2}\Delta_i^2,$$

under Cournot competition and

$$\max_{\Delta_i} \pi_i = \left(p_i^*\left(\Delta_i, \Delta_{-i}\right) - w - \left(c - \Delta_i\right)\right) q_i\left(p_i^*\left(\Delta_i, \Delta_{-i}\right), p_{-i}^*\left(\Delta_i, \Delta_{-i}\right)\right) - \frac{K}{2}\Delta_i^2,$$

under Bertrand competition. In contrast to the upstream monopolist, downstream firms are not primarily interested in the effect of investment on the industry output level, but on their individual output as well as prices. Maximization with respect to the investment $\Delta_i$ yields the following optimality conditions for the different modes of competition

$$\Delta_i^{Cournot} \quad : \quad \left\{ \underbrace{\frac{\partial p_i(q_i^*, q_{-i}^*)}{\partial q_{-i}} \frac{\partial q_{-i}}{\partial \Delta_i} q_i^*}_{strategic\, effect, >0} + \underbrace{q_i^*}_{quantity\, effect} - \underbrace{K\Delta_i}_{cost\, effect} = 0 \right\} \tag{2.3}$$

$$\Delta_i^{Bertrand} \quad : \quad \left\{ \underbrace{(p_i^* - w - (c - \Delta_i)) \frac{\partial q_i\left(p_i^*, p_{-i}^*\right)}{\partial p_{-i}} \frac{\partial p_{-i}}{\partial \Delta_i}}_{strategic\, effect, <0} + \underbrace{q_i\left(p_i^*, p_{-i}^*\right)}_{quantity\, effect} - \underbrace{K\Delta_i}_{cost\, effect} = 0 \right\}. \tag{2.4}$$

We can disentangle these optimality conditions into three different effects: $(i)$ Investment comes at a cost (*cost effect*). $(ii)$ As the investment lowers the unit cost of production, the firm has a positive effect of investment on every unit of output (*quantity effect*). Hence, the higher the firm's output, the larger is this effect. This is in contrast to our result on the upstream investment regime, where the monopolist considers only output changes, but not the cost reduction on infra-marginal output. $(iii)$ Finally, a *strategic effect* from investment exists which relates to our discussion in section 2.3.1. Under Cournot competition, the firms' output decisions are strategic substitutes. That is, when a firm acts aggressively in the market by increasing its output, the rival firm will react in an accommodating way and reduce its own sales. Hence, a firm additionally gains from investment as it induces an output reduction of the rival firm. That is, the strategic effect has a positive impact on investment. Under Bertrand competition, however, the firms' prices are strategic complements. That is, a firm causes more aggressive competition in the market and hurts its own profits, resulting in a negative strategic effect and hence, reduced investment incentives. Thus, investment under Bertrand competition is always lower than under Cournot competition (compare Qui, 1997).

Now we can state the first part of our main result, which compares investment under the upstream investment regime $\left(\Delta_{VS}^{Upstream}\right)$ with investment under the downstream investment regime $\left(\Delta_{VS}^{Downstream}\right)$.

**Proposition 2.1.** *[Comparison of Investment Regimes under Vertical Separation]*

$(i)$ *Under Cournot competition, the downstream investment regime always provides an investment outcome closer to the social optimum relative to the upstream investment regime,* $\Delta^{Welfare} > \Delta_{VS}^{Downstream} > \Delta_{VS}^{Upstream}$.

$(ii)$ *Under Bertrand competition, the upstream investment regime provides an investment outcome closer to the social optimum relative to the downstream investment regime,* $\Delta^{Welfare} > \Delta_{VS}^{Upstream} > \Delta_{VS}^{Downstream}$, *if and only if* $F$ *is sufficiently large,* $F > \hat{F}$, *with* $\hat{F} \sim \hat{w}_B\left(\hat{F}\right) = \frac{4-2\gamma^2}{8-3\gamma^2}\left(\alpha - c + \Delta_{VS}^{B*}\right)$.

*Proof.* See Appendix. ■

Let us now provide an intuition for this result. Under the downstream investment regime, the incentive to invest stems from the cost reduction induced through investment as well as from the effect of investment on competition. Under the upstream investment regime, however, the incentive to invest stems from the increase in total output induced by the investment. With Cournot competition, investment by one downstream firm leads to an output increase by that firm and an output reduction by the rival firm. Hence, the increase in market output is modest. This is beneficial for the downstream investor, but provides only modest investment incentives to the upstream monopolist. Thus, the downstream investment regime always leads to a higher investment level. With Bertrand competition, investment triggers more intense competition and hence, a large increase in market output. This is beneficial for the upstream monopolist, but hurts the downstream competitors. So, investment incentives under the upstream investment regime are relatively more pronounced while they are rather weak under the downstream investment regime. However, the upstream monopolist invests only, when the regulated wholesale margin is large enough to make investment attractive at all. This is only the case, when the fixed upstream cost $F$ is sufficiently large, such that a high upstream margin is needed for the monopolist in order to recoup this cost.

## 2.4 Vertical Integration (VI)

In this section, we consider the setting where the upstream and the downstream sector are partially integrated. That is, one of the downstream firms is owned by the upstream monopolist. The analysis of such a setting is particularly relevant in light of the ongoing discussion on the optimal vertical structure in network industries. This discussion focuses on the question whether the upstream monopolist should be allowed to engage at the downstream market (VI) or not (VS).[38] We denote the downstream affiliate of the upstream monopolist by $D1$ and the independent downstream firm by $D2$. While the independent downstream firm maximizes only its own downstream profits, $\pi_2$, the integrated firm maximizes the sum of upstream and downstream profits, $\Pi + \pi_1$.

### 2.4.1 Competition Stage

Under VI, the downstream affiliate of the integrated upstream monopolist takes the effect of its output resp. price choice on the upstream profit into account. That is, the behavior of the downstream affiliate might affect the independent downstream firm's demand for the

[38] A good overview on this discussion is provided by Motta (2004). Some recent literature discusses different vertical structures explicitly (compare Cremer et al., 2006, and Höffler and Kranz, 2011a, 2011b).

upstream good and hence, upstream profits. The maximization problem under Cournot competition is given by

$$\max_{q_1} \Pi + \pi_1 = w\left(q_1 + q_2\right) + \left(p_1\left(q_1, q_2\right) - w - \left(c - \Delta_1\right)\right) q_1.$$

This can be rewritten as

$$\max_{q_1} \Pi + \pi_1 = wq_2 + \left(p_1\left(q_1, q_2\right) - \left(c - \Delta_1\right)\right) q_1,$$

which reveals that the production cost of downstream firm 1 is now given only by $c - \Delta_1$ instead of $w + c - \Delta_1$. The independent downstream firm $D2$ maximizes only its downstream profits, that is,

$$\max_{q_2} \pi_2 = \left(p_2\left(q_1, q_2\right) - w - \left(c - \Delta_2\right)\right) q_2.$$

However, it takes the lower marginal cost of production of the integrated firm through its output choice $q_1$ into account. The corresponding maximization problems under Bertrand competition are stated in Section B.1 of the appendix. Under VI the same differences as under VS with respect to the different modes of competition persist. Therefore, we omit a more thorough discussion of these differences here and refer to Section 2.3.1. In addition, in the remainder of this chapter we report only the maximization problems and optimality conditions for Cournot competition and refer to Section B.1 of the appendix for the corresponding maximization problems under Bertrand competition.

### 2.4.2 Investment Stage

Before we analyze the differences in investment among the two modes of competition, we compare investment under the different investment regimes $\left(\Delta_{VI}^{Upstream}, \Delta_{VI}^{Downstream}\right)$ with the socially optimal investment $\left(\Delta^{Welfare}\right)$ in the following lemma.

**Lemma 2.2.** *[Investment under Vertical Integration] Under vertical integration, investment is always below the socially optimal level, regardless of the investment regime and the mode of competition, that is,* $\Delta^{Welfare} > \Delta_{VI}^{Upstream}, \Delta_{VI}^{Downstream}$.

*Proof.* See Appendix. ■

This result reflects our findings under VS in Section 2.3.2 and Lemma 2.1. Private investors do not take the effect of investment on consumers and the other firm's profits into account. As market power exists in our model, private investment is always below the socially optimal investment. Again, this result simplifies our subsequent analysis as we have to determine only the investment regime with the highest investment incentives in order to find the 'best' regime from a welfare perspective.

**Upstream Investment Regime.** Under the upstream investment regime, the monopolist chooses how much to invest in the cost reduction of the downstream firms. It anticipates downstream industry demand, that is, $Q^C$ under Cournot competition respectively $Q^B$ under Bertrand competition, and takes the wholesale price $w$ as given. Thereby, it takes its own downstream profits into account. Hence, under Cournot competition the upstream monopolist maximizes

$$\max_{\Delta_1, \Delta_2} \Pi + \pi_1 = wQ^* (\Delta_1, \Delta_2) + (p_1 (Q^* (\Delta_1, \Delta_2)) - w - c + \Delta_1) q_1^* (\Delta_1, \Delta_2) - \frac{K}{2}\Delta_1^2 - \frac{K}{2}\Delta_2^2.$$

The first term represents the upstream profit and the second term the downstream affiliate's profit. Maximization yields the following optimality conditions for investment in the own downstream affiliate's and the independent downstream firm's production cost

$$\Delta_1 \quad : \quad \left\{ \underbrace{w\frac{\partial Q^* (\Delta_1, \Delta_2)}{\partial \Delta_1}}_{>0} + \underbrace{\frac{\partial p_1(q_1^*, q_2^*)}{\partial q_2^*}\frac{\partial q_2^*}{\partial \Delta_1} q_1^*}_{strategic\, effect} + \underbrace{q_1^*}_{quantity\, effect} - \underbrace{K\Delta_1}_{cost\, effect} = 0 \right\} \tag{2.5}$$

$$\Delta_2 \quad : \quad \left\{ \underbrace{w\frac{\partial Q^* (\Delta_1, \Delta_2)}{\partial \Delta_2}}_{>0} + \underbrace{\frac{\partial p_1 (q_1^*, q_2^*)}{\partial q_2^*}\frac{\partial q_2^*}{\partial \Delta_2} q_1^* + (p_1^* - w - c + \Delta_1)\frac{\partial q_1^*}{\partial \Delta_2}}_{<0} - \underbrace{K\Delta_2}_{cost\, effect} = 0 \right\} \tag{2.6}$$

Investment in each of the two downstream firms boosts the demand for the upstream good just as under VS (the first term in expressions (2.5) and (2.6)). In addition, investment now also affects the downstream affiliate's profit: First, investment in the own downstream affiliate's production cost has the same effects on the affiliate's profit as investment by the downstream affiliate itself. These are the quantity, the strategic and the cost effect. Second, investment in the downstream rival's production cost hurts the own downstream affiliate's profits. That is, it makes the downstream rival more aggressive which leads to lower prices and output for the downstream affiliate. Thus, while investment in the own downstream affiliate $\Delta_1$ is larger than under VS, investment in the downstream rival $\Delta_2$ is lower than under VS. This can be easily seen by comparing the optimality conditions under VI (expressions (2.5) and (2.6)) and under VS (expression (2.1)).

**Downstream Investment Regime.** Under the downstream investment regime, the downstream firms choose how much to invest into the reduction of their own production cost. They take the access price $w$ as given and anticipate their future demand $q_1^*$ and $q_2^*$ in the subsequent competition stage. Thus, the downstream investment problem is given by

$$\max_{\Delta_1} \Pi + \pi_1 = wQ^* (\Delta_1, \Delta_2) + (p_1 (Q^* (\Delta_1, \Delta_2)) - w - c + \Delta_1) q_1^* (\Delta_1, \Delta_2) - \frac{K}{2}\Delta_1^2 - \frac{K}{2}\Delta_2^2.$$

for the integrated firm and

$$\max_{\Delta_2} \pi_2 = (p_2 (Q^* (\Delta_1, \Delta_2)) - w - (c - \Delta_2)) q_2^* (\Delta_1, \Delta_2) - \frac{K}{2}\Delta_2^2,$$

for the independent firm. Maximization with respect to the investments in cost reduction, $\Delta_1$ and $\Delta_2$, yields the following optimality conditions

$$\Delta_1 \quad : \quad \left\{ \underbrace{w\frac{\partial Q^*(\Delta_1,\Delta_2)}{\partial \Delta_1}}_{>0} + \underbrace{\frac{\partial p_1(q_1^*,q_2^*)}{\partial q_2^*}\frac{\partial q_2^*}{\partial \Delta_1}q_1^*}_{strategic\,effect} + \underbrace{q_1^*}_{quantity\,effect} - \underbrace{K\Delta_1}_{cost\,effect} = 0 \right\} \tag{2.7}$$

$$\Delta_2 \quad : \quad \left\{ \underbrace{\frac{\partial p_2(q_1^*,q_2^*)}{\partial q_1^*}\frac{\partial q_1^*}{\partial \Delta_2}q_2^*}_{strategic\,effect} + \underbrace{q_2^*}_{quantity\,effect} - \underbrace{K\Delta_2}_{cost\,effect} = 0 \right\} \tag{2.8}$$

Notice that the incentives to invest by downstream firm $D1$ are equal to the incentives under the upstream investment regime, holding investment of firm $D2$ constant (expressions (2.5) and (2.7) are identical). The reason for this result lies in the fact that the investment decision stays within the same firm regardless of the specific investment regime. The optimality condition for investment by downstream firm $D2$, however, is equivalent to the corresponding condition under VS.

Now we can state the second part of our main result, which compares investment under the upstream investment regime with investment under the downstream investment regime under VI.

**Proposition 2.2.** *[Comparison of Investment Regimes under Vertical Integration] The downstream investment regime always provides an investment outcome closer to the social optimum relative to the upstream investment regime regardless of the mode of competition, that is,* $\Delta^{Welfare} > \Delta_{VI}^{Downstream} > \Delta_{VI}^{Upstream}$.

*Proof.* See Appendix. ■

Let us now provide an intuition for this result. Under VI, the investment regime does not affect the incentives to invest in the integrated firm's downstream production cost as the investment decision always stays within the same firm. Thus, the investment regime plays only a role for investment in the independent downstream firm. As was described in this section, investment in the independent downstream firm hurts the integrated firm's downstream profits while it increases the upstream profits. Hence, under the upstream investment regime the integrated firm's investment incentives are rather weak. Under the downstream investment regime, however, investment incentives by the independent firm are identical to those under VS, given the integrated competitors investment. In sum, as is shown in the corresponding proof in the appendix, these are always higher than the integrated monopolist's incentives and hence, the downstream regime always provides a superior result under VI regardless of the mode of competition.

We should shortly mention here how the vertical ownership structure influences the downstream firms' investment activity. VI partly alleviates the double marginalization problem caused through the presence of a positive upstream fixed cost $F$ and the linear wholesale price $w$ needed for its recovery. That is, the integrated firm faces a lower marginal cost of production. This leads, for given investments, to higher output by the integrated firm $\left(q_1^{VS} < q_1^{VI}\right)$, lower output by the independent firm $\left(q_2^{VS} > q_2^{VI}\right)$ and higher total output $\left(Q^{VS} < Q^{VI}\right)$ under both modes of competition for given investments (see Section B.1 in the appendix for the explicit results). The investment levels are influenced according to the same pattern, as firm output is the main determinant of investment. That is, VI causes more investment by the integrated firm $\left(\Delta_1^{VS} < \Delta_1^{VI}\right)$, less investment by the independent firm $\left(\Delta_2^{VS} > \Delta_2^{VI}\right)$ and higher total investment $\left(\Delta_1^{VS} + \Delta_2^{VS} < \Delta_1^{VI} + \Delta_2^{VI}\right)$ compared to VS under both modes of competition. This aggravates the static effect of VI and leads to an even larger market output. Hence, in line with previous literature, VI yields a better overall performance compared to VS (compare, e.g., Buehler and Schmutzler, 2008).

Moreover, it is noteworthy that our assumption on linear wholesale prices with a positive upstream margin, caused by our assumption on upstream fixed cost recovery, is central for our results. An increase in the wholesale price, caused by an increase in the upstream fixed cost, stimulates upstream investment incentives and mitigates downstream investment incentives. Hence, only with a sufficiently high wholesale price, the mode of competition starts to matter for determining the 'best' investment regime. A linear access price as well as our underlying assumption on upstream capital cost recovery resemble the situation in many regulated network utilities.[39] Moreover, notice that a positive regulated upstream margin requires some commitment on the regulator's side. That is, the wholesale price has to be determined before the investment decision takes place. A similar approach is used by, e.g., Valletti and Cambini (2005). In addition, Valletti (2003) stresses the need, when implementing a regulatory policy, that regulators are endowed with some commitment power over time. A discussion on the commitment value of a regulator's decision can be found in Guthrie (2006) and Spiller (2005), p. 627-630.

Finally, we should discuss our assumption on upstream cost recovery which is related to the discussion on linear wholesale prices in the preceding paragraph. In our analysis, we have assumed that the revenues from the regulated wholesale price $w(F)$ just cover the upstream capital cost $F$. The cost of investment, however, is covered by an ex-ante subsidy which is paid whether or not the investment is undertaken. Technically, this subsidy ensures that the wholesale price $w(F)$ is independent of the investment regime. Consequently, a simple comparison of both investment regimes becomes possible. However, if the wholesale price would also cover the upstream investment cost, the wholesale

[39] Non-linear tariffs are under suspicion to make discrimination of the downstream competitors possible. See, e.g., European Commission (2007), p. 58. Moreover, the owners of a regulated infrastructure are generally entitled to revenues in order to recover their cost. See, e.g., §21 EnWG for the case of German energy sector regulation.

price would depend on the investment regime. That is, for a given upstream fixed cost $\bar{F}$, the wholesale price under the upstream investment regime would be larger than under the downstream investment regime $\left(w^{Upstream}\left(\bar{F}\right) > w^{Downstream}\left(\bar{F}\right)\right)$. Thus, a simple comparison of investment under both regimes would not be possible. Moreover, such an assumption would lead to an additional spot market distortion under the upstream investment regime. While this would imply an interesting trade-off to analyze, it is beyond the scope of this study.

## 2.5 Conclusion

The emergence of smart metering technology in electricity distribution networks has provoked an intense debate among policy makers as well as regulators. The debate has mainly centered on whether and how to promote their implementation. Smart meters are seen as a means to promote energy efficiency through higher functionality and accuracy compared to the traditional electromechanical induction meters. European authorities have exerted strong pressure on the EU member states to implement smart meters nationwide until 2020 (see, e.g., European Parliament, 2009). Several European countries have already enacted legislation to promote investment in this new technology. In the U.K., a 'Smart Metering Implementation Programme' (see DECC, 2010) has been initiated, while in Germany market rules have been established for conducting metering services (see Bundesregierung, 2008). In the U.S., several regional initiatives exist in order to enhance the implementation of metering services and demand response systems (see FERC, 2011).

Several contributions exist on how to optimally realize the potential gains from this new technology. Joskow and Tirole (2006, 2007) explore the effect of real-time pricing, associated with the introduction of smart metering, on electricity retail competition. Borenstein and Holland (2005) investigate the effect of real-time pricing on long-term capacity investments. Holland and Mansur (2006) and Allcott (2011) empirically investigate the short-run effects and Borenstein (2005) and Léautier (2011) empirically analyze the long-run effects of real-time pricing on welfare. Borenstein (2007) analyzes how much bill volatility is caused by real-time pricing and whether financial instruments can be used to reduce this volatility. However, none of these articles considers the incentives of private investors to implement advanced metering technologies in the first place. We explicitly investigate the effect of different regulation-imposed investment regimes on the incentives to invest in a technology that has similar properties to the smart metering technology.

Therefore, we develop a framework in which we compare investment in the implementation of such a new technology by a regulated upstream monopolist to investment by downstream competitors. We show that the nature of downstream competition as well as the vertical ownership structure of the industry should always be considered when determining the investment regime, as different regulatory approaches may be optimal under different modes of competition. It has become a common notion in the literature to interpret different natures of competition as a manifestation of the importance of capacity constraints (compare, e.g., Tirole, 1988, and Kreps and Scheinkman, 1983). Moreover, the capital intensity of the upstream infrastructure also plays a crucial role as it influences the regulated wholesale price and hence, the monopolist's margin, which is a major determinant of investment. As a central message of our findings, policy makers and regulators should be aware of the specific characteristics of the electricity sector under regulation when deciding on the optimal roll-out plan for smart metering devices.

# Chapter 3

# Exclusive Retailing

## 3.1 Introduction

When new mobile handsets enter a market, they are often exclusively marketed through one of the mobile carriers in this market. Examples for such 'exclusive retailing' (ER) arrangements from the U.S. mobile phone industry include the introduction of LG's 'Chocolate' via Verizon's cellular service, Samsung's 'Instinct' and Palm's 'Pre' via Sprint, Blackberry's 'Pearl' via T-Mobile, and Apple's 'iPhone' via AT&T. Most of such exclusive retailing arrangements are abandoned once the handset receives recognition in the market. Market observers argue that ER is largely used by small mobile handset producers (see BCG, 2006)[40]. However, the rationale of the handset producers behind the adoption as well as the withdrawal of ER have not been formally analyzed. Their effects on competition and welfare have also not received due analysis.

In this chapter, we provide a rationale for such exclusive retailing arrangements. ER eliminates the disciplining effect of intrabrand competition between retailers, giving the exclusive retailer market power and hence, a higher retail margin. While creating such a *double markup effect* is costly for the manufacturer, it also comes with two profit-enhancing effects. First, it can serve as a mechanism to enhance brand-specific marketing investments by retailers (*investment effect*). This can be profitable for the manufacturer if the retailer owns a relatively more efficient marketing investment technology.[41] Sec-

[40] Examples outside the mobile phone sector include AC/DC's new music album in 2008 which was exclusively sold via Walmart and the U.S. toy company Hasbro sells its toy action figures exclusively through Target (compare Subramanian, 2009).

[41] In our mobile handset context, this would mean that the ER arrangements enhance marketing investments by the mobile carrier into the handset. BCG (2006) argues that ER is largely used by small mobile handset producers. These are often not that well known for their products and the mobile carriers have a much better distribution network as well as access to customer data. Hence, mobile carriers have often a relatively better technology in marketing mobile handsets. A similar argument can be made for a lot of other products, in particular when the manufacturer does not have direct contact to its final customers.

ond, ER might serve as a commitment device for reduced interbrand competition among manufacturers. That is, the elimination of intrabrand competition by one manufacturer leads to a unilateral price increase, incentivizing the competing manufacturer to increase prices (*competition softening effect*). While the *investment effect* can be interpreted as *pro-competitive*, the two other effects are clearly *anti-competitive*.

Our model analyzes a vertically related industry where two upstream manufacturers produce differentiated brands and sell them to two downstream retailers at linear wholesale prices. The downstream retailers resell the upstream goods to consumers. Producing as well as reselling the brand is associated with constant production/resale costs which are set to zero for simplicity. While consumers have different preferences regarding the brands, they are indifferent between retailers. The manufacturers can choose to sell their brands via both retailers or exclusively via one of the retailers.[42] Thus, three different settings can arise: (*i*) Both manufacturers sell to both retailers. (*ii*) One manufacturer sells to both retailers, while the other manufacturer sells to only one retailer. (*iii*) Each manufacturer sells to only one retailer.[43] Besides reselling brands, retailers can also conduct brand specific marketing. Investment into marketing raises the perceived relative quality of a brand and enhances demand for the brand regardless of which retailer resells the good. We assume that the different parties cannot contract on a specific level of marketing effort.

When manufacturers sell their brand non-exclusively, intrabrand competition at the retail stage drives down prices to the retailers' marginal cost, which consists of the wholesale price being paid for the brand. Retailers could invest into brand specific marketing. But as intrabrand competition eliminates any retail margin, retailers would never gain from such an investment and hence, do not invest. If a manufacturer adopts ER, intrabrand competition at the retail stage does not exist anymore. Hence, the retailer can gain a positive margin on the sale of the brand. Moreover, the brand specific investment becomes now retailer specific. Thus, investment becomes lucrative for the retailer and positive investment levels can be observed. In addition, the possibility of the retailer to gain a positive margin results in a double markup problem. This leads to an unilateral retail price increase of the exclusively sold brand and thus, weakens interbrand competition.

Using this model, we can derive the following results. First, we find that (wholesale and retail) prices, investment and retail profits are higher when one or both manufacturers adopt exclusivity relative to a situation where none of the manufacturers chooses exclusivity. However, more exclusivity in the market does not necessarily mean higher equilibrium

For example, the microchip producer Intel partly relies on marketing by its downstream retailers.

[42]In other words, manufacturers can choose whether or not they want to have intrabrand competition at the retail stage.

[43]Here, we rule out the case where both manufacturers exclusively sell to the same retailer and hence, foreclose the second retailer from the market. Though it turns out that this setting would maximize industry profits, we believe that such foreclosure would never be allowed by competition authorities.

values.[44]

Second, with competition among upstream brands, we show that three types of equilibria exist, depending on the cost of investment and the intensity of interbrand competition: (*i*) Both manufacturers do not adopt exclusive retailing (NER). (*ii*) One manufacturer does not adopt ER, while the other manufacturer adopts ER. (*iii*) Both manufacturers adopt ER. When adopting ER, manufacturers trade off the cost (*double markup effect*) and the benefits (*investment effect* and *competition softening effect*) of such behavior. Equilibrium (*i*) occurs when the investment cost is large and interbrand competition is rather weak. Equilibrium (*ii*) occurs when both, investment cost and the intensity of interbrand competition, attain intermediate values. Equilibrium (*iii*) occurs for either very tough interbrand competition, very low investment costs or both.

Third, when upstream brands are asymmetric with respect to the investment cost in marketing their brand, the occurrence of equilibrium (*i*) is not affected. Moreover, the asymmetric equilibrium (*ii*) occurs for a larger parameter space, while equilibrium (*iii*) occurs for a smaller parameter space. In particular, for rather asymmetric brands the symmetric ER (*iii*) equilibrium only occurs for highly competitive markets.

Finally, we find that the incentive for a manufacturer to adopt ER contradicts with a welfare maximizing regulator's view of ER. This gives scope for regulatory intervention. In particular, ER should only be allowed if retail investment is sufficiently efficient or interbrand competition is rather tough.

This study contributes to two streams of literature, *vertical restraints* and *exclusive contracting*. Both analyze restrictions which are put on one trading party by another trading party. While in most of these articles the selling party restricts the buying party in establishing alternative trading relationships, in this work the selling party commits itself to trade only with one of the buyers.

The literature on *vertical restraints* considers different kinds of restrictions such as exclusive dealing, resale price maintenance, exclusive territories, franchise fees and quantity forcing. Similar to our work, this literature models the vertical structure of an industry explicitly. Besanko and Perry (1993, 1994) model the equilibrium incentives to adopt exclusivity when interbrand competition exists. Though we also consider interbrand competition, they look at exclusive arrangements where a retailer is allowed to deal with only one manufacturer, while we look at situations where a manufacturer deals with only one retailer. While the former is most often described as exclusive dealing, we characterize the latter as exclusive retailing. Moreover, Besanko and Perry (1993) investigate the situation when a manufacturer can conduct retailer-specific investment. We, in contrast, investi-

[44] E.g., wholesale prices might be lower when both brands are distributed exclusively compared to a situation when only one brand is distributed exclusively.

gate the case when the retailer can conduct manufacturer-specific investment. Besanko and Perry (1994) do not consider investments at all, but foreclosure of retailers. We explicitly rule out any foreclosure. Similar to our work, Mathewson and Winter (1984) and Winter (1993) analyze the role of vertical restraints for inducing retail advertising efforts. They investigate the effect of different kinds of vertical restraints, but do not consider ER. Moreover, they do not consider interbrand competition, as we do. Among others, Rey and Stiglitz (1995) discuss vertical restraints as a measure to weaken upstream competition.[45] They consider a similar setting to ours, but restrict their analysis to symmetric outcomes only where either none or both manufacturers choose exclusivity, while we also analyze potential asymmetric outcomes. Armstrong (1999) and Harbord and Ottaviani (2001) analyze the link between the type of payment within a contract (lump-sum vs. linear payment) and the manufacturer's decision to adopt exclusivity. They find that downstream competition and the possibility of resale among retailers play an important role on the optimality of exclusivity. However, they neither consider investments nor upstream competition.

The literature on *exclusive contracting* considers only exclusive dealing arrangements and no other forms of restraints. In contrast to our work, this literature uses an incomplete contracting framework. Two different views of exclusivity arrangements can be found. The anticompetitive view (Aghion and Bolton, 1987, Rasmusen et al., 1991, Bernheim and Whinston, 1998, and Segal and Whinston, 2000) argues that exclusivity serves to foreclose potential rivals from the market and hence, hinders competition. The procompetitive view (Klein, 1988, Frasco, 1991, Marvel, 1982, Masten and Snyder, 1993, and Areeda and Kaplow, 1988) argues that exclusivity is needed in order to protect the return on non-contractible asset-specific investments. Without exclusivity investment incentives would be reduced. Such contracting arrangements can therefore be welfare enhancing, even when these lead to the foreclosure of potential rivals (compare, e.g., Fumagalli et al., 2009). Although we use a different methodology, we incorporate both the pro- as well as the anticompetitive view of exclusivity. Finally, de Fontenay et al. (2010) analyze the equilibrium incentives to adopt exclusivity in a modified Nash bargaining framework and apply the results to a prominent example of ER mentioned in our introduction, the 'iPhone' by Apple. Inc. However, they do not consider any anticompetitive elements of exclusivity.

In the next Section we present our model. In Section 3.3 we derive the outcomes for all different regimes of ER and in Section 3.4 the equilibrium incentives of manufacturers to adopt exclusivity. In Section 3.5 we analyze the incentives of manufacturers to adopt ER in case of asymmetric manufacturers. In Section 3.6 we derive welfare results and in Section 3.7 we conclude.

[45]Similar contributions, but with a different objective, are Telser (1960) and Jullien and Rey (2007).

## 3.2 The Model

Our model consists of three types of agents: Manufacturers, retailers and consumers.

**Manufacturers.** We consider two manufacturers, denoted by $i = 1, 2$, who produce differentiated brands at a constant marginal cost equal to zero. The manufacturers need retailers in order to sell their goods to consumers. Manufacturers simultaneously choose whether to adopt exclusive retailing (ER) or non-exclusive retailing (NER). We define ER as selling exclusively to one retailer, while NER implies that the manufacturer sells to all retailers. After choosing the specific distribution system, the manufacturers are assumed to set a linear wholesale price $w_i$.[46]

Four different distribution systems can potentially arise:[47] (*i*) Both manufacturers choose NER (N/N). (*ii*) One of the manufacturers chooses NER, while the other manufacturer chooses ER (E/N). (*iii*) Both manufacturers choose ER (E/E) and both manufacturers choose different retailers. Hence, both retailers are active on the market, each reselling one brand. (*iv*) Both manufacturers choose ER and both manufacturers sell their brand via the same retailer. As a result, the other retailer is foreclosed from the market, while the first retailer has monopoly power over the whole market. The fourth case is excluded from our subsequent analysis, as we believe that such a monopolization of the market (which in fact yields the highest industry profits) would always be banned by competition authorities.[48]

**Retailers.** There are two retailers, denoted by $j = A, B$, who are active on the retail market with a constant marginal cost of reselling equal to zero. Hence, their perceived marginal cost consists only of the wholesale price $w_i$. The retailers are assumed to be undifferentiated. That is, consumers are indifferent between retailers, but they differentiate among brands. We assume retailers to compete in prices. Retailers can undertake brand-specific demand-enhancing investments. The investment raises the consumers valuation for a specific brand regardless of which retailer conducts the investment. $\theta_{ij}$ denotes investment by retailer $j$ in brand $i$ and $\theta_i$ is the sum of investments by both retailers in brand $i$. The investment is not contractible. Following our example from above, the investment

[46]The use of linear wholesale prices can be justified by our focus on 'innovative' industries. Such industries are usually associated with high degrees of uncertainty and asymmetric information regarding product quality (compare, e.g., Beggs, 1992, and Dana and Spier, 2001). Linear prices can serve as a tool to share the risk among trading parties. Moreover, linear wholesale prices are widely used in the literature, e.g. Arya et al. (2008), Buehler and Schmutzler (2008) as well as Inderst and Valletti (2009). A more thorough discussion follows at the end of this chapter.

[47]For a graphical illustration of the distribution systems see Appendix C.1.

[48]In principle, we can achieve the same results in a $n \times m$ model, where $n$ is the number of manufacturers and $m$ is the number of retailers. However, in an equilibrium where all manufacturers adopt exclusivity, $m > n$ implies that some of the retailers are foreclosed from the market. Moreover, in the same equilibrium, $n > m$ implies that at least one retailer has to sell two brands exclusively. This eliminates any competition between the two respective brands, which is equivalent to distribution system (*iv*).

can be thought of as marketing effort undertaken by mobile service providers into a specific handset/brand. Marketing for specific handsets by a mobile service provider can be more efficient than by the handset manufacturer itself, depending on the brand value in the mobile service sector as well as the available marketing technologies. Marketing effort is hard to contract on as the actual value of a marketing campaign depends on many 'soft' factors. The investment cost is assumed to be retailer- as well as brand-specific and given by $C(\theta_{ij}) = \frac{1}{2}K_i\theta_{ij}^2$. $K_i$ expresses the slope of the marginal cost of investment and might differ among brands, but not among retailers. For example, manufacturers having a high brand value in the mobile service sector are associated with a relatively high $K_i$, while manufacturers with a low brand value within the sector are associated with a relatively small $K_i$. In other words, retail investment is more efficient for manufacturers with just a weak brand value. For most of the analysis we analyze the case with $(K_1 = K_2 \equiv K)$, that is, symmetric brands. In Section 3.5 we consider a case with asymmetric brands $(K_1 \neq K_2)$.[49]

**Consumers.** We assume the following linear demand system that can be derived from a quadratic utility function as it is used in Singh and Vives (1984). Demand for brand 1 is given by $q_1(p_1, p_2)$ and demand for brand 2 by $q_2(p_2, p_1)$, with

$$q_1(p_1, p_2) = \alpha - \beta p_1 + \gamma p_2 + \theta_1 \quad \textit{and} \quad q_2(p_2, p_1) = \alpha - \beta p_2 + \gamma p_1 + \theta_2,$$

where $\alpha = {}^{1-d}/_{1-d^2}$, $\beta = {}^{1}/_{1-d^2}$, $\gamma = {}^{d}/_{1-d^2}$ and $\theta_i = \theta_{iA} + \theta_{iB}$. The parameter $d \,\epsilon\, (0,\, 1)$ represents the degree of product homogeneity. As $d$ approaches 0, the brands of the two manufacturers become independent. As $d$ approaches 1, the brands become completely homogeneous. In the remainder we will sometimes refer to a market with rather homogeneous brands as a market with tough (interbrand) competition. When both retailers sell the same brand and set the same price, demand is divided equally between both retailers. The investment $\theta_i$ can be thought of as increasing the relative valuation for brand 1 relative to brand 2. This implies that raising $\theta_i$ has no direct effect on the demand for brand $j$.

**Timing.** At stage 1 both manufacturers choose simultaneously their distribution channel(s). At stage 2 manufacturers set wholesale prices to one or both of the retailers, depending on the choice at stage 1. At stage 3 retail companies undertake the demand enhancing marketing investments. At stage 4 retail companies compete.

[49] We assume $K_i$ not to be too small in order to ensure that the model is well defined $\left(K_i > {}^{4(1-d^2)}/_{(8-4d-2d^2+d^3)}\right)$.

## 3.3 Characterization of Distribution Systems

As we show below, all the distribution systems mentioned above can occur as an equilibrium outcome in our model: $N/N$, $E/N$ and $E/E$. In this section, we characterize these equilibria with respect to prices, retail investment and profits. Before we do so, we introduce a framework in order to disentangle the different effects stemming from a manufacturer's exclusivity decision. Superscripts $E/E$ and $N/N$ describe the equilibrium values in the $E/E$ resp. $N/N$ equilibrium. $E/N$ describes the equilibrium values of the brand which is sold exclusively via one retailer, while the competing manufacturer sells her brands non-exclusively. In contrast, $N/E$ describes the equilibrium values of the brand not being sold exclusively, while the competing brand is sold exclusively. All equilibrium values and results can be found in the Appendix.

**Framework.** We identify three sub-effects from the introduction of $ER$: The *double markup effect* captures the unilateral price response to the exclusivity decision. The *competition softening effect* takes the competitive response to the double markup effect into account. Finally, the *investment effect* captures the impact from retail investment which is linked to the introduction of $ER$. We characterize the three effects using the case where only one manufacturer adopts $ER$ relative to the situation without exclusivity ($N/N \rightarrow E/N$), which serves as our benchmark case. The effects from the introduction of $ER$ by the second brand ($N/N \rightarrow E/E$) are derived correspondingly and can be found in the appendix.

($I$) **Double markup effect.** Exclusivity grants the downstream retailer a monopoly in reselling the brand. This allows the retailer to increase the retail price above the wholesale price and earn an additional markup. The double markup effect captures the unilateral effect stemming from this retail market power. Conceptually, we define the double markup effect as the unilateral effect stemming from the introduction of exclusivity, neglecting the investment possibility and holding all the (wholesale and retail) competitors' choice variables constant. This allows us to abstract from any effect resulting from the competition among manufacturers and to focus solely on the price increase of the exclusive brand. Technically, we take the difference of the variable of interest in equilibrium with and without exclusivity, fixing all the choice variables of the competing brand at the level without exclusivity and setting the investment level to zero, $f_i\left(E/N \mid w_j = w_j^{N/N}, p_j = p_j^{N/N}, \theta_i = 0\right) - f_i\left(N/N\right)$, where $f_i\left(\cdot\right)$ denotes the variable of interest.

($II$) **Competition softening effect.** The competition softening effect captures the effect from exclusivity which stems from the existence of interbrand competition, neglecting any investment opportunities. Thus, while the double markup effect is capturing the unilateral effect from exclusivity, the competition softening effect captures the additional bilateral effect (or the competitive response) to the double markup effect, neglecting the investment possibility. Technically, the competition softening effect is given by $f_i\left(E/N \mid \theta_i = 0\right) - f_i\left(E/N \mid w_j = w_j^{N/N}, p_j = p_j^{N/N}, \theta_i = 0\right)$. As the firms' choice variables are strategic complements, the unilateral price increase due to the double markup effect is followed by a price increase by the competing firm. Hence, the competition softening effect captures the anticompetitive element of ER.

$(III)$ **Investment effect.** The investment effect captures the effect from investment (induced by the exclusivity choice) on all the variables, taking into account the unilateral as well as the bilateral effect from retail market power. Technically, we derive the investment effect as the residual effect (the total effect net of the double markup as well as the competition softening effect), which is given by $f_i\left(E/N\right) - f_i\left(E/N \mid \theta_i = 0\right)$. The investment effect captures the pro-competitive element of ER.

We can now characterize the different equilibrium distribution systems.

**Both manufacturers choose *NER* - *(N/N).*** Under $N/N$, the outcome of the market game coincides with a standard differentiated Bertrand game: When both manufacturers distribute their brand non-exclusively, intrabrand competition exists for both brands. Retail firms are undifferentiated and compete in prices. Hence, competition drives down retail prices to the retailers' marginal cost, which consists of the wholesale price ($p_1 = w_1$, $p_2 = w_2$). Thus, retail companies do not make any profit ($\pi_A = \pi_B = 0$). Retail investment is brand-specific, that is, regardless of which retailer undertakes the investment, the demand enhancing effect from investment affects all retailers to the same extent. As retail companies do not earn a positive retail margin, they do not have any incentive to invest and hence, no investment takes place ($\theta_1 = \theta_2 = 0$). Consequently, manufacturers set their wholesale prices just as retail firms would not exist and the outcome of the market game coincides with a standard differentiated Bertrand game.

**One manufacturer chooses *ER* and the other manufacturer chooses *NER* - *(E/N).*** When one of the manufacturers chooses exclusivity, intrabrand competition for this brand is broken and a retail monopoly is created. While this changes the analysis of the exclusive brand completely, the analysis of the retail and investment stage of the nonexclusive brand remains identical to the $N/N$-case. We denote the exclusive brand by 1 and the nonexclusive brand by 2.

The adoption of ER by one retailer induces an increase of wholesale and retail prices of both brands relative to the $N/N$-equilibrium as well as a positive retail investment level and retail profit for the exclusive brand. The effects in detail are as follows:
The monopoly right on the sale of brand 1 allows the exclusive retailer to raise the retail price above the wholesale price and to gain a positive retail margin, while the wholesale price stays constant (*double markup effect*). As for brand 2 intrabrand competition still

exists, no extra retail margin can be gained here.
Retail prices are strategic complements. Hence, the nonexclusive brand raises its retail as well as its wholesale price.[50] The price increase of the nonexclusive brand softens interbrand competition in the market and gives the exclusive retailer and the manufacturer scope to set higher prices (*competition softening effect*).
As investment is retailer-specific now, the exclusive retailer can recoup some of the benefit from investment and faces an increased incentive to invest. A positive investment level in brand 1 can be observed, while no investment is undertaken in brand 2 ($\theta_1^* > 0$, $\theta_2^* = 0$). Investment increases the consumers' valuation of the brand, which in turn makes a higher retail and wholesale price of the exclusive brand optimal. Due to the strategic complementarity of retail prices, the nonexclusive brand's prices also increase (*investment effect*).
As all three effects have a positive impact on prices and no intrabrand competition exists for brand 1 anymore, the profit of the exclusive retailer increases. As for brand 2 intrabrand competition still exists, no retail profits can be made on the sale of this brand. Moreover, the profit of manufacturer 2 increases due to the higher price level and hence, weaker interbrand competition. However, the effect on the profit of manufacturer 1 is ambiguous as the double markup effect decreases profits, while the other two effects increase the manufacturer's profit.

**Both manufacturers choose *ER* - *(E/E)*.** When both manufacturers choose exclusivity in selling their brands, they break intrabrand competition for both brands and create monopolies on the downstream market for selling the particular brand. According to the same reasoning from above, this means higher prices, investments and retail profits for both brands relative to the $N/N$-regime. However, this is not necessarily true relative to the $E/N$-regime as the three effects of exclusivity partly change when both manufacturers adopt ER.

Both retailers have a monopoly right on the sale of 'their' brand. Consequently, both retailers can raise the retail price above the wholesale price and gain a positive retail margin, while both wholesale prices stay constant. As this double markup effect is constructed as a unilateral effect, the impact is exactly the same as under the $E/N$ regime. But this time, both retail prices increase and not only one of them (*double markup effect*).
The competition softening effect is stronger on all (wholesale and retail) prices compared to the $E/N$-equilibrium. Due to the reciprocal adoption of $ER$ both retail prices are higher and hence, the competitive price adjustment is stronger (*competition softening effect*).
Investment has become retailer-specific for both retailers. That is, both retailers invest in 'their' respective brand. Individual investment levels are higher relative to when only

[50] As interbrand competition for brand 2 still exists, $p_2^{N/E}\left(w_2^{N/E}\right) = w_2^{N/E}$. Hence, when manufacturer 2 raises the wholesale price, the retail price increases by the same amount, $\partial p_2^{N/E} / \partial w_2^{N/E} = 1$.

one retailer undertakes the investment: The demand enhancing investment increases the quantity which consumers are willing to purchase at a given price. In the E/E-regime the price level is already higher relative to the E/N regime (both without investment). So is the retail margin and investment is more lucrative. Moreover, higher investment levels also lead to a retail price increase, which again increases the retail margin and hence, investment incentives. The higher investment level has a positive impact on all prices relative to the N/N regime.
However, the impact relative to the E/N regime is ambiguous: For a very efficient investment technology (very low values of $K$), it becomes lucrative for the manufacturer to decrease the wholesale price in order to increase the retail margin and hence, incentivize additional investment. In other words, the effect of investment on a manufacturer's sales are so high that it overcompensates the wholesale price decrease. Nevertheless, this effect is not strong enough to overcompensate the positive impact on prices through the double markup and competition softening effect as shown in Proposition 3.1 (*investment effect*).

In sum, all equilibrium values under the E/E regime are higher than under the N/N regime. Moreover, the retail prices, investments and profits under the E/E-regime are also higher compared to the E/N-regime. However, this is not necessarily true for the wholesale prices as is shown in the next section. In addition, we can say that the adoption of exclusivity by the manufacturer of a nonexclusive brand has a positive impact on the profit of a manufacturer who has also adopted ER.

**Equilibrium comparison.** The following Proposition compares retail as well as wholesale prices, investment levels and retail profits in the three different equilibria and summarizes the results we have described in this section. The comparison of wholesale profits can be found in Section 3.4.

**Proposition 3.1.** *[Equilibrium Comparison] Retail as well as wholesale prices, retail profits and investment levels are highest when both manufacturers adopt exclusive retailing and lowest when both firms do not adopt exclusive retailing. In the asymmetric distribution regime, the retail price, the investment level and the retail profit of the exclusive brand are higher relative to the nonexclusive brand. In contrast, the wholesale price of the exclusive brand is lower relative to the nonexclusive brand. That is,*

$$\begin{array}{llllllll}
p_i: & p_i^{E/E} & > & p_i^{E/N} & > & p_i^{N/E} & > & p_i^{N/N} \\
w_i: & w_i^{E/E} & >^{(*)} & w_i^{N/E} & > & w_i^{E/N} & > & w_i^{N/N} \\
\theta_i: & \theta_i^{E/E} & > & \theta_i^{E/N} & > & \theta_i^{N/E} & = & \theta_i^{N/N} \\
\pi_i^{Retail}: & \pi_i^{E/E} & > & \pi_i^{E/N} & > & \pi_i^{N/E} & = & \pi_i^{N/N}.
\end{array}$$

(*) *If and only if* $K > \bar{K} = \left(4-2d-5d^2+2d^3+d^4\right)/\left(4-d^2\right)$.

*Proof.* See Appendix. ■

Generally, we can say that a higher degree of exclusivity leads to higher prices at the wholesale and at the retail stage as well as to higher retail profits. In addition, also the investment level increases.
All three effects stemming from ER affect the retail price positively. Hence, it is not surprising that the retail price is increasing with exclusivity. But it should be noted that the retail price of the exclusive brand in the asymmetric equilibrium is higher than the retail price of the nonexclusive brand. This is because the double markup and the investment effect affect the retail price of the exclusive brand directly while the retail price of the nonexclusive brand is affected only indirectly via the competition softening as well as the investment effect due to the strategic complementarity of retail prices.
The opposite result can be observed for the wholesale prices. As described above, the double markup effect does not affect any of the wholesale prices, but both wholesale prices are affected by the competition softening and the investment effect. However, the sum of these effects is stronger on the wholesale price of the nonexclusive brand than on the wholesale price of the exclusive brand. As for the former no retail margin exists, the price responses by the manufacturer are always more extreme and hence, the effects are stronger.[51] However, the wholesale price under the E/E-regime is only higher relative to the N/E-regime, whenever $K$ is not extremely small $\left(K > \bar{K}\right)$. If this was the case, retail investment is so efficient that it is optimal for the manufacturer to give the retail company additional incentives to invest by lowering the wholesale price and hence, leave the retail company a larger share of the joint profit. This effect is stronger under the E/E-regime as investment incentives are higher relative to the E/N regime.[52]
Investment in a brand is zero whenever the manufacturer has not adopted exclusivity, while the investment level is positive when exclusivity has been adopted. Moreover, the investment level in a brand increases when also the competing brand adopts exclusivity as investment levels are strategic complements. The adoption of exclusivity by the competing manufacturer increases the price level and retail margin in the market and hence, softens competition. A higher retail margin makes investment more lucrative, as investment increases sales (for a given price) which are associated with a higher retail margin now. Hence, investment incentives and eventually, investment levels are higher.
Finally, the retail profit is zero whenever the retailer does not have an exclusive distribution right, and positive when he has one. Moreover, the retail profit is higher when

[51] The exclusive manufacturer faces a trade-off when increases $w^{E/N}$. On the one hand, it allows the manufacturer to extract more of the joint profit. On the other hand, it exaggerates the double markup problem $\left(\partial p^{E/N}/\partial w^{E/N} > 0\right)$ and decreases the investment activity of the retailer.

[52] Note that this additional constraint $\left(\bar{K}\right)$ is just slightly stronger than the constraints implied by the SOCs. So, this case appears only for extremely efficient retail investment technologies. Moreover, it should be noted that for these values the $E/E$-regime would arise endogenously.

both manufacturers have adopted ER relative to when only one manufacturer has done so $\left(\pi_i^{E/E} > \pi_i^{E/N}\right)$: Interbrand competition is weakest when both manufacturers have adopted ER due to the double markup as well as competition softening effect. Weaker competition allows retail firms to increase their retail price and hence, they can earn a higher margin and profit.

## 3.4 Endogenous Choice of Distribution System

The preceding analysis has taken the distribution system as given. In this section, we show that all the contractual solutions, we described in the last section, can arise as the equilibrium outcome of this game. As mentioned above, the manufacturers choose non-cooperatively whether they sell their brand exclusively or non-exclusively at the beginning of this game. The Nash equilibrium in this stage depends on the relative size of the manufacturers' equilibrium profits, $\pi_i^{E/E}$, $\pi_i^{N/N}$, $\pi_i^{E/N}$ and $\pi_i^{N/E}$.

The following Proposition states our main result regarding the existence of the different first stage equilibria.

**Proposition 3.2.** *[Endogenous Choice of Distribution System] There exist three equilibria in pure strategies in this game, given different combinations of $d$ and $K$:*

$(i)$ *Both manufacturers do not adopt exclusive retailing.*

$(ii)$ *One manufacturer adopts exclusive retailing and the other manufacturer does not adopt exclusive retailing.*

$(iii)$ *Both manufacturers adopt exclusive retailing.*

*In addition, multiple equilibria of type $(i)$ and $(iii)$ exist for some parameter combinations.*

*Proof.* See Appendix. ■

In Figure 3.1, we can observe that all three equilibria emerge for a rather substantial parameter space. Notice that the investment cost has to be sufficiently convex ($K_i$ has to be large enough) to establish an equilibrium. In the white area in Figure 3.1 this 'convexity condition' is not fulfilled and no equilibrium can be established. The occurrence of the different equilibria can be explained quite intuitively using the manufacturers rationale for ER and how it is affected by the intensity of competition $d$ and the investment cost $K$.

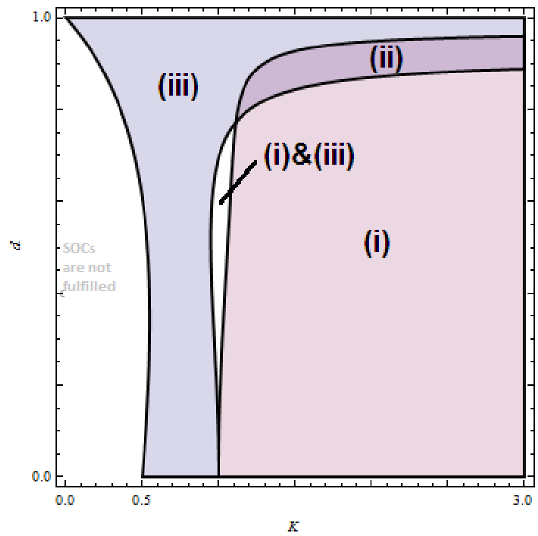
If the retail investment technology is very efficient (low $K$), the benefit for the manufacturer from ER through the investment effect is larger than the cost from ER through the double markup effect. But if the investment becomes more expensive ($K$ increases), retail investment becomes less important and hence, ER becomes less profitable or unprofitable. Hence, for a low $K$ ER is more profitable than for a high $K$ and more firms adopt ER.[53] Moreover, if interbrand competition is rather weak (low $d$), the retail markup under ER is large as the competitive pressure on the exclusive retailer from the competing brand is weak. Hence, the double markup effect is large and ER is costly for the manufacturer. However, if $d$ is high, the competitive pressure on the retailer under ER from the competing brand is also high. Thus, the retail markup is small and ER becomes more lucrative. When $d$ is very high, ER is optimal for manufacturers even when retail investment is not feasible (e.g. $K \to \infty$). With a very high $d$, the double markup effect vanishes, but the competition softening effect prevails. Hence, manufacturers might adopt ER even without the possibility of retail investment.

It remains to be explained, when and why only one and not the other manufacturer adopts exclusivity for some parameter combinations and not for others.[54] As can be seen in Figure 3.1, for intermediate values of $d$ and $K$ one manufacturer has the incentive to adopt exclusivity, given the other manufacturer does not adopt exclusivity. When the first manufacturer chooses ER, the retail prices increase and interbrand competition in the market becomes softer. This raises the nonexclusive manufacturer's profit $\left(\pi^{N/E}_{Manufacturer} > \pi^{N/N}_{Manufacturer}\right)$. Hence, the effect from ER on the second manufacturer's profit has to be stronger than for the first manufacturer, so that she actually adopts ER. The adoption of ER is more profitable, when $d$ is relatively higher or/and $K$ is relatively lower as then the cost/benefit of ER would be lower/higher (see above). Consequently, combinations of $d$ and $K$ exist, so that one manufacturer adopts ER and the other manufacturer does not do so.

[53]Note that the double markup as well as the competition softening effect are not dependent on $K$ by construction.

[54]In more formal terms, we can say that for the parameter constellations leading to one of the symmetric equilibria, the manufacturers' incentive to (not) adopt exclusivity is a dominant strategy regardless of what the competing manufacturer is doing. In contrast, for the parameter constellations leading to the asymmetric equilibrium, the manufacturer's decision to (not) adopt exclusivity is dependent on the belief what the other manufacturer is doing. Hence, the competing manufacturers choice alters the own optimality condition in such a way that a different decision becomes optimal. We are interested in how the respective optimality conditions are altered.

Figure 3.1: Illustration of the distribution systems arising in equilibrium under different combinations of $d$ and $K$.




## 3.5 Asymmetric Brands

In this section, we analyze manufacturers differing in their associated retail investment efficiency. That is, we assume that the cost of retail investment is different among brands ($K_2 \neq K_1$). However, we continue to assume that retail firms are symmetric. This implies that investment in one brand is cheaper than investment in the other brand, regardless of the retail firm undertaking the investment. We define the difference in the retail investment cost by $K_2 - K_1 = \Delta > 0$.

A natural and realistic interpretation of these assumptions is as follows: The parameter $K_i$ can be interpreted as the efficiency of retail marketing relative to manufacturer marketing in a certain brand. The efficiency of retail marketing usually depends on a manufacturer's brand reputation in a market and the marketing skills of the retailer. If a firm's brand reputation is well established in the market, retail investment might be inefficiently costly (relative to marketing by the manufacturer itself) and hence, the respective cost parameter $K_i$ should be rather high. In contrast, if a manufacturer has recently entered a new market and retail companies are well-established in that market, $K_i$ should be rather low. Moreover, manufacturers not having any direct contact to their final customers and selling their products via retailers should be associated with a low $K_i$.[55]

Different retail marketing efficiencies among brands can appear, if an established brand is already present in the market (high $K_i$), while another brand is a new entrant or

[55]As already mentioned above, the microchip producer Intel largely relies on marketing by its downstream retailers.

without a high brand reputation in this market (low $K_i$). This reflects the situation in the mobile phone industry as our leading example quite well. While the three largest mobile handset producers in 2007 (Nokia, Samsung, Motorola) covered almost 2/3 of worldwide sales, Apple was a newcomer in this market and LG as well as Palm only played a minor role (see Gartner, 2007). This also implies that the large producers already had established marketing channels and their products were well known, while the small and new manufacturers might have lacked a high brand reputation or had to arrange new marketing channels. Thus, for Apple, LG and Palm it was relatively more efficient to rely on marketing by a third party already active in the mobile phone market. Referring to the examples of ER in the mobile handset industry mentioned in the introduction, ER has been used by these rather small or unknown mobile handset producers.

Our main result for asymmetric brands is summarized in the following Proposition.

**Proposition 3.3.** *[Asymmetric Brands] Suppose upstream manufacturers are asymmetric with respect to the brand specific investment technology parameter, $K_1 \neq K_2$, then:*

($i$) *The parameter space of the $N/N$-equilibrium and the parameter space, where either the $E/N$- or the $E/E$-equilibrium occur does not change.*

($ii$) *The parameter space where the $E/N$-equilibrium occurs increases to the expense of the parameter space where the $E/E$-equilibrium occurs.*

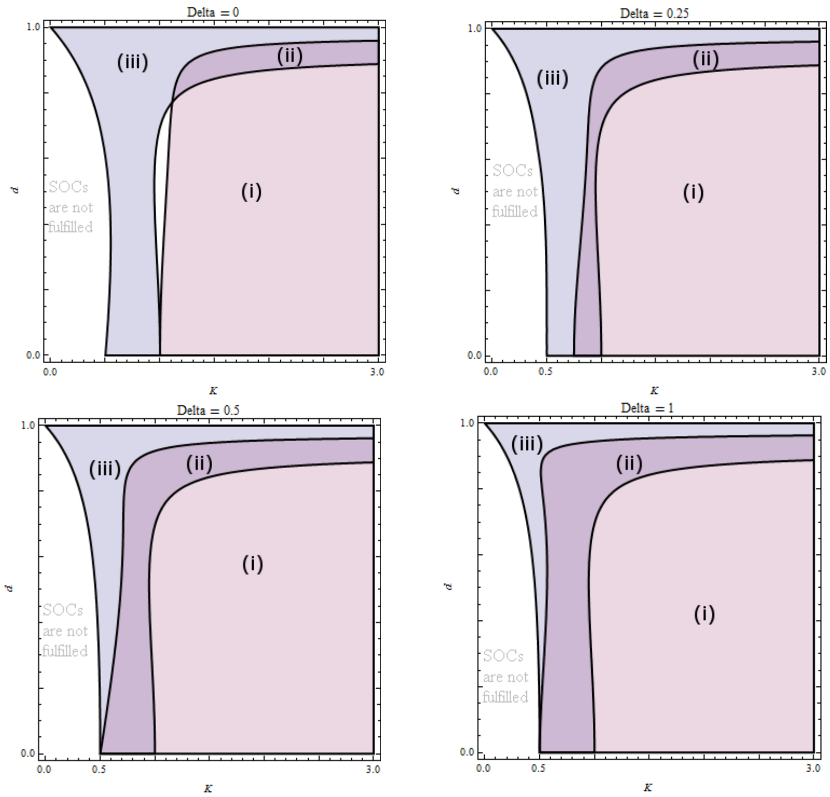
*Proof.* See Appendix. ■

Figure 3.2 illustrates the occurrence of the equilibrium outcomes for different values of $\Delta$, with $\Delta = K_2 - K_1$ and $K = K_1$.

First, introducing asymmetric brands does not alter the parameter space of the $N/N$-equilibrium. The value of $K_i$ matters only for a firm actually adopting $ER$, as otherwise no investment is undertaken. Hence, there is no change in the occurrence of the $N/N$-equilibrium. Moreover, the introduction of asymmetric brands keeps the parameter space, where either the $E/N$- or the $E/E$-equilibrium occurs, constant. This follows immediately from the preceding result.

Second, the introduction of asymmetric brands increases the space, where the $E/N$-equilibrium occurs and decreases the space of the E/E-equilibrium. Consequently, the asymmetric equilibrium occurs for a larger set of parameters and the E/E-equilibrium for a smaller set of parameters, the larger the asymmetry among brands. The intuition for this is as follows. Suppose, we observe the $E/E$-equilibrium and raise the cost difference $K_2 - K_1$ by increasing $K_2$: For manufacturer 1's decision, whether or not to adopt ER, nothing changes. But if the increase in $K_2$ is sufficiently large, exclusivity might not be the optimal strategy for manufacturer 2 anymore and she chooses not to adopt ER. Hence, the larger the cost difference $K_2 - K_1$ , the larger is the '$E/N$ space' to the expense of the '$E/E$ space'. Notice that it is sufficient to introduce a very small asymmetry for the multiplicity of equilibria to disappear.

Figure 3.2: Asymmetric Brands: Illustration of the equilibrium distribution systems for different asymmetries among brands ($\Delta :$ 0, 0.25, 0.5, 1).




BCG (2006) argues that exclusive retailing arrangements are largely used by small mobile handset producers. Moreover, it can be observed frequently that ER is used directly after the introduction of a new mobile handset, while it is abandoned when the handset has been established in the market. A potential interpretation of these findings could be as follows. The relative efficiency of retail marketing is most likely higher for new handsets by rather small producers or by a new entrant in the market than for their well known and large competitors $\left(K_{small/unkown} < K_{large/established}\right)$. This makes ER more attractive for new products or entrants than for established brands. Consequently, it is optimal for the former to adopt ER, while most of the latter refrain from such arrangements. Figure 3.2 illustrates this in the context of our model. That is, the larger the difference in the retail marketing efficiency, the larger is the parameter space where the asymmetric equilibrium occurs. However, it could be argued, further, that once the new handset receives recognition in the market the relative retail marketing efficiency decreases. That is, the handset is better known, and its producer does not have to rely on marketing investment by its retailer. This means, while ER is often a profitable strategy just after market entry, it is not profitable anymore after being present in the market for a longer time. In our model, this would imply that the difference in retail market efficiencies became smaller $\left(K_{small/unkown} - K_{large/established}\right) \downarrow$ and so has the parameter space in which the asymmetric equilibrium occurs.

## 3.6 Welfare Implications

As has been shown in the preceding analysis, a manufacturer trades of the cost (*double markup effect*) against the benefits from ER (*investment effect* and *strategic effect*) when adopting ER. In contrast to this rationale, a welfare maximizing regulator trades off the pro-competitive effect of ER (*investment effect*) against the anticompetitive effect of ER (*double markup effect* and the *strategic effect*). This simple comparison already suggests that a manufacturer's interest in adopting $ER$ is not aligned with a regulator's interest, rationalizing government intervention. In this section, we analyze this issue in more depth using again the case of symmetric manufacturers.

The first part of our welfare result is summarized in the following Proposition:

**Proposition 3.4.** *[Consumer Surplus] Suppose manufacturers are symmetric:*

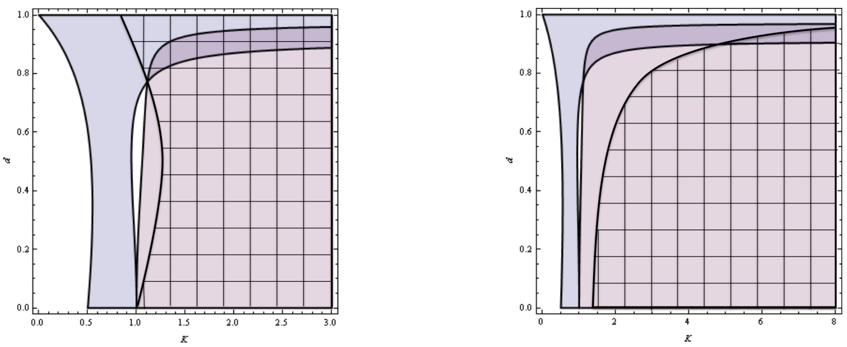
($i$) *Consumer surplus is decreasing with exclusive retailing when only one manufacturer adopts ER and the other manufacturer does not adopt ER.*

($ii$) *Consumer surplus is increasing with exclusive retailing, if and only if both manufacturers adopt ER and the retail investment technology is sufficiently efficient.*

*Proof.* See Appendix. ■

Graph ($a$) in Figure 3.3 illustrates these results. In the meshed area, consumers lose from ER, while in the remaining area consumers benefit from ER (given the manufacturer(s) adopt ER).

Figure 3.3: Consumer Surplus ($a$): Inside (outside) the meshed area, consumer surplus is lower (higher) under ER. Welfare ($b$): Inside (outside) the meshed area, welfare is lower (higher) under ER.



($a$) ($b$)

A more efficient retail investment technology results in a higher investment effect, which unambiguously increases consumer surplus. This effect has to be strong enough to counter the price increase from the double markup as well as the competition softening effect, which unambiguously decrease consumer surplus. As is shown in Proposition 3.1, (individual and total) retail investment is lower in the $E/N$-regime than in the $E/E$-regime and so is the investment effect. This smaller investment effect under $E/N$ turns out be insufficient to counter the two other effects which decrease consumer surplus. Hence, the adoption of ER by one manufacturer always harms consumers (Prop. 3.4 ($i$)), while it benefits consumers when it is adopted by both manufacturers and investment is relatively efficient (Prop. 3.4 ($ii$)).

The second part of our welfare result is summarized in the following Proposition:

**Proposition 3.5.** *[Welfare] Suppose manufacturers are symmetric and the retail investment technology is sufficiently efficient:*

($i$) *In contrast to Proposition 3.4, welfare is also increasing with exclusive retailing, if only one manufacturer adopts ER.*

($ii$) *For exclusive retailing to be welfare enhancing, retail investment must be more cost efficient the weaker the interbrand competition is.*

*Proof.* See Appendix. ■

Graph ($b$) in Figure 3.3 the effect of ER on welfare. In the meshed area, ER decreases welfare, while in the remaining area ER increases welfare (given the manufacturer(s) adopt ER).

In order to understand this result, it is helpful to disentangle the separate effects on consumer and producer surplus: The investment effect unambiguously increases consumer and producer surplus. In contrast, the double markup and the competition softening effect unambiguously decrease welfare. However, while the double markup effect is negative on consumer as well as producer surplus, the competition softening effect is sometimes positive on producer surplus.

Furthermore, the overall harm caused by the double markup and the competition softening effect is decreasing in the intensity of competition. Therefore, in addition to the result on consumer surplus, welfare is also increasing in exclusivity for a relatively high investment cost and hence, a smaller investment effect, given the competition is sufficiently tough. This can be easily seen by comparing the meshed areas in the two graphs of Figure 3.3.

Based on this analysis, we can make two observations, which are in contrast to Proposition 3.4: First, ER can also have a positive effect on welfare in the $E/N$-regime, as the benefit for producers from the investment effect outweighs the harm caused by the double markup as well as the competition softening effect, if competition is not too weak.

Second, a negative relationship between the cost of investment $K$ and the intensity of competition $d$ exists, for ER to be welfare enhancing. While the (positive) investment effect decreases with the investment cost, the adverse impact from the double markup and the competition softening effect decrease with tougher competition. Hence, ER turns out to be welfare enhancing for a rather inefficient investment technology as long as competition is sufficiently tough. The right graph in Figure 3.3 illustrates when ER is welfare enhancing and when not. In the meshed area, ER decreases welfare. In the remaining area, ER enhances welfare (given the manufacturer(s) adopt ER).

## 3.7 Conclusion

This study has identified a new rationale for exclusive retailing agreements, combining a pro- and an anticompetitive view of ER. ER comes at a cost for the manufacturer as it distorts downstream competition, gives retail firms a margin and creates a double markup problem. However, it is this retail margin that incentivizes downstream retailers to invest in (pro-competitive) brand-specific marketing which benefits the manufacturer of the brand. Moreover, the additional margin for the retail firm is a (anticompetitive) commitment device for higher prices in the market and softer interbrand competition.

We analyze the equilibrium incentives for a manufacturer to adopt ER when inter- and intrabrand competition exist. Therefore, we prove that parameter combinations exists under which no manufacturer, one manufacturer and both manufacturers adopt $ER$. We find, the more efficient the retail investment technology and the tougher interbrand competition, the more often $ER$ arrangements can be observed. In addition, we characterize each of these equilibria with respect to prices, investment levels and profits.

We find that manufacturers adopt $ER$ too often from a welfare point of view. $ER$ is usually welfare enhancing, whenever retail investment is rather efficient and/or interbrand competition is are rather tough. But if interbrand is sufficiently weak and manufacturers do not depend on retail marketing, such arrangements should be forbidden by competition authorities.

We shall discuss the importance of some of the assumptions for our results in the remainder. In our model, firms compete in prices. In principle, $ER$ also occurs in a setup where firms compete in quantities. However, the competition softening effect would vanish, while the double markup and the investment effect remain to exist.
Moreover, our results do not depend on the timing in our model. That is, all effects in this analysis continue to exist qualitatively when the manufacturer cannot commit to set a wholesale price before the retail investment is undertaken.
Furthermore, we have only considered demand enhancing investments, increasing consumers' perceived quality of a brand. This kind of investment has always a positive effect on the competing firm's profit. An interesting case would be to consider cost decreasing investments as this would always have a negative effect on the competitor's profit.

It is noteworthy that our assumption on linear wholesale prices is central to our analysis. This assumption causes the double markup and the competition softening effect. If we allow for non-linear wholesale tariffs, both effects vanish and any inefficiency stemming from the introduction of exclusivity does not appear anymore. This assumption on the pricing structure can be understood as the simplest possible way to model potential downstream distortions caused through $ER$. Another possibility for modelling a similar downstream distortion is the introduction of product differentiation at the downstream stage. The introduction of $ER$ would restrict the product variety in the industry and hence, harm consumers and welfare.
In addition, empirical as well as theoretical evidence justifies our assumption on linear wholesale prices. Iyer and Villas-Boas (2003), Milliou and Petrakis (2007), and Milliou, Petrakis and Vettas (2009) offer support for the use of simple, linear contracts in vertical trading relationships. They find that the distribution of bargaining power between the contracting parties, the ability to renegotiate contracts and product non-specifiability play an important role for the superiority of linear wholesale prices. Chintagunta, Liu and Zhu (2011) provide evidence that linear wholesale prices are widely used between mobile handset producers and wireless carriers. Linear wholesale tariffs can also be observed in other retail sectors. The U.K. Competition Commission produced evidence in its 2007 Groceries Market investigation on the usage of linear wholesale prices in the British

groceries market (see, e.g., Competition Commission, 2007).

Finally, we should mention that another interesting project for future research would be to explicitly include upstream market entry in our framework. New market entrants should be particularly dependent on third party marketing investment. As we have shown, ER serves as an instrument to incentivize such investment and hence, might have an entry promoting effect.

# Appendix A

## A.1 Preliminary Definitions.

$(I)$ **Feasible capacity.** $\Phi$ describes the feasible capacity and $\Phi_1$ describes the feasible baseload capacity in the market. It is given by

$$\Phi = \begin{cases} X, & if\, X \leq L \\ L, & if\, X > L \end{cases}, \qquad \Phi_1 = \begin{cases} X_1, & if\, X_1 \leq L \\ L, & if\, X_1 > L \end{cases}.$$

The feasible peakload capacity is given by $\Phi - \Phi_1$.

$(II)$ **Spot market definitions.** The different critical spot market realizations are defined as follows.

$$\begin{array}{llll}
\theta^{\underline{X_1}}: & P\left(X_1, \theta^{\underline{X_1}}\right) - c_1 = 0, & \theta_\tau^{\underline{X_1}}: & P\left(X_1, \theta_\tau^{\underline{X_1}}\right) - (c_1 + \tau) = 0 \\
\theta^{\overline{X_1}}: & P\left(X_1, \theta^{\overline{X_1}}\right) - c = 0, & \theta_\tau^{\overline{X_1}}: & P\left(X_1, \theta_\tau^{\overline{X_1}}\right) - (c_1 + \tau) = 0 \\
\theta^{X}: & P\left(X, \theta^{X}\right) - c = 0, & \theta_\tau^{X}: & P\left(X, \theta_\tau^{X}\right) - (c_1 + \tau) = 0 \\
\theta^{L}: & P\left(L, \theta^{L}\right) - c = 0, & \theta_\tau^{L}: & P\left(L, \theta_\tau^{L}\right) - (c_1 + \tau) = 0 \\
\theta^{\underline{M_1}}: & P\left(\Phi_1, \theta^{\underline{M_1}}\right) - c_1 = 0, & \theta^{\tau}: & P\left(0, \theta^{\tau}\right) - (c_1 + \tau) = 0 \\
\theta^{\overline{M_1}}: & P\left(\Phi_1, \theta^{\overline{M_1}}\right) - c = 0, & \theta^{M}: & P\left(\Phi, \theta^{M}\right) - c = 0
\end{array}$$

Remember that the actual size of the transmission line $T$ differs from the nominal size $L$. The frequency of the capacity is denoted by $g\left(T\right)$, its support is given by $[-\epsilon, +\epsilon]$, and its cumulative distribution is denoted by $G\left(T\right)$. If the size of the transmission and generation capacities is sufficiently different, that is, $|X - L| > \epsilon$, the former (latter) is larger (smaller) with probability 1 (0). However, if transmission and generation capacities are sufficiently close, the uncertainty of the transmission line also affects the relative size of the generation and transmission capacities. $G\left(.\right)$ is the probability that the transmission line is binding before the generation capacity is and $1 - G\left(.\right)$ is the probability that the generation capacity is binding before the transmission line is doing so. Formally, we assign the following probabilities

$$G\left(X - L\right) = \begin{cases} 0, & if\, L - X > \epsilon \\ 1, & if\, X - L > \epsilon \\ \left(0, 1\right), & otherwise \end{cases}$$

$(III)$ **Spot market profits and welfare under simultaneous market clearing.** In this section, we present the profits of generators and transmission owners as well as welfare for different spot markets. $W(X, X_1, L, \theta)$ denotes the economy's welfare and $\pi_i(x, x_1, l, \theta)$ the profit of a generator.

• at spot markets $\theta\epsilon\left[\underline{\theta}, \theta^{\underline{M_1}}\right]$

$$\begin{aligned} W(X, X_1, L, \theta) &= \int_0^Q (P(v,\theta) - c_1)\, dv \\ \pi(x, x_1, l, \theta) &= 0 \end{aligned}$$

• at spot markets $\theta\epsilon\left[\theta^{\underline{M_1}}, \theta^{\overline{M_1}}\right]$

$$\begin{aligned} W(X, X_1, L, \theta) &= (1 - G(X_1 - L)) \int_0^{X_1} (P(v,\theta) - c_1)\, dv + G(X_1 - L) \int_0^{L} (P(v,\theta) - c_1)\, dv \\ \pi(x, x_1, l, \theta) &= (1 - G(X_1 - L))(P(X_1, \theta) - c_1)\, x_1 \end{aligned}$$

• at spot markets $\theta\epsilon\left[\theta^{\overline{M_1}}, \theta^{M}\right]$

$$\begin{aligned} W(X, X_1, L, \theta) &= (1 - G(X_1 + Q - L)) \left( \int_0^{X_1+Q} P(v,\theta)\, dv - \int_0^{X_1} c_1 dv - \int_{X_1}^{X_1+Q} c dv \right) \\ &\quad + G(X_1 + Q - L) \left( \int_0^{L} P(v,\theta)\, dv - \int_0^{X_1} c_1 dv - \int_{X_1}^{L} c dv \right) \\ \pi(x, x_1, l, \theta) &= (1 - G(X_1 + Q - L))(P(X_1 + Q, \theta) - c_1)\, x_1 + G(X_1 + Q - L)(c - c_1)\, x_1 \end{aligned}$$

• at spot markets $\theta\epsilon\left[\theta^{M}, \overline{\theta}\right]$

$$\begin{aligned} W(X, X_1, L, \theta) &= (1 - G(X - L)) \left( \int_0^{X} P(v,\theta)\, dv - \int_0^{X_1} c_1 dv - \int_{X_1}^{X} c dv \right) \\ &\quad + G(X - L) \left( \int_0^{L} P(v,\theta)\, dv - \int_0^{X_1} c_1 dv - \int_{X_1}^{L} c dv \right) \\ \pi(x, x_1, l, \theta) &= (1 - G(X - L))((P(X, \theta) - c_1)\, x_1 + (P(X, \theta) - c)(x - x_1)) \\ &\quad + G((X - L))(c - c_1)\, x_1 \end{aligned}$$

$(IV)$ **Spot market profits and welfare under sequential market clearing.** In this section, we present the profits of generators and transmission owners as well as welfare for different spot markets. $W(X, X_1, L, \theta)$ denotes the economy's welfare and $\pi_i(x, x_1, l, \theta)$ the profit of a generator at spot market realization $\theta$. Notice that welfare under sequential market clearing only differs from welfare in simultaneous market clearing as the generators' choice variables $Q(\tau(L))$, $X_1(\tau(L))$ and $X(\tau(L))$ are now depending on the transmission fee $(\tau(L))$ which has to be taken into account. In addition, the critical spot market realizations are also affected by the transmission fee.

- at spot markets $\theta\epsilon\left[\underline{\theta},\theta_{\tau}^{M_1}\right]$

$$
\begin{aligned}
W\left(X,X_1,L,\theta\right) &= \int_0^{Q(\tau(L))}\left(P\left(v,\theta\right)-c_1\right)dv \\
\pi\left(x,x_1,l,\theta\right) &= 0
\end{aligned}
$$

- at spot markets $\theta\epsilon\left[\theta_{\tau}^{M_1},\theta_{\tau}^{\overline{M_1}}\right]$

$$
\begin{aligned}
W\left(X,X_1,L,\theta\right) &= \left(1-G\left(X_1-L\right)\right)\int_0^{X_1(\tau(L))}\left(P\left(v,\theta\right)-c_1\right)dv+G\left(X_1-L\right)\int_0^{L}\left(P\left(v,\theta\right)-c_1\right)dv \\
\pi\left(x,x_1,l,\theta\right) &= \left(P\left(X_1,\theta\right)-c_1\right)x_1
\end{aligned}
$$

- at spot markets $\theta\epsilon\left[\theta_{\tau}^{\overline{M_1}},\theta_{\tau}^{M}\right]$

$$
\begin{aligned}
W\left(X,X_1,L,\theta\right) &= \left(1-G\left(X_1+Q-L\right)\right)\left(\int_0^{X_1(\tau(L))+Q(\tau(L))}P\left(v,\theta\right)dv-\int_0^{X_1(\tau(L))}c_1dv-\int_{X_1(\tau(L))}^{X_1(\tau(L))+Q(\tau(L))}cdv\right) \\
&\quad +G\left(X_1+Q-L\right)\left(\int_0^{L}P\left(v,\theta\right)dv-\int_0^{X_1(\tau(L))}c_1dv-\int_{X_1(\tau(L))}^{L}cdv\right) \\
\pi\left(x,x_1,l,\theta\right) &= \left(P\left(X_1+Q,\theta\right)-c_1\right)x_1
\end{aligned}
$$

- at spot markets $\theta\epsilon\left[\theta_{\tau}^{M},\overline{\theta}\right]$

$$
\begin{aligned}
W\left(X,X_1,L,\theta\right) &= \left(1-G\left(X-L\right)\right)\left(\int_0^{X(\tau(L))}P\left(v,\theta\right)dv-\int_0^{X_1(\tau(L))}c_1dv-\int_{X_1(\tau(L))}^{X(\tau(L))}cdv\right) \\
&\quad +G\left(X-L\right)\left(\int_0^{L}P\left(v,\theta\right)dv-\int_0^{X_1(\tau(L))}c_1dv-\int_{X_1(\tau(L))}^{L}cdv\right) \\
\pi\left(x,x_1,l,\theta\right) &= \left(P\left(X,\theta\right)-c_1\right)x_1+\left(P\left(X,\theta\right)-c\right)\left(x-x_1\right)
\end{aligned}
$$

## A.2 Proof of Remark 1.1

$(I)$ **Welfare and first order conditions.** The previous results enable us to derive overall welfare. It is obtained by the integral over all spot markets.

$$
W\left(X,X_1,L\right)=\int_{\underline{\theta}}^{\overline{\theta}}W\left(X,X_1,L,\theta\right)dF\left(\theta\right)-k_1x_1-k\left(x-x_1\right)-tl
$$

Note that the integrand in this expression is continuous in $\theta$. The first derivatives are given by:

$$
\begin{aligned}
W_X &= (1 - G(X - L)) \int_{\theta^M}^{\overline{\theta}} (P(X, \theta) - c)\, dF(\theta) - k \\
W_{X_1} &= (1 - G(X_1 - L)) \int_{\theta^{\underline{M_1}}}^{\theta^{\overline{M_1}}} (P(X_1, \theta) - c_1)\, dF(\theta) + \int_{\theta^{\overline{M_1}}}^{\theta^M} (P(X_1 + Q, \theta) - c_1)\, dF(\theta) \\
&\quad + \int_{\theta^M}^{\overline{\theta}} (c - c_1)\, dF(\theta) - (k - k_1) \\
W_L &= G(X_1 - L) \int_{\theta^{\underline{M_1}}}^{\theta^{\overline{M_1}}} (P(L, \theta) - c_1)\, dF(\theta) + G(X_1 + Q - L) \int_{\theta^{\overline{M_1}}}^{\theta^M} (P(L, \theta) - c)\, dF(\theta) \\
&\quad + G(X - L) \int_{\theta^M}^{\overline{\theta}} (P(L, \theta) - c)\, dF(\theta) - t
\end{aligned}
$$

$(II)$ **Equilibrium.** In equilibrium the first derivatives have to be equal to zero. Hence, the transmission line and total generation capacity have to be of the same size:

$$X^* = L^*$$

This is

$$W_X(X^*, X_1^*, L^*) + W_L(X^*, X_1^*, L^*) = \int_{\theta^X}^{\overline{\theta}} (P(X^*, \theta) - c)\, dF(\theta) - (k + t) = 0 \tag{A.1}$$

$$W_{X_1}(X^*, X_1^*, L^*) = \int_{\theta^{\underline{X_1}}}^{\theta^{\overline{X_1}}} (P(X_1^*, \theta) - c_1)\, dF(\theta) + \int_{\theta^{\overline{X_1}}}^{\overline{\theta}} (c - c_1)\, dF(\theta) - (k_1 - k) = 0 \tag{A.2}$$

$(III)$ **Uniqueness.** As in equilibrium $X^* = L^*$ has to hold, it is sufficient to check the second order conditions only for the joint equilibrium conditions from $(II)$ with respect to $X$ and $X_1$. The second derivatives are given by

$$
\begin{aligned}
W_{XX}(X^*, X_1^*, L^*) + W_{LL}(X^*, X_1^*, L^*) &= \int_{\theta^X}^{\overline{\theta}} P_q(X^*, \theta)\, dF(\theta) < 0 \\
W_{X_1X_1}(X^*, X_1^*, L^*) &= \int_{\theta^{\underline{X_1}}}^{\theta^{\overline{X_1}}} P_q(X_1^*, \theta) + \int_{\theta^{\overline{X_1}}}^{\theta^X} P_q(X_1^* + Q, \theta) < 0 \\
W_{XX_1}(X^*, X_1^*, L^*) &= 0
\end{aligned}
$$

It is easy to see that the absolute value of the cross derivatives is smaller than the absolute value of any of the second derivatives

$$| W_{xx}(X, X_1, L) |, | W_{x_1x_1}(X, X_1, L) | > | W_{xx_1}(X, X_1, L) |$$

Hence, the product of the cross derivatives is smaller than the product of the second derivatives:

$$\pi_{xx}(X, X_1, L) \cdot \pi_{x_1x_1}(X, X_1, L) > 0$$

That is, the first order conditions describe a unique equilibrium.

## A.3 Proof of Lemma 1.1

$(I)$ **Preliminaries: Profits and first order conditions.** The results for the spot market equilibria enable us to derive the investors' overall profits. It is obtained by the integral over all spot markets. For generators this is given by:

$$\pi_i\left(x, x_1, l\right)=\int_{\underline{\theta}}^{\overline{\theta}} \pi_i\left(x, x_1, l, \theta\right) dF(\theta)-k_1 x_1-k\left(x-x_1\right) \tag{A.3}$$

Note that the integrand in this expression is continuous in $\theta$. The first derivatives are given by:

$$\begin{aligned}
\pi_x &= (1-G(X-L)) \int_{\theta^M}^{\overline{\theta}}(P(X, \theta)-c) dF(\theta)-k \\
\pi_{x_1} &= \left(1-G\left(X_1-L\right)\right) \int_{\underline{\theta^{M_1}}}^{\overline{\theta^{M_1}}}\left(P\left(X_1, \theta\right)-c_1\right) dF(\theta) \\
&\quad +\left(1-G\left(X_1+Q-L\right)\right) \int_{\overline{\theta^{M_1}}}^{\theta^M}\left(P\left(X_1+Q, \theta\right)-c_1\right) dF(\theta) \\
&\quad +G\left(X_1+Q-L\right) \int_{\overline{\theta^{M_1}}}^{\theta^M}\left(c-c_1\right) dF(\theta)-\left(k_1-k\right)
\end{aligned}$$

The first derivative with respect to the optimal transmission line is already given in the proof of 1.1:

$$\begin{aligned}
W_L &= G\left(X_1-L\right) \int_{\underline{\theta^{M_1}}}^{\overline{\theta^{M_1}}}\left(P(L, \theta)-c_1\right) dF(\theta)+G\left(X_1+Q-L\right) \int_{\overline{\theta^{M_1}}}^{\theta^M}(P(L, \theta)-c) dF(\theta) \\
&\quad +G(X-L) \int_{\theta^M}^{\overline{\theta}}(P(L, \theta)-c) dF(\theta)-t
\end{aligned}$$

$(II)$ **Equilibrium.** The equilibrium equates the first derivatives to zero. Hence, in equilibrium, transmission and generation capacity have to be of equal size:

$$\hat{X}=\hat{L}$$

This is

$$\pi_X = \left(1-G\left(\hat{X}-\hat{L}\right)\right) \int_{\theta^X}^{\overline{\theta}}\left(P\left(\hat{X}, \theta\right)-c\right) dF(\theta)-k=0 \tag{A.4}$$

$$\pi_{X_1} = \int_{\underline{\theta^{X_1}}}^{\overline{\theta^{X_1}}}\left(P\left(\hat{X}_1, \theta\right)-c_1\right) dF(\theta)+\int_{\overline{\theta^{X_1}}}^{\overline{\theta}}\left(c-c_1\right) dF(\theta)-\left(k_1-k\right)=0 \tag{A.5}$$

$$W_L = G\left(\hat{X}-\hat{L}\right) \int_{\theta^X}^{\overline{\theta}}\left(P\left(\hat{L}, \theta\right)-c\right) dF(\theta)-t=0 \tag{A.6}$$

Comparing equations (A.4), (A.5) and (A.6) with the first order conditions of the socially optimal investment (A.1) and (A.2), it is straightforward to see that investment under simultaneous market clearing leads to the socially optimal investment outcome.

$(III)$ **Uniqueness.** The first oder conditions are identical to the first order conditions characterizing the socially optimal investment (Remark 1.1). As we have shown, these characterize a unique equilibrium. Hence, also the first order conditions under $(II)$ do.

## A.4 Proof of Lemma 1.2

### A.4.1 Preliminaries: Balanced Budget

We assume that the regulator has to fulfill the following budget balancing equation:

$$
\begin{aligned}
BB: \quad & -\int_{\theta_\tau^L}^{\theta_\tau^X} \int_L^{Q^*(\tau(L),\theta)} \left(P\left(L,\theta\right) - c - \tau\left(L\right)\right) dy dF\left(\theta\right) - \int_{\theta_\tau^X}^{\overline{\theta}} \int_L^{X(\tau(L))} \left(P\left(L,\theta\right) - c - \tau\left(L\right)\right) dy dF\left(\theta\right) \\
& + \int_{\theta^\tau}^{\theta_\tau^{\underline{X_1}}} Q^\tau\left(\tau\left(L\right),\theta\right) \tau\left(L\right) dF\left(\theta\right) + \int_{\theta_\tau^{\underline{X_1}}}^{\theta_\tau^{\overline{X_1}}} X_1\left(\tau\left(L\right)\right) \tau\left(L\right) dF\left(\theta\right) \\
& + \int_{\theta_\tau^{\overline{X_1}}}^{\theta_\tau^L} \left(X_1\left(\tau\left(L\right)\right) + Q^*\left(\tau\left(L\right)\right)\right) \tau\left(L\right) dF\left(\theta\right) + \int_{\theta_\tau^L}^{\bar{\theta}} L\tau\left(L\right) dF\left(\theta\right) - tL = 0
\end{aligned}
\tag{A.7}
$$

This equation implies that the revenues from the transmission fee are equal to the investment cost and the cost to run the adjustment market.

### A.4.2 Market generation investment

$(I)$ **Preliminaries: Profits and first order conditions.** The results for the spot market equilibria enable us to derive the investors' overall profits. It is obtained by the integral over all spot markets. For generators this is given by:

$$
\pi_i\left(x^B, x^P, l\right) = \int_{\underline{\theta}}^{\overline{\theta}} \pi_i\left(x^B, x^P, l, \theta\right) dF\left(\theta\right) - k_1 x_1 - k\left(x - x_1\right) \tag{A.8}
$$

Note that the integrand in this expression is continuous in $\theta$. The first derivatives are given by:

$$
\begin{aligned}
\pi_x\left(x, x_1, l\right) &= \int_{\theta_\tau^X}^{\overline{\theta}} \left(P\left(X,\theta\right) - \tau - c\right) dF\left(\theta\right) - k \\
\pi_{x_1}\left(x, x_1, l\right) &= \int_{\theta_\tau^{\underline{X_1}}}^{\theta_\tau^{\overline{X_1}}} \left(P\left(X_1,\theta\right) - \tau - c_1\right) dF\left(\theta\right) + \int_{\theta_\tau^{\overline{X_1}}}^{\theta_\tau^X} \left(P\left(X_1 + Q,\theta\right) - \tau - c_1\right) dF\left(\theta\right) \\
&\quad + \int_{\theta_\tau^X}^{\overline{\theta}} \left(c - c_1\right) dF\left(\theta\right) - \left(k_1 - k\right)
\end{aligned}
$$

$(II)$ **Equilibrium.** The equilibrium equates the first derivatives to zero. This is

$$\tilde{X} \quad : \quad \int_{\theta_\tau^X}^{\overline{\theta}} \left(P\left(\tilde{X},\theta\right) - \tau - c\right) dF(\theta) - k = 0 \tag{A.9}$$

$$\tilde{X}_1 \quad : \quad \int_{\theta_\tau^{\underline{X_1}}}^{\theta_\tau^{\overline{X_1}}} \left(P\left(\tilde{X}_1,\theta\right) - \tau - c_1\right) dF(\theta) + \int_{\theta_\tau^{\overline{X_1}}}^{\overline{\theta}} (c - c_1)\, dF(\theta) - (k_1 - k) = 0 \tag{A.10}$$

$(III)$ **Uniqueness.** The second derivatives are given by

$$\begin{aligned}
\pi_{x_1x_1}(x, x_1, l) &= \int_{\theta_\tau^{\underline{X_1}}}^{\theta_\tau^{\overline{X_1}}} 2P_q\left(\tilde{X}_1,\theta\right) dF(\theta) + \int_{\theta_\tau^{\overline{X_1}}}^{\theta_\tau^X} 2P_q\left(\tilde{X}_1 + Q,\theta\right) dF(\theta) < 0 \\
\pi_{xx}(x, x_1, l) &= \int_{\theta_\tau^X}^{\overline{\theta}} 2P_q\left(\tilde{X},\theta\right) dF(\theta) < 0 \\
\pi_{xx_1}(x, x_1, l) &= 0
\end{aligned}$$

As is easy to see, the absolute value of the cross derivatives is smaller than the absolute value of any of the second derivatives and hence, the product of the cross derivatives is smaller than the product of the second derivatives

$$|\pi_{xx_1}(x, x_1, l)| < |\pi_{xx}(x, x_1, l)|, |\pi_{x_1x_1}(x, x_1, l)|$$

$$\pi_{xx}(x, x_1, l) \cdot \pi_{x_1x_1}(x, x_1, l) > 0.$$

That is, the first order conditions describe an unique equilibrium.

## A.4.3 Optimal transmission line investment

$(I)$ **Welfare.** The results for the spot market welfare enable us to derive the investors' overall profits. It is obtained by the integral over all spot markets. Welfare is given by

$$W(X, X_1, L) = \int_{\underline{\theta}}^{\overline{\theta}} W(X, X_1, L, \theta)\, dF(\theta) - k\left(X(\tau(L)) - X_1(\tau(L))\right) - k_1 X_1(\tau(L)) - tL \tag{A.11}$$

Taking the first derivative and rearranging gives:

$$\begin{aligned}
W_L \quad = \quad & \int_{\underline{\theta}}^{\theta_\tau^{\underline{X_1}}} \tau(L)\, Q_\tau^*(\tau(L))\, \tau_L(L)\, dF(\theta) + \int_{\theta_\tau^{\underline{X_1}}}^{\theta_\tau^{\overline{X_1}}} \left(P\left(X_1(\tau(L)),\theta\right) - c_1\right) X_{1\tau}(\tau(L))\, \tau_L(L)\, dF(\theta) \\
& + \int_{\theta_\tau^{\overline{X_1}}}^{\theta_\tau^L} \tau(L)\left(X_{1\tau}(\tau(L)) + Q_\tau^*(\tau(L))\right) \tau_L(L)\, dF(\theta) + \int_{\theta_\tau^{\overline{X_1}}}^{\overline{\theta}} (c - c_1)\, X_{1\tau}(\tau(L))\, \tau_L(L)\, dF(\theta) \\
& + \int_{\theta_\tau^L}^{\overline{\theta}} \left(P(L,\theta) - c\right) dF(\theta) - kX_\tau(\tau(L))\, \tau_L(L) - (k_1 - k)\, X_{1\tau}(\tau(L))\, \tau_L(L) - t
\end{aligned} \tag{A.12}$$

$(II)$ **Balanced Budget.** Taking the first derivative of the budget balancing equation and rearranging gives

$$\begin{aligned}
BB_L = \;& \int_{\theta^{\tau}}^{\theta_{\tau}^{\underline{X_1}}} \tau(L)\, Q_{\tau}^{\tau}(\tau(L),\theta)\,\tau_L(L)\,dF(\theta) + \int_{\theta_{\tau}^{\underline{X_1}}}^{\theta_{\tau}^{\overline{X_1}}} \tau(L)\, X_{1\tau}(\tau(L))\,\tau_L(L)\,dF(\theta) \\
& + \int_{\theta_{\tau}^{X_1}}^{\theta_{\tau}^{L}} \tau(L)\left(X_{1\tau}(\tau(L)) + Q_{\tau}^{*}(\tau(L))\right)\tau_L(L)\,dF(\theta) + \int_{\theta_{\tau}^{L}}^{\bar{\theta}} \left(P(L,\theta) - c\right) dF(\theta) \\
& - kX_{\tau}(\tau(L))\,\tau_L(L)\,dF(\theta) - t - \int_{\theta_{\tau}^{L}}^{\theta_{\tau}^{X}} \left(P(L,\theta) - c - \tau(L)\right) Q_{\tau}^{*}(\tau(L),\theta)\,\tau_L(L)\,dF(\theta) \\
& - \int_{\theta_{\tau}^{X}}^{\overline{\theta}} \left(P(L,\theta) - P(X,\theta)\right) X_{\tau}(\tau(L))\,dF(\theta) + \int_{\theta_{\tau}^{L}}^{\theta_{\tau}^{X}} Q^{*}(\tau(L),\theta)\,\tau_L(L)\,dF(\theta) \\
& + \int_{\theta_{\tau}^{X}}^{\overline{\theta}} X(\tau(L))\,\tau_L(L)\,dF(\theta) + \int_{\theta^{\tau}}^{\theta_{\tau}^{\underline{X_1}}} Q^{\tau}(\tau(L),\theta)\,\tau_L(L)\,dF(\theta) \\
& + \int_{\theta_{\tau}^{\underline{X_1}}}^{\theta_{\tau}^{\overline{X_1}}} X_1(\tau(L))\,\tau_L(L)\,dF(\theta) + \int_{\theta_{\tau}^{X_1}}^{\theta_{\tau}^{L}} \left(X_1(\tau(L)) + Q^{*}(\tau(L))\right)\tau_L(L)\,dF(\theta) = 0
\end{aligned} \tag{A.13}$$

We can now substitute $BB_L$ (expression (A.13)) into $W_L$ (expression (A.12)):

$$\begin{aligned}
W_L = \;& \tau_L(L)\left(\int_{\theta_{\tau}^{L}}^{\theta_{\tau}^{X}} \left(P(L,\theta) - c - \tau(L)\right) Q_{\tau}^{*}(\tau(L),\theta)\,dF(\theta) + \int_{\theta_{\tau}^{X}}^{\overline{\theta}} \left(P(L,\theta) - P(X,\theta)\right) X_{\tau}(\tau(L))\,dF(\theta)\right) \\
& - \tau_L(L)\left(\int_{\theta_{\tau}^{L}}^{\theta_{\tau}^{X}} Q^{*}(\tau(L),\theta)\,dF(\theta) + \int_{\theta_{\tau}^{X}}^{\overline{\theta}} X(\tau(L),\theta)\,dF(\theta) + \int_{\theta^{\tau}}^{\theta_{\tau}^{\underline{X_1}}} Q^{*}(\tau(L),\theta)\,dF(\theta)\right) \\
& - \tau_L(L)\left(\int_{\theta_{\tau}^{\underline{X_1}}}^{\theta_{\tau}^{\overline{X_1}}} X_1(\tau(L))\,dF(\theta) + \int_{\theta_{\tau}^{X_1}}^{\theta_{\tau}^{L}} \left(X_1(\tau(L)) + Q^{*}(\tau(L))\right) dF(\theta)\right)
\end{aligned}$$

As all elements within the brackets are positive, the whole term is also positive. If we determine the sign of $\tau_L$, we know the sign of $W_L$. $\tau_L$ is given by

$$\begin{aligned}
\tau_L = \;& \left(t - \int_{\theta_{\tau}^{L}}^{\overline{\theta}} \left(P(L,\theta) - c\right) dF(\theta)\right)\Bigg(\int_{\theta_{\tau}^{L}}^{\theta_{\tau}^{X}} Q^{*}(\tau(L),\theta)\,dF(\theta) + \int_{\theta_{\tau}^{X}}^{\overline{\theta}} X(\tau(L))\,dF(\theta) \\
& + \int_{\theta_{\tau}^{X_1}}^{\theta_{\tau}^{L}} \left(\left(X_{1\tau}(\tau(L)) + Q_{\tau}^{*}(\tau(L))\right)\tau(L) + \left(X_1(\tau(L)) + Q^{*}(\tau(L))\right)\right) dF(\theta) \\
& + \int_{\theta^{\tau}}^{\theta_{\tau}^{\underline{X_1}}} \left(Q_{\tau}^{\tau}(\tau(L),\theta)\,\tau(L) + Q^{\tau}(\tau(L),\theta)\right) dF(\theta) + \int_{\theta_{\tau}^{\underline{X_1}}}^{\theta_{\tau}^{\overline{X_1}}} \left(X_{1\tau}(\tau(L))\,\tau(L) + X_1(\tau(L))\right) dF(\theta) \\
& - \int_{\theta_{\tau}^{L}}^{\theta_{\tau}^{X}} \left(\left(P(L,\theta) - c - \tau(L)\right) Q_{\tau}^{*}(\tau(L),\theta)\right) dF(\theta) - \int_{\theta_{\tau}^{X}}^{\overline{\theta}} \left(P(L,\theta) - c - \tau(L)\right) X_{\tau}(\tau(L))\,dF(\theta)\Bigg)^{-1}
\end{aligned}$$

Note that the second term is positive for $\eta \geq -1$. Hence, the sign of $\tau_L$ only depends on the first term of the equation, that is,

$$sign\,\tau_L = sign\left(t - \int_{\theta_{\tau}^{L}}^{\overline{\theta}} \left(P(L,\theta) - c\right) dF(\theta)\right), \tag{A.14}$$

Thus, $\tau_L$ also describes the size of the transmission line. In order to evaluate the size of the transmission capacity relative to the generation stock, we subtract the first order condition describing generation investment (expression (A.9)) from the term in brackets in expression (A.14).

$$\int_{\theta_\tau^L}^{\overline{\theta}} \left(P\left(\tilde{L},\theta\right)-c\right) dF\left(\theta\right) - t - \int_{\theta_\tau^X}^{\overline{\theta}} \left(P\left(\tilde{X},\theta\right)-\tau-c\right) dF\left(\theta\right) + k \gtrless 0$$

We get:
$(i)$ $t \leq k + \left(1 - F\left(\theta_\tau^X\right)\right)\tau \Rightarrow \tau_L \leq 0$: The transmission line matches the generation capacity (corner solution).
$(ii)$ $t > k + \left(1 - F\left(\theta_\tau^X\right)\right)\tau \Rightarrow \tau_L > 0$: The transmission line does not match the generation capacity (interior solution).
Hence, given our assumption $t < k$ on the transmission line, $(i)$ always holds. That is, the line capacity matches the generation capacity, $\tilde{X} = \tilde{L}$. Q.e.d.

# A.5 Proof of Proposition 1.1

This proposition compares the investment incentives under sequential market clearing with the investment incentives under simultaneous market clearing. In order to show whether under sequential market clearing investment incentives are stronger or weaker, it is sufficient to subtract the respective equilibrium conditions from each other. We start with total capacity:

## A.5.1 Total Generation Capacity

We evaluate the difference between the first derivatives describing total capacity under sequential market clearing (expression (A.9)) and under simultaneous market clearing (expression (A.4) and expression (A.6)) evaluated at the sequential market clearing equilibrium values, $\tilde{X} = \tilde{L}$.

$$\begin{aligned} &\int_{\theta_\tau^X}^{\bar{\theta}} \left(P\left(\tilde{X},\theta\right)-c\right) dF\left(\theta\right) - \int_{\theta_\tau^X}^{\bar{\theta}} \tau dF\left(\theta\right) - k \\ &\qquad - \int_{\theta^X}^{\bar{\theta}} \left(P\left(\tilde{X},\theta\right)-c\right) dF\left(\theta\right) + (k+t) \quad \gtrless \quad 0 \end{aligned}$$

Reformulating yields the following expression:

$$\int_{\underline{\theta}}^{\theta^X} \frac{Q^\tau}{\tilde{L}} dF\left(\theta\right) + \int_{\theta^X}^{\theta_\tau^X} \left(\frac{Q^\tau}{\tilde{L}} - \frac{P\left(\tilde{L},\theta\right)-c}{\tau}\right) dF\left(\theta\right)$$

The first term is clearly positive. If the second term is also positive, the whole expression is positive and hence, total capacity under sequential market clearing exceeds total capacity under simultaneous market clearing. The second term can be rewritten as

$$\frac{1}{L\tau}\int_{\theta^{X}}^{\theta_{\tau}^{X}}\int_{0}^{\tau}Q^{\tau}(v,\theta)\left(\underbrace{\frac{\partial Q^{\tau}(v,\theta)}{\partial\tau}\frac{v}{Q^{\tau}(v,\theta)}}_{=\eta_{\tau}}+1\right)dvdF(\theta)$$

$$-\frac{1}{L\tau}\int_{\theta^{X}}^{\theta_{\tau}^{X}}\int_{0}^{L}P(v,\theta)\left(\underbrace{\frac{\partial P(v,\theta)}{\partial L}\frac{v}{P(v,\theta)}}_{=\eta_{L}^{-1}}+\underbrace{\frac{P(v,\theta)-c}{P(v,\theta)}}_{\epsilon[0,1]}\right)dvdF(\theta).$$

This expression is positive, if $\eta \geq -1$. Q.e.d.

### A.5.2 Baseload Generation Capacity

Again, we evaluate the difference between the first order conditions describing baseload capacity under sequential market clearing (expression (A.10)) and under simultaneous market clearing (expression (A.5)) evaluated at the equilibrium value under sequential market clearing, $\tilde{X}_1$.

$$\begin{aligned}&\int_{\theta_{\tau}^{\underline{X_1}}}^{\theta_{\tau}^{\overline{X_1}}}\left(P\left(\tilde{X}_1,\theta\right)-\tau-c_1\right)dF(\theta)+\int_{\theta_{\tau}^{\overline{X_1}}}^{\bar{\theta}}(c-c_1)\,dF(\theta)-(k_1-k)\\&\quad-\int_{\theta^{\underline{X_1}}}^{\theta^{\overline{X_1}}}\left(P\left(\tilde{X}_1,\theta\right)-c_1\right)dF(\theta)-\int_{\theta^{\overline{X_1}}}^{\bar{\theta}}(c-c_1)\,dF(\theta)+(k_1-k)\quad\gtrless\quad 0\end{aligned}$$

Reformulating yields the following expression, which is weakly negative.

$$\Leftrightarrow\underbrace{\int_{\theta^{\overline{X_1}}}^{\theta_{\tau}^{\overline{X_1}}}\left(P\left(\tilde{X}_1,\theta\right)-\tau-c\right)dF(\theta)}_{\leq 0}-\int_{\theta^{\underline{X_1}}}^{\theta_{\tau}^{\underline{X_1}}}\left(P\left(\tilde{X}_1,\theta\right)-c_1\right)dF(\theta)-\int_{\theta_{\tau}^{\underline{X_1}}}^{\theta^{\overline{X_1}}}\tau dF(\theta)\leq 0$$

Hence, baseload capacity is lower under sequential market clearing than under simultaneous market clearing.

### A.5.3 Transmission Capacity

From the proof in subsection A.4.3 we know that for our assumption $t < k$ the transmission capacity always matches the generation capacity, that is, $\tilde{X} = \tilde{L}$. Moreover, it has also been shown in subsection A.5.1 that the generation capacity with sequential market clearing exceeds the generation capacity with simultaneous market clearing, $\tilde{X} > \hat{X}$. Hence, it holds that $\tilde{L} > \hat{L}$. Q.e.d.

However, if we allow for $t > k$, $\tilde{X} = \tilde{L}$ does not necessarily hold. In order to understand how this influences our result with respect to the transmission capacity, we again evaluate the difference between the first order conditions describing transmission capacity under

sequential market clearing (expression (A.14)) and under simultaneous market clearing (expression (A.6)) evaluated at the sequential market clearing equilibrium value $\tilde{L}$.
First-best line investment is given by

$$\int_{\theta^L}^{\overline{\theta}} \left(P\left(\hat{L},\theta\right)-c\right) dF(\theta)-(k+t)=0$$

Optimal investment under sequential market clearing is given by,

$$\int_{\theta_\tau^L}^{\overline{\theta}} \left(P\left(\tilde{L},\theta\right)-c\right) dF(\theta)-t=0$$

Subtracting these two expressions from each other and evaluating the difference at the equilibrium values under sequential market clearing gives:

$$\begin{aligned}&\overbrace{\int_{\theta_\tau^L}^{\overline{\theta}} \left(P\left(\tilde{L},\theta\right)-c\right) dF(\theta)-t}^{Sequential\,Market\,Clearing}-\overbrace{\int_{\theta^L}^{\overline{\theta}} \left(P\left(\tilde{L},\theta\right)-c\right) dF(\theta)-(k+t)}^{Simultaneous\,Market\,Clearing}\\ &=\underbrace{-\int_{\theta^L}^{\theta_\tau^L} \left(P\left(\tilde{L},\theta\right)-c\right) dF(\theta)}_{spot\,market\,distortion\,effect}+\underbrace{k}_{sunk\,cost\,effect}.\end{aligned}$$

If the equation above is greater than zero, it holds that $\tilde{X}>\hat{X}$. If it is smaller than zero, the opposite is true, that is $\tilde{X}<\hat{X}$. Notice that the first and the second term of the equation are independent of each other. Hence, for $k$ large enough - everything else equal - the former holds, otherwise the latter is true.

# A.6 Generalization

## A.6.1 Preliminary Definitions

$(I)$ **Definitions.** For tractability, we now explicitly express the peakload capacity. That is, $L-L_1=L_0$ and $X-X_1=X_0$ and $\Phi-\Phi_1=\Phi_0$, with

$$\Phi_1=\begin{cases} X_1, & if\, X_1\le L_1\\ L_1, & if\, X_1>L_1\end{cases},\ \Phi_0=\begin{cases} X_0, & if\, X_0\le L_0\\ L_0, & if\, X_0>L_0\end{cases}.$$

As with the two-node network, the actual size of the transmission lines, $T_1$ resp. $T_0$, differs from their nominal size, $L_1$ resp. $L_0$. The frequencies, the support and the cdf are denoted and given just as in the two-node network. Notice that the transmission line uncertainties are independent among lines.

$(II)$ **Spot market profits and welfare under simultaneous market clearing.** In this section, we present the profits of generators and transmission owners as well as welfare for different spot markets. $W(X,X_1,L,L_1,\theta)$ denotes the economy's welfare and $\pi_i(x,x_1,l,l_1,\theta)$ the profit of a generator.

- at spot markets $\theta\epsilon\left[\underline{\theta},\theta^{\underline{M_1}}\right]$

$$\begin{aligned}W\left(X_1,X_0,L_1,L_0,\theta\right) &= \int_0^Q \left(P\left(v,\theta\right)-c_1\right)dv\\ \pi\left(x_1,x_0,l_1,l_0,\theta\right) &= 0\end{aligned}$$

- at spot markets $\theta\epsilon\left[\theta^{\underline{M_1}},\theta^{\overline{M_1}}\right]$

$$\begin{aligned}W\left(X_1,X_0,L_1,L_0,\theta\right) &= \left(1-G\left(X_1-L_1\right)\right)\int_0^{X_1}\left(P\left(v,\theta\right)-c_1\right)dv\\ &\quad +G\left(X_1-L_1\right)\int_0^{L_1}\left(P\left(v,\theta\right)-c_1\right)dv\\ \pi\left(x_1,x_0,l_1,l_0,\theta\right) &= \left(1-G\left(X_1-L_1\right)\right)\left(P\left(X_1,\theta\right)-c_1\right)x_1\end{aligned}$$

- at spot markets $\theta\epsilon\left[\theta^{\overline{M_1}},\theta^{M}\right]$

$$\begin{aligned}W\left(X_1,X_0,L_1,L_0,\theta\right) &= \left(1-G\left(X_1-L_1\right)\right)\left(\int_0^{X_1+Q}P\left(v,\theta\right)dv-\int_0^{X_1}c_1dv-\int_{X_1}^{X_1+Q}cdv\right)\\ &\quad +G\left(X_1-L_1\right)\left(\int_0^{L_1+Q}P\left(v,\theta\right)dv-\int_0^{L_1}c_1dv-\int_{L_1}^{L_1+Q}cdv\right)\\ \pi\left(x_1,x_0,l_1,l_0,\theta\right) &= \left(1-G\left(X_1-L_1\right)\right)\left(P\left(X_1+Q,\theta\right)-c_1\right)x_1\end{aligned}$$

- at spot markets $\theta\epsilon\left[\theta^{M},\overline{\theta}\right]$

$$\begin{aligned}W\left(X_1,X_0,L_1,L_0,\theta\right) &= \left(1-G\left(X_1-L_1\right)\right)\left(1-G\left(X_0-L_0\right)\right)\left(\int_0^{X}P\left(v,\theta\right)dv-\int_0^{X_1}c_1dv-\int_{X_1}^{X}cdv\right)\\ &\quad +G\left(X_1-L_1\right)\left(1-G\left(X_0-L_0\right)\right)\left(\int_0^{L_1+X_0}P\left(v,\theta\right)dv-\int_0^{L_1}c_1dv-\int_{L_1}^{L_1+X_0}cdv\right)\\ &\quad +\left(1-G\left(X_1-L_1\right)\right)G\left(X_0-L_0\right)\left(\int_0^{X_1+L_0}P\left(v,\theta\right)dv-\int_0^{X_1}c_1dv-\int_{X_1}^{X_1+L_0}cdv\right)\\ &\quad +G\left(X_1-L_1\right)G\left(X_0-L_0\right)\left(\int_0^{L}P\left(v,\theta\right)dv-\int_0^{L_1}c_1dv-\int_{L_1}^{L}cdv\right)\\ \pi\left(x_1,x_0,l_1,l_0,\theta\right) &= \left(1-G\left(X_1-L_1\right)\right)\left(1-G\left(X_0-L_0\right)\right)\left(\left(P\left(X,\theta\right)-c_1\right)x_1+\left(P\left(X,\theta\right)-c\right)x_0\right)\\ &\quad +G\left(X_1-L_1\right)\left(1-G\left(X_0-L_0\right)\right)\left(P\left(X_1+L_0,\theta\right)-c_1\right)x_1\\ &\quad +\left(1-G\left(X_1-L_1\right)\right)G\left(X_0-L_0\right)\left(P\left(L_1+X_0,\theta\right)-c\right)x_0.\end{aligned}$$

$(III)$ **Spot market profits and welfare under sequential market clearing.** In this section, we present the profits of generators and transmission owners as well as welfare for different spot markets. $W\left(X,X_1,L,L_1,\theta\right)$ denotes the economy's welfare and $\pi_i\left(x,x_1,l,l_1,\theta\right)$ the profit of a generator. Notice that here we only state the generation spot market profits for $X_1\leq L_1$ and $X_0\leq L_0$. As is shown below, this is the only relevant case.

- at spot markets $\theta\epsilon\left[\underline{\theta},\theta_{\tau}^{M_1}\right]$

$$\begin{aligned} W\left(X,X_1,L,L_1\theta\right) &= \int_0^{Q^*(\tau(L))}\left(P\left(v,\theta\right)-c_1\right)dv \\ \pi\left(x,x_1,l,\theta\right) &= 0 \end{aligned}$$

- at spot markets $\theta\epsilon\left[\theta_{\tau}^{M_1},\theta_{\tau}^{\overline{M_1}}\right]$

$$\begin{aligned} W\left(X,X_1,L,L_1,\theta\right) &= \int_0^{X_1(\tau(L))}\left(P\left(v,\theta\right)-c_1\right)dv \\ \pi\left(x,x_1,l,\theta\right) &= \left(P\left(X_1,\theta\right)-c_1\right)x_1 \end{aligned}$$

- at spot markets $\theta\epsilon\left[\theta_{\tau}^{\overline{M_1}},\theta_{\tau}^{M}\right]$

$$\begin{aligned} W\left(X,X_1,L,L_1,\theta\right) &= \int_0^{X_1(\tau(L))+Q^*(\tau(L))}P\left(v,\theta\right)dv-\int_0^{X_1(\tau(L))}c_1dv-\int_0^{Q^*(\tau(L))}cdv \\ \pi\left(x,x_1,l,l_1,\theta\right) &= \left(P\left(X_1+Q,\theta\right)-c_1\right)x_1 \end{aligned}$$

- at spot markets $\theta\epsilon\left[\theta_{\tau}^{M},\overline{\theta}\right]$

$$\begin{aligned} W\left(X,X_1,L,L_1,\theta\right) &= \int_0^{\phi}P\left(v,\theta\right)dv-\int_0^{X_1(\tau(L))}c_1dv-\int_{X_1(\tau(L))}^{\phi}cdv \\ \pi\left(x,x_1,l,l_1,\theta\right) &= \left(P\left(X,\theta\right)-c_1\right)x_1+\left(P\left(X,\theta\right)-c\right)\left(x-x_1\right) \end{aligned}$$

### A.6.2 Proof of Remark 1.2.

#### Socially optimal investment

$(I)$ **Welfare and first order conditions.** The previous results enable us to derive overall welfare. It is obtained by the integral over all spot markets.

$$W\left(X_1,X_0,L_1,L_0\right)=\int_{\underline{\theta}}^{\overline{\theta}}W\left(X_1,X_0,L_1,L_0,\theta\right)dF\left(\theta\right)-k_1x_1-kx_0-tl_1-tl_0 \tag{A.15}$$

Note that the integrand in this expression is continuous in $\theta$. The first derivatives are given by:

$$
\begin{aligned}
W_{X_1} &= (1-G(X_1-L_1))\int_{\underline{\theta^{M_1}}}^{\overline{\theta^{M_1}}}(P(X_1,\theta)-c_1)\,dF(\theta) \\
&+(1-G(X_1-L_1))\int_{\overline{\theta^{M_1}}}^{\theta^M}(P(X_1+Q,\theta)-c_1)\,dF(\theta) \\
&+(1-G(X_1-L_1))(1-G(X_0-L_0))\int_{\theta^M}^{\overline{\theta}}(P(X,\theta)-c_1)\,dF(\theta) \\
&+(1-G(X_1-L_1))G(X_0-L_0)\int_{\theta^M}^{\overline{\theta}}(P(X_1+L_0,\theta)-c_1)\,dF(\theta)-k_1
\end{aligned}
$$

$$
\begin{aligned}
W_{X_0} &= (1-G(X_1-L_1))(1-G(X_0-L_0))\int_{\theta^M}^{\overline{\theta}}(P(X,\theta)-c)\,dF(\theta) \\
&+G(X_1-L_1)(1-G(X_0-L_0))\int_{\theta^M}^{\overline{\theta}}(P(L_1+X_0,\theta)-c)\,dF(\theta)-k
\end{aligned}
$$

$$
\begin{aligned}
W_{L_1} &= G(X_1-L_1)\int_{\underline{\theta^{M_1}}}^{\overline{\theta^{M_1}}}(P(L_1,\theta)-c_1)\,dF(\theta)+G(X_1-L_1)\int_{\overline{\theta^{M_1}}}^{\theta^M}(P(L_1+Q,\theta)-c_1)\,dF(\theta) \\
&+G(X_1-L_1)(1-G(X_0-L_0))\int_{\theta^M}^{\overline{\theta}}(P(L_1+X_0,\theta)-c_1)\,dF(\theta) \\
&+G(X_1-L_1)G(X_0-L_0)\int_{\theta^M}^{\overline{\theta}}(P(L,\theta)-c_1)\,dF(\theta)-t
\end{aligned}
$$

$$
\begin{aligned}
W_{L_0} &= (1-G(X_1-L_1))G(X_0-L_0)\int_{\theta^M}^{\overline{\theta}}(P(X_1+L_0,\theta)-c)\,dF(\theta) \\
&+G(X_1-L_1)G(X_0-L_0)\int_{\theta^M}^{\overline{\theta}}(P(L,\theta)-c)\,dF(\theta)-t
\end{aligned}
$$

$(II)$ **Equilibrium.** In equilibrium, the first derivatives have to be equal to zero. Hence, transmission and generation capacity have to be of the equal capacity:

$$X_1^*=L_1^* \quad and \quad X_0^*=L_0^*$$

Using $X-X_1=X_0$ and $L-L_1=L_0$, this is

$$X^* \ : \ \int_{\theta^X}^{\overline{\theta}}(P(X^*,\theta)-c)\,dF(\theta)-(k+t)=0 \tag{A.16}$$

$$X_1^* \ : \ \int_{\underline{\theta^{X_1}}}^{\overline{\theta^{X_1}}}(P(X_1^*,\theta)-c_1)\,dF(\theta)+\int_{\overline{\theta^{X_1}}}^{\overline{\theta}}(c-c_1)\,dF(\theta)-(k_1-k)=0 \tag{A.17}$$

$(III)$ **Uniqueness.** As in equilibrium $X^*=L^*$ and $X_1^*=L_1^*$ have to hold, it is sufficient to check the second order conditions only for the joint equilibrium conditions from $(II)$

with respect to $X$ and $X_1$. The second derivatives are given by

$$
\begin{aligned}
W_{XX}\left(X, X_1, L, L_1 \theta\right)+W_{LL}\left(X, X_1, L, L_1 \theta\right) &= \int_{\theta^X}^{\overline{\theta}} P_q\left(X, \theta\right) dF\left(\theta\right)<0 \\
W_{X_1 X_1}\left(X, X_1, L, \theta\right) &= \int_{\theta^{\underline{X_1}}}^{\theta^{\overline{X_1}}} P_q\left(X_1, \theta\right)+\int_{\theta^{\overline{X_1}}}^{\theta^X} P_q\left(X_1+Q, \theta\right)<0 \\
W_{X X_1}\left(X, X_1, L, \theta\right) &= 0
\end{aligned}
$$

As is easy to see, the absolute value of the cross derivatives is smaller than the absolute value of any of the second derivatives

$$
\mid W_{xx}\left(X, X_1, L\right)\mid, \mid W_{x_1 x_1}\left(X, X_1, L\right)\mid>\mid W_{x x_1}\left(X, X_1, L\right)\mid
$$

Hence, the product of the cross derivatives is smaller than the product of the second derivatives:

$$
\pi_{xx}\left(X, X_1, L\right) \cdot \pi_{x_1 x_1}\left(X, X_1, L\right)>0
$$

That is, the first order conditions describe a unique equilibrium.

### Investment under simultaneous market clearing

$(I)$ **Profits and first order conditions.** The previous results enable us to derive overall profits and welfare. These are obtained by the integral over all spot markets and given by

$$
\pi_i\left(x_1, x_0, l_1, l_0\right)=\int_{\underline{\theta}}^{\overline{\theta}} \pi_i\left(x_1, x_0, l_1, l_0, \theta\right) dF\left(\theta\right)-k_1 x_1-k x_0 \tag{A.18}
$$

Note that the integrand in this expression is continuous in $\theta$. The first derivatives for generation investment are given by:

$$
\begin{aligned}
\pi_{X_1} = &\left(1-G\left(X_1-L_1\right)\right) \int_{\theta^{\underline{M_1}}}^{\theta^{\overline{M_1}}}\left(P\left(X_1, \theta\right)-c_1\right) dF\left(\theta\right) \\
&+\left(1-G\left(X_1-L_1\right)\right) \int_{\theta^{\overline{M_1}}}^{\theta^M}\left(P\left(X_1+Q, \theta\right)-c_1\right) dF\left(\theta\right) \\
&+\left(1-G\left(X_1-L_1\right)\right)\left(1-G\left(X_0-L_0\right)\right) \int_{\theta^M}^{\overline{\theta}}\left(P\left(X, \theta\right)-c_1\right) dF\left(\theta\right) \\
&+\left(1-G\left(X_1-L_1\right)\right) G\left(X_0-L_0\right) \int_{\theta^M}^{\overline{\theta}}\left(P\left(X_1+L_0, \theta\right)-c_1\right) dF\left(\theta\right)-k_1 \\
\pi_{X_0} = &\left(1-G\left(X_0-L_0\right)\right)\left(1-G\left(X_1-L_1\right)\right) \int_{\theta^M}^{\overline{\theta}}\left(P\left(X, \theta\right)-c\right) dF\left(\theta\right) \\
&+\left(1-G\left(X_0-L_0\right)\right) G\left(X_1-L_1\right) \int_{\theta^M}^{\overline{\theta}}\left(P\left(L_1+X_0, \theta\right)-c\right) dF\left(\theta\right) \\
&+G\left(X_0-L_0\right)\left(1-G\left(X_1-L_1\right)\right) \int_{\theta^M}^{\overline{\theta}}\left(P\left(X_1+L_0, \theta\right)-c\right) dF\left(\theta\right)-k
\end{aligned}
$$

The first order conditions for the socially optimal transmission line investment are identical to those in section A.6.2.

$(II)$ **Equilibrium.** The equilibrium equates the first derivatives to zero. Hence, in equilibrium, transmission lines and generation capacity have to be of equal size:

$$\hat{X}_1 = \hat{L}_1 \quad and \quad \hat{X}_0 = \hat{L}_0$$

This is

$$\begin{aligned}
\pi_{X_1} &= \left(1 - G\left(\hat{X}_1 - \hat{L}_1\right)\right) \int_{\underline{\theta^{M_1}}}^{\overline{\theta^{M_1}}} \left(P\left(\hat{X}_1, \theta\right) - c_B\right) dF(\theta) \qquad \text{(A.19)} \\
&+ \left(1 - G\left(\hat{X}_1 - \hat{L}_1\right)\right) \int_{\overline{\theta^{M_1}}}^{\theta^M} \left(P\left(\hat{X}_1 + Q, \theta\right) - c_B\right) dF(\theta) \\
&+ \left(1 - G\left(\hat{X}_1 - \hat{L}_1\right)\right) \int_{\theta^M}^{\overline{\theta}} \left(P\left(\hat{X}, \theta\right) - c_1\right) dF(\theta) - k_1 = 0
\end{aligned}$$

$$\pi_{X_0} = \left(1 - G\left(X_0 - L_0\right)\right) \int_{\theta^M}^{\overline{\theta}} \left(P\left(\hat{X}, \theta\right) - c_P\right) dF(\theta) - k = 0 \qquad \text{(A.20)}$$

$$\begin{aligned}
W_{L_1} &= G\left(\hat{X}_1 - \hat{L}_1\right) \int_{\underline{\theta^{M_1}}}^{\overline{\theta^{M_1}}} \left(P\left(\hat{X}_1, \theta\right) - c_1\right) dF(\theta) \qquad \text{(A.21)} \\
&+ G\left(\hat{X}_1 - \hat{L}_1\right) \int_{\overline{\theta^{M_1}}}^{\theta^M} \left(c - c_1\right) dF(\theta) \\
&+ G\left(\hat{X}_1 - \hat{L}_1\right) \int_{\theta^M}^{\overline{\theta}} \left(P\left(\hat{X}, \theta\right) - c_1\right) dF(\theta) - t
\end{aligned}$$

$$W_{L_0} = G\left(\hat{X}_0 - \hat{L}_0\right) \int_{\theta^M}^{\overline{\theta}} \left(P\left(\hat{L}, \theta\right) - c\right) dF(\theta) - t = 0 \qquad \text{(A.22)}$$

The sum of conditions (A.19) and (A.21) is identical to condition (A.17) and the sum of conditions (A.20) and (A.22) is identical to condition (A.16). Hence, under simultaneous market clearing the socially optimal investment outcome emerges. Q.e.d.

$(III)$ **Uniqueness.** Conditions (A.19), (A.20), (A.21) and (A.22) are identical to the conditions describing the socially optimal investment (expression (A.16) and (A.17)). As we have shown, the latter constitute an unique equilibrium. Hence, also the first order conditions (A.19), (A.20), (A.21) and (A.22) do. Q.e.d.

### A.6.3 Proof of Proposition 1.2.

The generation profit function, the welfare function and the budget balancing equation are identical to the respective functions in the two-node case (eq. (A.3), (A.7) and (A.11)). Hence, given our assumption $t < k$ on the transmission line, total transmission capacity always matches total generation capacity, $\tilde{X} = \tilde{L}$. Moreover, the transmission capacity at any line never exceeds the generation capacity. This implies that $\tilde{L}_1 = \tilde{X}_1$ and $\tilde{L}_0 = \tilde{X}_0$. Hence, the results from the two-node case also apply here. Q.e.d.

# Appendix B

## B.1 Preliminaries.

$(I)$ **Preliminaries: Utility function and demand system.** The representative consumer's utility function is given by

$$U(q_i, q_{-i}) = \alpha (q_i + q_{-i}) - 1/2 \left(q_i^2 + 2\gamma q_i q_{-i} + q_{-i}^2\right),$$

with, $i$, $-i = 1$, 2, $i \neq -i$. The respective demand system for product $i$ is given by

$$q_i(p_i, p_{-i}) = \frac{1}{1+\gamma}\alpha - \frac{1}{1-\gamma^2}p_i + \frac{\gamma}{1-\gamma^2}p_{-i}.$$

Consequently, inverse demand is given by

$$p_i(q_i, q_{-i}) = \alpha - p_i - \gamma p_{-i}.$$

$(II)$ **Preliminaries: Welfare.** Welfare in our model is given by the sum of consumer surplus, upstream and downstream firm profits net the investment cost and the fixed infrastructure cost of the upstream firm, taking the mode of downstream competition and the vertical structure as given:

$$W = CS + \Pi + \pi_i + \pi_{-i} - \frac{K}{2}\left(\Delta_i^2 + \Delta_{-i}^2\right) - F.$$

Given our linear demand system, consumer surplus can be expressed solely in terms of market quantities,

$$CS = q_i^2 + 2\gamma q_i q_{-i} + q_{-i}^2.$$

Notice that for for all symmetric outcomes, consumer surplus can be expressed as $(1+\gamma)Q$, with $Q = q_i + q_{-i}$.

$(III)$ **Preliminaries: Upstream profit $\Pi$.** The profit function of the (regulated) upstream monopolist is given by

$$\Pi(Q) = wQ - F,$$

where $w$ is the regulated upstream price and $wQ = F$.

$(IV)$ **Preliminaries: Downstream profits under vertical separation $\pi_i$.** The profit function of downstream firm $i$ for a given wholesale price $w$ and investment $\Delta_i$ under

Cournot competition is

$$\pi_i\left(q_i, q_{-i}\right) = \left(p_i\left(q_i, q_{-i}\right) - w - c + \Delta_i\right) q_i.$$

The respective profit function under Bertrand competition is given by

$$\pi_i\left(p_i, p_{-i}\right) = \left(p_i - w - c + \Delta_i\right) q_i\left(p_i, p_{-i}\right).$$

$(V)$ **Preliminaries: Profits under vertical integration, $\Pi$, $\pi_1$ and $\pi_2$.** In contrast to vertical separation, the integrated firm - denoted by 1 - also considers its ‘upstream’ profit $\Pi$ when choosing the optimal quantity $q_1$ resp. price $p_1$. The independent downstream competitor - denoted by 2 - makes its choice as under vertical separation taking into account that the integrated monopolist faces a lower perceived cost of production. The profit functions for a given wholesale price $w$ and investments, $\Delta_1$ and $\Delta_2$, under Cournot competition are given by

$$\begin{aligned}
\Pi\left(q_1, q_2\right) + \pi_1\left(q_1, q_2\right) &= wQ + \left(p_1\left(q_1, q_2\right) - w - c + \Delta_1\right) q_1 - F \\
&= wq_2 + \left(p_1\left(q_1, q_2\right) - c + \Delta_1\right) q_1 - F \\
\pi_2\left(q_1, q_2\right) &= \left(p_2\left(q_1, q_2\right) - w - c + \Delta_2\right) q_2.
\end{aligned}$$

The respective profit functions under Bertrand competition are given by

$$\begin{aligned}
\Pi\left(p_1, p_2\right) + \pi_1\left(p_1, p_2\right) &= wQ\left(p_1, p_2\right) + \left(p_1 - w - c + \Delta_1\right) q_1\left(p_1, p_2\right) - F \\
&= wq_2\left(p_1, p_2\right) + \left(p_1 - c + \Delta_1\right) q_1\left(p_1, p_2\right) - F \\
\pi_2\left(p_1, p_2\right) &= \left(p_2 - w - c + \Delta_2\right) q_2\left(p_1, p_2\right)
\end{aligned}$$

$(VI)$ **Preliminaries: Cournot downstream competition under vertical separation.** In this section, we present the outcomes of the downstream competition for given wholesale prices and investments depending on the ex ante investments, where $q_i^*$ represents individual output of firm $i$, $Q^*$ represents market output and $p_i^*$ represents the price of the good produced by firm $i$ for $i$, $-i = 1, 2$, $i \neq -i$.

$$\begin{aligned}
&q_i^*\left(\Delta_i, \Delta_{-i}\right) = \tfrac{(2-\gamma)(a-c-w)+2\Delta_i-\gamma\Delta_{-i}}{4-\gamma^2}, && Q^*\left(\Delta_i, \Delta_{-i}\right) = \tfrac{2(2-\gamma)(a-c-w)+(2-\gamma)(\Delta_i+\Delta_{-i})}{4-\gamma^2} \\
&p_i^*\left(\Delta_i, \Delta_j\right) = \tfrac{(2-\gamma)(\alpha+(1+\gamma)(c+w))-\left(2-\gamma^2\right)\Delta_i-\gamma\Delta_{-i}}{4-\gamma^2}, && \pi_i^*\left(\Delta_i, \Delta_{-i}\right) = \left(\tfrac{(2-\gamma)(a-c-w)+2\Delta_i-\gamma\Delta_{-i}}{4-\gamma^2}\right)^2
\end{aligned}$$

$(VII)$ **Preliminaries: Bertrand downstream competition under vertical separation.** In this section, we present the outcomes of the Bertrand downstream competition depending on the ex ante investments, where $q_i^*$ represents individual output of firm $i$, $Q^*$ represents market output and $p_i^*$ represents the price of the good produced by firm $i$ for $i$, $-i = 1, 2$, $i \neq -i$.

$$\begin{aligned}
&q_i^*\left(\Delta_i, \Delta_{-i}\right) = \tfrac{(1-\gamma)(2+\gamma)(\alpha-c-w)+\left(2-\gamma^2\right)\Delta_i-\gamma\Delta_{-i}}{(1-\gamma^2)(4-\gamma^2)}, && Q^*\left(\Delta_i, \Delta_{-i}\right) = \tfrac{2(\alpha-c-w)+\Delta_i+\Delta_{-i}}{(1+\gamma)(2-\gamma)} \\
&p_i^*\left(\Delta_i, \Delta_{-i}\right) = \tfrac{(2+\gamma)((1-\gamma)\alpha+c+w)-2\Delta_i-\gamma\Delta_{-i}}{4-\gamma^2}, && \pi_i^*\left(\Delta_i, \Delta_{-i}\right) = \tfrac{\left((1-\gamma)(2+\gamma)(\alpha-c-w)+\left(2-\gamma^2\right)\Delta_i-\gamma\Delta_{-i}\right)^2}{(1-\gamma^2)(4-\gamma^2)^2}
\end{aligned}$$

$(VIII)$ **Preliminaries: Cournot downstream competition under vertical integration.** In this section, we present the outcomes of the Cournot downstream competition depending on the ex ante investments, where $q_1^*$ ($q_2^*$) represents individual output of firm $D1$ ($D2$), $Q^*$ represents market output and $p_1^*$ ($p_2^*$) represents the price of the good produced by firm $D1$ ($D2$).

$$q_1^*(\Delta_1,\Delta_2)=\tfrac{(2-\gamma)(a-c)+\gamma w+2\Delta_1-\gamma\Delta_2}{4-\gamma^2},\qquad Q^*(\Delta_1,\Delta_2)=\tfrac{2(a-c)-w+\Delta_1+\Delta_2}{2+\gamma}$$

$$q_2^*(\Delta_1,\Delta_2)=\tfrac{(2-\gamma)(a-c)-2w+2\Delta_2-\gamma\Delta_1}{4-\gamma^2},\qquad \pi_1^*(\Delta_1,\Delta_2)=\left(\tfrac{(2-\gamma)(a-c)+\gamma w+2\Delta_1-\gamma\Delta_2}{4-\gamma^2}\right)^2$$

$$p_1^*(\Delta_1,\Delta_2)=\tfrac{(2-\gamma)(\alpha+(1+\gamma)c)+\gamma w-\left(2-\gamma^2\right)\Delta_1-\gamma\Delta_2}{4-\gamma^2},\qquad \pi_2^*(\Delta_1,\Delta_2)=\left(\tfrac{(2-\gamma)(a-c)-2w+2\Delta_2-\gamma\Delta_1}{4-\gamma^2}\right)^2$$

$$p_2^*(\Delta_1,\Delta_2)=\tfrac{(2-\gamma)(\alpha+(1+\gamma)c)+\left(2-\gamma^2\right)w-\left(2-\gamma^2\right)\Delta_2-\gamma\Delta_1}{4-\gamma^2},$$

$(IX)$ **Preliminaries: Bertrand downstream competition under vertical integration.** In this section, we present the outcomes of the Bertrand downstream competition depending on the ex ante investments, where $q_1^*$ ($q_2^*$) represents individual output of firm $D1$ ($D2$), $Q^*$ represents market output and $p_1^*$ ($p_2^*$) represents the price of the good produced by firm $D1$ ($D2$).

$$q_1^*(\Delta_1,\Delta_2)=\tfrac{(1-\gamma)(2+\gamma)(\alpha-c)-\gamma\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_1-\gamma\Delta_2}{(1-\gamma^2)(4-\gamma^2)},\quad Q^*(\Delta_1,\Delta_2)=\tfrac{2(\alpha-c)+\Delta_1+\Delta_2-(1+\gamma)w}{(1+\gamma)(2-\gamma)}$$

$$q_2^*(\Delta_1,\Delta_2)=\tfrac{(1-\gamma)(2+\gamma)(\alpha-c)-2\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_2-\gamma\Delta_1}{(1-\gamma^2)(4-\gamma^2)},\quad p_1^*(\Delta_1,\Delta_2)=\tfrac{(2+\gamma)((1-\gamma)\alpha+c)+3\gamma w-2\Delta_1-\gamma\Delta_2}{4-\gamma^2}$$

$$p_2^*(\Delta_1,\Delta_2)=\tfrac{(2+\gamma)((1-\gamma)\alpha+c)+\left(2+\gamma^2\right)w-2\Delta_2-\gamma\Delta_1}{4-\gamma^2}$$

$$\begin{aligned}\pi_1(\Delta_1,\Delta_2)&=\tfrac{(1-\gamma)(2+\gamma)(\alpha-c)-\gamma\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_1-\gamma\Delta_2}{((1-\gamma)(2+\gamma)(\alpha-c)-(4+\gamma)(1-\gamma)w+(2-\gamma^2)\Delta_1-\gamma\Delta_2)^{-1}(1-\gamma^2)(4-\gamma^2)^2}\\ \pi_2(\Delta_1,\Delta_2)&=\tfrac{\left((2+\gamma)(1-\gamma)(\alpha-c)-2\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_2-\gamma\Delta_1\right)^2}{(1-\gamma^2)(4-\gamma^2)^2}\end{aligned}$$

## B.2 Socially optimal investment

### B.2.1 Vertical Separation

$(I)$ **Cournot competition.** The socially optimal investment under Cournot competition is derived by maximizing the respective welfare function taking the Cournot downstream competition outcome as given:

$$W=CS_{Sep}^C+\Pi_{Sep}^C+2\pi_{Sep}^C-\frac{K}{2}\Delta_1^2-\frac{K}{2}\Delta_2^2-F$$

The symmetric first-order conditions are given by

$$\begin{aligned}W_{\Delta_i}&=2(1+\gamma)(2-\gamma)^2\frac{2(a-c-w)+\Delta_i+\Delta_{-i}}{\left(4-\gamma^2\right)^2}+w\frac{(2-\gamma)\left(4-\gamma^2\right)}{\left(4-\gamma^2\right)^2}\\&\quad+4\frac{(2-\gamma)(a-c-w)+2\Delta_i-\gamma\Delta_{-i}}{\left(4-\gamma^2\right)^2}-2\gamma\frac{(2-\gamma)(a-c-w)+2\Delta_{-i}-\gamma\Delta_i}{\left(4-\gamma^2\right)^2}-K\Delta_i=0\end{aligned}\tag{B.1}$$

for $i \epsilon \{1, 2\}$ and $i \neq -i$. The second derivatives are given by

$$W_{\Delta_i \Delta_i} = \frac{2(1+\gamma)(2-\gamma)^2 + 2(4+\gamma^2)}{(4-\gamma^2)^2} - K.$$

$$W_{\Delta_i \Delta_{-i}} = \frac{2(1+\gamma)(2-\gamma)^2}{(4-\gamma^2)^2}$$

Hence, for the second order conditions to hold, $K$ has to be sufficiently large, that is, $K > \frac{2(1+\gamma)(2-\gamma)^2+2(4+\gamma^2)}{(4-\gamma^2)^2}$.

$(II)$ **Bertrand competition.** The socially optimal investment under Bertrand competition is derived by maximizing the respective welfare function taking the Bertrand downstream competition outcome as given:

$$W = CS^B_{Sep} + \Pi^B_{Sep} + 2\pi^B_{Sep} - \frac{K}{2}\left(\Delta_1^2 + \Delta_2^2\right) - F$$

The symmetric first-order conditions are given by

$$\begin{aligned} W_{\Delta_i} \quad = \quad & 2(1+\gamma)\frac{2(\alpha - c - w) + \Delta_i + \Delta_j}{(1+\gamma)^2(2-\gamma)^2} + w\frac{1}{(1+\gamma)(2-\gamma)} \\ & +2\left(2-\gamma^2\right)\frac{(1-\gamma)(2+\gamma)(\alpha - c - w) + \left(2-\gamma^2\right)\Delta_i - \gamma\Delta_{-i}}{(1-\gamma^2)(4-\gamma^2)^2} \\ & -2\gamma\frac{\left((1-\gamma)(2+\gamma)(\alpha - c - w) + \left(2-\gamma^2\right)\Delta_{-i} - \gamma\Delta_i\right)}{(1-\gamma^2)(4-\gamma^2)^2} - K\Delta_i = 0 \end{aligned} \tag{B.2}$$

for $i \epsilon \{1, 2\}$ and $i \neq -i$. The second derivatives are given by

$$\begin{aligned} W_{\Delta_i \Delta_i} \quad &= \quad 2\frac{(1-\gamma)(2+\gamma)^2 + \left(2-\gamma^2\right)^2 + \gamma^2}{(1-\gamma)^2(4-\gamma^2)^2} - K \\ W_{\Delta_i \Delta_{-i}} \quad &= \quad 2\frac{(1-\gamma)(2+\gamma)^2 - 2\gamma\left(2-\gamma^2\right)}{(1-\gamma^2)(4-\gamma^2)^2} \end{aligned} \tag{B.3}$$

Hence, for the second order conditions to hold, $K$ has to be sufficiently large, that is, $K > 2\frac{(1-\gamma)(2+\gamma)^2+\left(2-\gamma^2\right)^2+\gamma^2}{(1-\gamma)^2(4-\gamma^2)^2}$.

### B.2.2 Vertical Integration

$(I)$ **Cournot competition.** The socially optimal investment under Cournot competition is derived by maximizing the respective welfare function taking the Cournot downstream competition outcome as given:

$$W = CS^C_{Int} + \Pi^C_{Int} + \pi^C_{Int_1} + \pi^C_{Int_2} - \frac{K}{2}\left(\Delta_1^2 + \Delta_2^2\right) - F$$

The first-order conditions are given by

$$\begin{aligned} W_{\Delta_1} &= 2\frac{(1+\gamma)(2-\gamma)^2(a-c)-\gamma^3 w+\left(4-3\gamma^2\right)\Delta_1+\gamma^3\Delta_2}{\left(4-\gamma^2\right)^2}+w\frac{(2-\gamma)}{4-\gamma^2} \\ &+4\frac{(2-\gamma)(a-c)+\gamma w+2\Delta_1-\gamma\Delta_2}{\left(4-\gamma^2\right)^2}-2\gamma\frac{(2-\gamma)(a-c)-2w+2\Delta_2-\gamma\Delta_1}{\left(4-\gamma^2\right)^2}-K\Delta_1=0 \end{aligned} \tag{B.4}$$

$$\begin{aligned} W_{\Delta_2} &= 2\frac{(1+\gamma)(2-\gamma)^2(a-c)-\left(4-3\gamma^2\right)w+\left(4-3\gamma^2\right)\Delta_2+\gamma^3\Delta_1}{\left(4-\gamma^2\right)^2}+w\frac{(2-\gamma)}{4-\gamma^2} \\ &-2\gamma\frac{(2-\gamma)(a-c)+\gamma w+2\Delta_1-\gamma\Delta_2}{\left(4-\gamma^2\right)^2}+4\frac{(2-\gamma)(a-c)-2w+2\Delta_2-\gamma\Delta_1}{\left(4-\gamma^2\right)^2}-K\Delta_2=0. \end{aligned} \tag{B.5}$$

The second derivatives are given by

$$\begin{aligned} W_{\Delta_1\Delta_1}=W_{\Delta_2\Delta_2} &= \frac{4}{4-\gamma^2}-K \\ W_{\Delta_1\Delta_2} &= -\frac{2\gamma}{4-\gamma^2} \end{aligned}$$

Hence, for the second order conditions to hold, $K$ has to be sufficiently large, that is, $K>\frac{4}{4-\gamma^2}$.

$(II)$ **Bertrand competition.** The socially optimal investment under Bertrand competition is derived by maximizing the respective welfare function taking the Bertrand downstream competition outcome as given:

$$W=CS^B_{Int}+\Pi^B_{Int}+\pi^B_{Int_1}+\pi^B_{Int_2}-\frac{K}{2}\left(\Delta_1^2+\Delta_2^2\right)-F$$

The first-order conditions are given by

$$\begin{aligned} W_{\Delta_1} &= 2\frac{(1-\gamma)(2+\gamma)^2(\alpha-c)-4\gamma\left(1-\gamma^2\right)w+\left(4-3\gamma^2\right)\Delta_1-\gamma^3\Delta_2}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} \\ &+w\frac{1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)} \\ &+\left(2-\gamma^2\right)\frac{2(1-\gamma)(2+\gamma)(\alpha-c)-\left(4+2\gamma+\gamma^2\right)(1-\gamma)w+2\left(2-\gamma^2\right)\Delta_1-2\gamma\Delta_2}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} \\ &-2\gamma\frac{(2+\gamma)(1-\gamma)(\alpha-c)-2\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_2-\gamma\Delta_1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2}-K\Delta_1=0 \end{aligned} \tag{B.6}$$

$$\begin{aligned} W_{\Delta_2} &= 2\frac{(1-\gamma)(2+\gamma)^2(\alpha-c)-\left(4-3\gamma^2-\gamma^4\right)w+\left(4-3\gamma^2\right)\Delta_2-\gamma^3\Delta_1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} \\ &+w\frac{1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)} \\ &-\gamma\frac{2(1-\gamma)(2+\gamma)(\alpha-c)-\left(4+2\gamma+\gamma^2\right)(1-\gamma)w+2\left(2-\gamma^2\right)\Delta_1-2\gamma\Delta_2}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} \\ &+2\left(2-\gamma^2\right)\frac{(2+\gamma)(1-\gamma)(\alpha-c)-2\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_2-\gamma\Delta_1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2}-K\Delta_2=0 \end{aligned} \tag{B.7}$$

The second derivatives are given by

$$\begin{aligned} W_{\Delta_1\Delta_1} = W_{\Delta_2\Delta_2} &= \frac{2\left(2-\gamma^2\right)}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)} - K \\ W_{\Delta_1\Delta_2} &= -\frac{2\gamma}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)} \end{aligned}$$

Hence, for the second order conditions to hold, $K$ has to be sufficiently large, that is, $K > 2\frac{\left(2-\gamma^2\right)}{(1-\gamma^2)(4-\gamma^2)}$. Moreover, as is easy to show, the absolute value of the second derivatives is larger than the absolute value of the cross derivative. Hence, the product of the second derivatives is larger than the product of cross derivatives. Given, the lower bound on $K$, the first order conditions constitute an unique equilibrium.

# B.3 Proof of Lemma 2.1

## B.3.1 Cournot competition

$(I)$ **Upstream Investment Regime.** Under the upstream investment regime, the upstream monopolist maximizes its profits taking the regulated wholesale price $w$ as given. The respective maximization problem is given by

$$\Pi\left(\Delta_1, \Delta_2\right) = w\frac{2\left(2-\gamma\right)\left(a-c-w\right) + \left(2-\gamma\right)\left(\Delta_1+\Delta_2\right)}{4-\gamma^2} - \frac{K}{2}\Delta_1^2 - \frac{K}{2}\Delta_2^2$$

The symmetric first-order conditions are given by

$$\Pi_{\Delta_i}\left(\Delta_i, \Delta_{-i}\right) = \frac{w}{2+\gamma} - K\Delta_i = 0 \tag{B.8}$$

for $i\epsilon\left\{1,2\right\}$ and $i \neq -i$. Notice that in equilibrium, the upstream monopolist invests the same amount in both downstream firms. The second order conditions are given by

$$\begin{aligned} \Pi_{\Delta_i\Delta_i} &= -K < 0 \\ \Pi_{\Delta_i\Delta_{-i}} &= 0 \end{aligned}$$

As both second derivatives are negative and the product of the second derivatives is larger than the product of cross derivatives, the first order conditions constitute a unique equilibrium. As a next step, we compare the socially optimal investment with investment by the upstream monopolist. Therefore, we subtract expression (B.8) from expression (B.1) at the equilibrium value of (B.8).

$$W_{\Delta_i} - \Pi_{\Delta_i} = \frac{2\left(2-\gamma\right)^2\left(3+2\gamma\right)\left(a-c-w+\Delta_i^*\right)}{\left(4-\gamma^2\right)^2} > 0$$

This expression is clearly positive. As $\Delta_i^* = \Delta_{-i}^*$ this result holds for investment in both downstream firms. Hence, investment by the upstream monopolist falls short of the socially optimal investment. Q.e.d.

$(II)$ **Downstream Investment Regime.** Under the downstream investment regime, the downstream competitors maximize their profits taking the regulated wholesale price

$w$ as given. The respective maximization problems are given by

$$\pi_i\left(\Delta_i, \Delta_{-i}\right) = \left(\frac{(2-\gamma)(a-c-w) + 2\Delta_i - \gamma\Delta_{-i}}{4-\gamma^2}\right)^2 - \frac{K}{2}\Delta_i^2$$

for $i\epsilon\{1,2\}$ and $i \neq -i$. The first-order conditions are given by

$$\pi_{i\Delta_i} = 4\frac{(2-\gamma)(a-c-w) + 2\Delta_i - \gamma\Delta_{-i}}{(4-\gamma^2)^2} - K\Delta_i = 0 \tag{B.9}$$

and the second order conditions are given by

$$\pi_{i\Delta_i\Delta_i} = \frac{8}{(4-\gamma^2)^2} - K < 0$$

For the second derivatives to hold, $K$ has to be sufficiently large, that is, $K > \frac{8}{(4-\gamma^2)^2}$. If this is the case, both second derivatives are negative. Thus, the first order conditions constitute an unique equilibrium. As a next step, we compare the socially optimal investment with investment by the downstream competitors, by subtracting expression (B.9) from expression (B.1) at the equilibrium value of (B.9).

$$W_{\Delta_i} - \pi_{\Delta_i} = 2\left(2(1+\gamma)(2-\gamma) - \gamma\right)\frac{a-c-w+\Delta_i^*}{(2+\gamma)(4-\gamma^2)} + \frac{w}{(2+\gamma)} > 0$$

This expression is clearly positive. As $\Delta_i^* = \Delta_{-i}^*$ this result holds for investment in both downstream firms. Hence, investment by the downstream firms falls short of the socially optimal investment. Q.e.d.

### B.3.2 Bertrand competition

$(I)$ **Upstream Investment Regime.** Under the upstream investment regime, the upstream monopolist maximizes its profits by choosing investments $\Delta_i$ and $\Delta_{-i}$ taking the regulated wholesale price $w$ as given. The respective maximization problem is given by

$$\Pi\left(\Delta_i, \Delta_{-i}\right) = w \cdot \frac{2(\alpha-c-w) + \Delta_i + \Delta_{-i}}{(1+\gamma)(2-\gamma)} - \frac{K}{2}\Delta_i^2 - \frac{K}{2}\Delta_{-i}^2$$

for $i\epsilon\{1,2\}$ and $i \neq -i$. The first-order conditions are given by

$$\Pi_{\Delta_i} = \frac{w}{(1+\gamma)(2-\gamma)} - K\Delta_i = 0 \tag{B.10}$$

and the second order conditions are given by

$$\begin{aligned} \Pi_{\Delta_i\Delta_i} &= -K < 0 \\ \Pi_{\Delta_i\Delta_{-i}} &= 0 \end{aligned}$$

Both second derivatives are negative and their product is larger than the product of cross-derivatives. Hence, the first order conditions constitute a unique equilibrium. As a next step, we compare the upstream monopolist's investment incentives with the socially optimal investment. Therefore, we subtract expression (B.10) from expression (B.2) at the equilibrium value of (B.10).

$$W_{\Delta_i} - \Pi_{\Delta_i} = 4(1-\gamma)^2 \frac{2(\alpha-c-w)+\Delta_i^*+\Delta_{-i}^*}{(1+\gamma)^2(2-\gamma)^2} + 2(2+\gamma)^2(1-\gamma)^2 \frac{(\alpha-c-w+\Delta_i^*)}{(1-\gamma^2)(4-\gamma^2)^2} > 0$$

This expression is clearly positive. Hence, investment by the upstream monopolist falls short of the socially optimal investment. Notice that as the investment equilibrium is symmetric, that is, $\Delta_i^* = \Delta_{-i}^*$, it is sufficient to show this result only for investment in one of the downstream firms.

$(II)$ **Downstream Investment Regime.** Under the downstream investment regime, the downstream competitors maximize their profits by choosing their investment level $\Delta_i$ resp. $\Delta_{-i}$ taking the regulated wholesale price $w$ as given. The profit functions are given by

$$\pi_i(\Delta_i, \Delta_j) = \frac{\left((1-\gamma)(2+\gamma)(\alpha-c-w)+\left(2-\gamma^2\right)\Delta_i-\gamma\Delta_{-i}\right)^2}{(1-\gamma^2)(4-\gamma^2)^2} - \frac{K}{2}\Delta_i^2$$

for $i\epsilon\{1,2\}$ and $i \neq -i$. The first-order conditions are given by

$$\pi_i(\Delta_i, \Delta_j) = 2\left(2-\gamma^2\right)\frac{(1-\gamma)(2+\gamma)(\alpha-c-w)+\left(2-\gamma^2\right)\Delta_i-\gamma\Delta_{-i}}{(1-\gamma^2)(4-\gamma^2)^2} - K\Delta_i = 0 \qquad \text{(B.11)}$$

and the second-order conditions are given by

$$\pi_{\Delta_i\Delta_i} = \frac{2\left(2-\gamma^2\right)^2}{(1-\gamma^2)(4-\gamma^2)^2} - K < 0$$

For the second derivatives to hold, $K$ has to be sufficiently large, that is, $K > \frac{2\left(2-\gamma^2\right)^2}{(1-\gamma^2)(4-\gamma^2)^2}$. As a next step, we compare investment by the downstream firms with the socially optimal investment. Therefore, we subtract expression (B.11) from expression (B.2) at the equilibrium value of (B.11).

$$W_{\Delta_i} - \pi_{\Delta_i} = \frac{2(4(1+\gamma)(2+\gamma)-\gamma)(2+\gamma)(\alpha-c-w+\Delta_i^*)+w(2-\gamma)(2+\gamma)^2(1-\gamma)}{(1-\gamma^2)(4-\gamma^2)^2} > 0$$

This expression is clearly positive. Hence, investment by the upstream monopolist falls short of the socially optimal investment.

## B.4 Proof of Proposition 2.1

$(I)$ **Cournot competition.** We compare the investment incentives of the upstream monopolist with those of the downstream competitors. Therefore, we subtract expression (B.8) from expression (B.9) and evaluate this difference at the values given through expression B.8. That is,

$$\pi_{\Delta_i} - \Pi_{\Delta_i} = 4\frac{(2-\gamma)(a-c-w)+2\Delta_i^*-\gamma\Delta_{-i}^*}{(4-\gamma^2)^2} - \frac{w}{2+\gamma}$$

This can be rewritten as

$$\pi_{\Delta_i} - \Pi_{\Delta_i} = \frac{4\left(a-c+\Delta_i^*\right)-\left(8-\gamma^2\right)w}{\left(2+\gamma\right)\left(4-\gamma^2\right)} > 0. \tag{B.12}$$

This expression is positive as long as $w < 4\frac{a-c+\Delta_i}{8-\gamma^2}$ holds. Notice that $w$ never exceeds the profit maximizing wholesale price, that is, $w^{Monopolist} = \frac{a-c+\Delta_i}{2}$. As $\frac{a-c+\Delta_i}{2} < 4\frac{a-c+\Delta_i}{8-\gamma^2}$ it always holds that expression (B.12) is positive and the downstream firms invest more relative to the upstream monopolist. Notice that - as $\Delta_i^* = \Delta_j^*$ - it is sufficient to show this result for investment in only one downstream firm. From lemma 2.1, we know that underinvestment takes place relative to the socially optimal investment regime in all investment regimes. Hence, the downstream investment regime always yields a better performance than the upstream investment regime from a welfare perspective. Q.e.d.

$(II)$ **Bertrand competition.** We compare the investment incentives and, thus, the investment outcome, by subtracting the investment first derivative of the upstream monopolist (expression (B.10)) from the respective investment first derivative of one of the downstream firms (expression (B.11)). That is,

$$\Pi_{\Delta_i} - \pi_{\Delta_i} = -\frac{2\left(2-\gamma^2\right)\left(a-c+\Delta_i^*\right)-\left(8-3\gamma^2\right)w}{\left(2-\gamma\right)^2\left(1+\gamma\right)\left(2+\gamma\right)}$$

This expression is positive if and only if $w > \hat{w}_B = \frac{4-2\gamma^2}{8-3\gamma^2}\left(\alpha - c + \Delta_i\right)$ holds. Hence, for $w > \hat{w}_B$ the upstream investment regime yields more investment relative to the downstream investment regime. Notice that - unlike for Cournot competition - this threshold is clearly below the upstream profit maximizing wholesale price. Q.e.d.

# B.5 Proof of Lemma 2.2

## B.5.1 Cournot competition

$(I)$ **Upstream Investment Regime.** Under the upstream investment regime, the upstream monopolist maximizes its profits taking its downstream affiliate's profit into account and the regulated wholesale price $w$ as given. The respective maximization problem is given by

$$\begin{aligned}\Pi\left(\Delta_1,\Delta_2\right) &= w\frac{2\left(2-\gamma\right)\left(a-c\right)-\left(2-\gamma\right)w+\left(2-\gamma\right)\left(\Delta_1+\Delta_2\right)}{4-\gamma^2} \\ &+\left(\frac{\left(2-\gamma\right)\left(a-c\right)+\gamma w+2\Delta_1-\gamma\Delta_2}{4-\gamma^2}\right)^2-\frac{K}{2}\Delta_1^2-\frac{K}{2}\Delta_2^2\end{aligned}$$

Notice that - unlike with vertical separation - the upstream monopolist would not like to invest the same amount in both downstream firms. The first-order conditions are given by

$$\Pi_{\Delta_1} = w\frac{2-\gamma}{4-\gamma^2} + 4\frac{(2-\gamma)(a-c)+\gamma w + 2\Delta_1 - \gamma\Delta_2}{(4-\gamma^2)^2} - K\Delta_1 = 0 \quad \text{(B.13)}$$

$$\Pi_{\Delta_2} = w\frac{2-\gamma}{4-\gamma^2} - 2\gamma\frac{(2-\gamma)(a-c)+\gamma w + 2\Delta_1 - \gamma\Delta_2}{(4-\gamma^2)^2} - K\Delta_2 = 0 \quad \text{(B.14)}$$

and the second order conditions are given by

$$\Pi_{\Delta_1\Delta_1} = \tfrac{8}{(4-\gamma^2)^2} - K, \qquad \Pi_{\Delta_2\Delta_2} = -\tfrac{2\gamma^2}{(4-\gamma^2)^2} - K, \qquad \Pi_{\Delta_2\Delta_1} = \tfrac{4\gamma}{(4-\gamma^2)^2}$$

For the first order condition to constitute an unique equilibrium it has to hold that $K$ is sufficiently large, that is, $K > \frac{8}{(4-\gamma^2)^2}$. Notice that this condition also ensures that the determinant of the Hessian has the correct sign. As a next step, we compare the socially optimal investment with investment by the upstream monopolist. Therefore, we subtract expression (B.13) from expression (B.4) at the equilibrium value of (B.13) and expression (B.14) from expression (B.5) at the equilibrium value of expression (B.14).

$$W_{\Delta_1} - \Pi_{\Delta_1} = 2\frac{(1-\gamma)(4-\gamma^2)(a-c) + \gamma(4-\gamma^2)w + (4-\gamma^2)\Delta_1 - \gamma(4-\gamma^2)\Delta_2}{(4-\gamma^2)^2} \quad \text{(B.15)}$$

$$\begin{aligned} W_{\Delta_2} - \Pi_{\Delta_2} &= 2\frac{(1+\gamma)(2-\gamma)^2(a-c) - (4-3\gamma^2)w + (4-3\gamma^2)\Delta_2 + \gamma^3\Delta_1}{(4-\gamma^2)^2} \\ &\quad +4\frac{(2-\gamma)(a-c) - 2w + 2\Delta_2 - \gamma\Delta_1}{(4-\gamma^2)^2} \end{aligned} \quad \text{(B.16)}$$

Both expression are clearly positive. Hence, investment by the upstream monopolist falls short of the socially optimal investment. Q.e.d.

(*II*) **Downstream Investment Regime.** Under the downstream investment regime, the downstream competitors maximize their profits taking the regulated wholesale price $w$ as given. The respective maximization problems are given by

$$\begin{aligned} \pi_1(\Delta_1, \Delta_2) &= w\frac{2(2-\gamma)(a-c) - (2-\gamma)w + (2-\gamma)(\Delta_1+\Delta_2)}{4-\gamma^2} \\ &\quad + \left(\frac{(2-\gamma)(a-c) + \gamma w + 2\Delta_1 - \gamma\Delta_2}{4-\gamma^2}\right)^2 - \frac{K}{2}\Delta_1^2 \\ \pi_2(\Delta_1, \Delta_2) &= \left(\frac{(2-\gamma)(a-c) - 2w + 2\Delta_2 - \gamma\Delta_1}{4-\gamma^2}\right)^2 - \frac{K}{2}\Delta_2^2 \end{aligned}$$

The first-order conditions are given by

$$\pi_{1\Delta_1} = w\frac{(2-\gamma)}{4-\gamma^2} + 4\frac{(2-\gamma)(a-c) + \gamma w + 2\Delta_1 - \gamma\Delta_2}{(4-\gamma^2)^2} - K\Delta_i = 0 \quad \text{(B.17)}$$

$$\pi_{2\Delta_2} = 4\frac{(2-\gamma)(a-c) - 2w + 2\Delta_2 - \gamma\Delta_1}{(4-\gamma^2)^2} - K\Delta_2 = 0 \quad \text{(B.18)}$$

and the second order conditions are given by

$$\pi_{1\Delta_1\Delta_1} = \pi_{2\Delta_2\Delta_2} = \frac{8}{(4-\gamma^2)^2} - K$$

For the second derivatives to hold, $K$ has to be sufficiently large, that is, $K > \frac{8}{(4-\gamma^2)^2}$.

Thus, the first order conditions constitute a unique equilibrium.

As a next step, we compare the socially optimal investment with investment by the downstream competitors. For investment by the integrated firm we subtract expression (B.17) from expression (B.4) at the equilibrium value of (B.17) for evaluating the integrated firm.

$$W_{\Delta_1} - \pi_{1\Delta_1} = 2\frac{(1-\gamma)\left(4-\gamma^2\right)(a-c) + \gamma\left(4-\gamma^2\right)w + \left(4-\gamma^2\right)\Delta_1 - \gamma\left(4-\gamma^2\right)\Delta_2}{\left(4-\gamma^2\right)^2} > 0$$

For evaluating investment by the independent downstream firm, we subtract expression (B.18) from expression (B.5) at the equilibrium value of (B.18)

$$W_{\Delta_2} - \pi_{2\Delta_2} = 2\frac{(2-\gamma)\left(2-\gamma^2\right)(a-c) - 2\left(2-\gamma^2\right)w + 2\left(2-\gamma^2\right)\Delta_2 - \gamma\left(2-\gamma^2\right)\Delta_1}{\left(4-\gamma^2\right)^2} + w\frac{(2-\gamma)\left(4-\gamma^2\right)}{4-\gamma^2} > 0$$

Both expressions are clearly positive. Hence, investment by both firms is below the socially optimal investment level. Q.e.d.

### B.5.2 Bertrand competition

$(I)$ **Upstream Investment Regime.** Under the upstream investment regime, the upstream monopolist maximizes its profits taking its downstream affiliate's profit into account and the regulated wholesale price $w$ as given. The respective maximization problem is given by

$$\begin{aligned}\Pi\left(\Delta_1,\Delta_2\right) &= w\cdot\frac{2(\alpha-c)+\Delta_1+\Delta_2-(1+\gamma)w}{(1+\gamma)(2-\gamma)} \\ &\quad+\frac{\left((1-\gamma)(2+\gamma)(\alpha-c)-\gamma\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_1-\gamma\Delta_2\right)}{\left((2+\gamma)(1-\gamma)(\alpha-c)-(4+\gamma)(1-\gamma)w+(2-\gamma^2)\Delta_i-\gamma\Delta_j\right)^{-1}(1-\gamma^2)\left(4-\gamma^2\right)^2} \\ &\quad-\frac{K}{2}\Delta_1^2-\frac{K}{2}\Delta_2^2\end{aligned}$$

Notice that - unlike with vertical separation - the upstream monopolist prefers to invest more in his downstream affiliate than the independent downstream firm. The first-oder conditions are given by

$$\begin{aligned}\Pi_{\Delta_1} &= w\cdot\frac{1}{(1+\gamma)(2-\gamma)} \\ &\quad+\left(2-\gamma^2\right)\frac{2(1-\gamma)(2+\gamma)(\alpha-c)-\left(4+2\gamma+\gamma^2\right)(1-\gamma)w+2\left(2-\gamma^2\right)\Delta_1-2\gamma\Delta_2}{(1-\gamma^2)\left(4-\gamma^2\right)^2}-K\Delta_1=0\end{aligned} \tag{B.19}$$

$$\begin{aligned}\Pi_{\Delta_2} &= w\cdot\frac{1}{(1+\gamma)(2-\gamma)} \\ &\quad-\gamma\frac{2(1-\gamma)(2+\gamma)(\alpha-c)-\left(4+2\gamma+\gamma^2\right)(1-\gamma)w+2\left(2-\gamma^2\right)\Delta_1-2\gamma\Delta_2}{(1-\gamma^2)\left(4-\gamma^2\right)^2}-K\Delta_2=0\end{aligned} \tag{B.20}$$

In equilibrium, these have to be equal to 0. The second order conditions are given by

$$\Pi_{\Delta_1\Delta_1} = \frac{2\left(2-\gamma^2\right)^2}{(1-\gamma^2)\left(4-\gamma^2\right)^2} - K$$

$$\Pi_{\Delta_2\Delta_2} = \frac{2\gamma^2}{(1-\gamma^2)\left(4-\gamma^2\right)^2} - K$$

The second order conditions are negative if $K$ is sufficiently large, that is, $K > \frac{2\left(2-\gamma^2\right)^2}{(1-\gamma^2)(4-\gamma^2)^2}$. Thus, the first order condition constitute an unique equilibrium. As a next step, we compare the socially optimal investment with investment by the upstream monopolist. Therefore, we subtract expression (B.19) from expression (B.6) at the equilibrium value of (B.19) and expression (B.20) from expression (B.7) at the equilibrium value of (B.20).

$$\begin{aligned} W_{\Delta_1} - \Pi_{\Delta_1} &= 4\frac{(2+\gamma)(1-\gamma)(\alpha-c) - \gamma\left(1-\gamma^2\right)w + \left(2-\gamma^2\right)\Delta_1 - \gamma\Delta_2}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} > 0 \qquad \text{(B.21)} \\ W_{\Delta_2} - \Pi_{\Delta_2} &= 2\frac{(1-\gamma)(2+\gamma)^2(\alpha-c) - \left(4-3\gamma^2-\gamma^4\right)w + \left(4-3\gamma^2\right)\Delta_2 - \gamma^3\Delta_1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} \\ &\quad +2\left(2-\gamma^2\right)\frac{(2+\gamma)(1-\gamma)(\alpha-c) - 2\left(1-\gamma^2\right)w + \left(2-\gamma^2\right)\Delta_2 - \gamma\Delta_1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} > 0 \end{aligned}$$

As is easy to see, both expressions are positive. Thus, investment by the upstream monopolist falls short of the socially optimal investment. Q.e.d.

$(II)$ **Downstream Investment Regime.** Under the downstream investment regime, the downstream competitors maximize their profits taking the regulated wholesale price $w$ as given. The respective maximization problems are given by

$$\begin{aligned} \pi_1(\Delta_1,\Delta_2) &= w\cdot\frac{2(\alpha-c)+\Delta_i+\Delta_j-(1+\gamma)w}{(1+\gamma)(2-\gamma)} \\ &\quad +\frac{\left((1-\gamma)(2+\gamma)(\alpha-c)-\gamma\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_1-\gamma\Delta_2\right)}{\left((2+\gamma)(1-\gamma)(\alpha-c)-(4+\gamma)(1-\gamma)w+\left(2-\gamma^2\right)\Delta_1-\gamma\Delta_2\right)^{-1}\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} - \frac{K}{2}\Delta_1^2 \\ \pi_2(\Delta_1,\Delta_2) &= \frac{\left((2+\gamma)(1-\gamma)(\alpha-c)-2\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_2-\gamma\Delta_1\right)^2}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} - \frac{K}{2}\Delta_2^2 \end{aligned}$$

The first-order conditions are given by

$$\begin{aligned} \pi_{1\Delta_1} &= w\cdot\frac{1}{(1+\gamma)(2-\gamma)} \qquad \text{(B.22)} \\ &\quad +\left(2-\gamma^2\right)\frac{2(1-\gamma)(2+\gamma)(\alpha-c)-\left(4+2\gamma+\gamma^2\right)(1-\gamma)w+2\left(2-\gamma^2\right)\Delta_1-2\gamma\Delta_2}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} - K\Delta_1 = 0 \\ \pi_{2\Delta_2} &= 2\left(2-\gamma^2\right)\frac{(2+\gamma)(1-\gamma)(\alpha-c)-2\left(1-\gamma^2\right)w+\left(2-\gamma^2\right)\Delta_2-\gamma\Delta_1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} - K\Delta_2 = 0 \qquad \text{(B.23)} \end{aligned}$$

The second order conditions are given by

$$\pi_{1\Delta_1\Delta_1} = \pi_{2\Delta_2\Delta_2} = \frac{2\left(2-\gamma^2\right)^2}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} - K$$

For the second derivatives to hold, $K$ has to be sufficiently large, that is, $K > \frac{2\left(2-\gamma^2\right)^2}{(1-\gamma^2)(4-\gamma^2)^2}$. Thus, the first order conditions constitute an unique equilibrium.

As a next step, we compare the socially optimal investment with investment by the downstream competitors. Therefore, we subtract expression (B.22) from expression (B.6) at the equilibrium value of (B.22) for evaluating the integrated firm.

$$W_{\Delta_1} - \pi_{1\Delta_1} = 4\frac{(2+\gamma)(1-\gamma)(\alpha-c) - \gamma\left(1-\gamma^2\right)w + \left(2-\gamma^2\right)\Delta_1 - \gamma\Delta_2}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} > 0$$

Notice that this expression is identical to expression (B.21) and is clearly positive. In order to evaluate investment by the independent downstream firm, we subtract expression (B.23) from expression (B.7) at the equilibrium value of (B.23)

$$W_{\Delta_2} - \pi_{2\Delta_2} = 4\frac{(1-\gamma)(2+\gamma)(\alpha-c) + \left(2-\gamma^2\right)\Delta_2 - \gamma\Delta_1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2} - \frac{4(1-\gamma) - \gamma^2\left(3-\gamma+\gamma^2\right)}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2}w$$

This expression can be rewritten as

$$\Leftrightarrow W_{\Delta_2} - \pi_{2\Delta_2} = \frac{4(1-\gamma)((2+\gamma)(\alpha-c)-w) + \gamma^2\left(3-\gamma+\gamma^2\right)w + 4\left(2-\gamma^2\right)\Delta_2 - 4\gamma\Delta_1}{\left(1-\gamma^2\right)\left(4-\gamma^2\right)^2 \Leftrightarrow} > 0$$

This expression is also clearly positive. Hence, investment by both firms is below the socially optimal investment level. Q.e.d.

## B.6 Proof of Proposition 2.2

$(I)$ **Cournot competition.** In this section, we compare the investment incentives among investment regimes by comparing the respective first order conditions describing equilibrium investment. For investment by the integrated firm, we investigate the difference of expression (B.17) and (B.13). It is given by

$$\Pi_{\Delta_1} - \pi_{1\Delta_1} = 0.$$

Notice that for investment in the integrated firms' production cost, the investment regime does not matter as the investment decision stays within the same firm. For investment in the independent firm's production cost, we subtract expression (B.18) from expression (B.14):

$$\begin{aligned} \Pi_{\Delta_2} - \pi_{2\Delta_2} \quad = \quad & \frac{w(2-\gamma)\left(4-\gamma^2\right)}{\left(4-\gamma^2\right)^2} - 2\gamma\frac{(2-\gamma)(a-c) + \gamma w + 2\Delta_1 - \gamma\Delta_2}{\left(4-\gamma^2\right)^2} \\ & -4\frac{(2-\gamma)(a-c) - 2w + 2\Delta_2 - \gamma\Delta_1}{\left(4-\gamma^2\right)^2} \end{aligned} \tag{B.24}$$

This expression is positive if and only if $w > \frac{2}{4-\gamma}(a-c+\Delta_2)$ holds. However, this threshold is weakly larger than the profit maximizing wholesale price an unregulated upstream monopolist would set. Hence, expression (B.24) is negative and investment by the independent downstream firm is weakly larger than by the upstream firm. Q.e.d.

$(II)$ **Bertrand competition.** In this section, we compare the investment incentives among the different investment regimes by comparing the respective first order conditions describing equilibrium investment. For investment by the integrated firm, we investigate the difference of expression (B.19) and (B.22). It is given by

$$\Pi_{\Delta_1} - \pi_{1\Delta_1} = 0$$

Notice that for investment in the integrated firms' production cost, the investment regime does not matter as the investment decision stays within the same firm. For investment in the independent firm's production cost, we subtract expression (B.20) from expression (B.23):

$$\begin{aligned}\Pi_{\Delta_2} - \pi_{2\Delta_2} &= w \cdot \frac{1}{(1+\gamma)(2-\gamma)} \\ &\quad -\gamma \frac{2(1-\gamma)(2+\gamma)(\alpha-c) - \left(4+2\gamma+\gamma^2\right)(1-\gamma)w + 2\left(2-\gamma^2\right)\Delta_1 - 2\gamma\Delta_2}{(1-\gamma^2)(4-\gamma^2)^2} - K\Delta_2 \\ &\quad -2\left(2-\gamma^2\right)\frac{(2+\gamma)(1-\gamma)(\alpha-c) - 2\left(1-\gamma^2\right)w + \left(2-\gamma^2\right)\Delta_2 - \gamma\Delta_1}{(1-\gamma^2)(4-\gamma^2)^2} + K\Delta_2.\end{aligned}$$

This can be rewritten an

$$\Pi_{\Delta_j} - \pi_{j\Delta_j} = -2\frac{(\alpha - c + \Delta_2) - 2w}{4-\gamma^2} < 0 \tag{B.25}$$

This expression is negative if $w < \frac{1}{2}(a - c + \Delta_2)$ holds. This threshold is equal to the profit maximizing wholesale price an unregulated upstream monopolist would set. Hence, expression (B.25) is weakly negative and hence, investment by the independent downstream firm is weakly larger than by the upstream firm. Q.e.d.

## B.7 Regulated wholesale price

We assume that the wholesale price is set in order to ensure fixed cost recovery of the upstream monopolist. This reflects, for instance, the procedure under rate-of-return regulation. That is, the following budget balancing equation has to be fulfilled

$$BBEq: \; wQ^* - F = 0,$$

where $F$ is the upstream infrastructure/capital cost. However, it is also (implicitly) assumed that the investment cost is not covered by the regulated price. A possible interpretation is that the investment cost is covered by an ex-ante R&D subsidy. Notice that we also assume that the wholesale price is determined before the downstream cost reducing investment takes place. In this section, we show that the wholesale price $w$ is increasing in the fixed cost $F$, that is, $w_F(F) > 0$. Using the implicit function theorem, we can express the sign of $w_F(F)$ as

$$sgn\frac{dw}{dF} = sgn\left(-\frac{\frac{\partial BBEq_D}{\partial F}}{\frac{\partial BBEq_D}{\partial w}}\right) = sgn\left(wQ_w^* + Q^*\right)$$

It is sufficient to determine the sign of $(wQ_w^* + Q^*)$ in order to determine the sign of $w_F(F) > 0$. Here, we report the corresponding values $wQ_w^* + Q$ takes, given the different modes of competition, vertical structures and investment regimes:

| *Downstream* | *Cournot* | *Bertrand* |
|---|---|---|
| $VS$ | $2\frac{(a-c-2w)(2+\gamma)^2K}{(1+\gamma)((4-\gamma^2)(2+\gamma)K-4)}$ | $2\frac{(a-c-2w)\left(4-\gamma^2\right)K}{K(1+\gamma)(2-\gamma)(4-\gamma^2)-2(2-\gamma^2)}$ |
| $VI$ | $2\frac{(\alpha-c-w)K\left(4-\gamma^2\right)+w(2+\gamma)}{(1+\gamma)(K(2-\gamma)(4-\gamma^2)-4)}$ | $2\frac{(2+\gamma)\left(2-\gamma^2\right)K(\alpha-c-(1+\gamma)w)+\gamma(2-\gamma)w}{(2-\gamma)(2-\gamma^2)((1+\gamma)(2+\gamma)K-2)}$ |

| *Upstream* | *Cournot* | *Bertrand* |
|---|---|---|
| $VS$ | $2\frac{(a-c-2w)(2+\gamma)K+2w}{K(2+\gamma)^2}$ | $2\frac{(1+\gamma)(2-\gamma)(a-c-2w)K+2w}{(2-\gamma)^2(1+\gamma)^2K}$ |
| $VI$ | $\frac{2(a-c-w)+\Delta_1+\Delta_2+w(\Delta_{1w}+\Delta_{2w})}{2+\gamma}$ | $\frac{2(a-c-(1+\gamma)w)+\Delta_1+\Delta_2+w(\Delta_{1w}+\Delta_{2w})}{2+\gamma}$ |

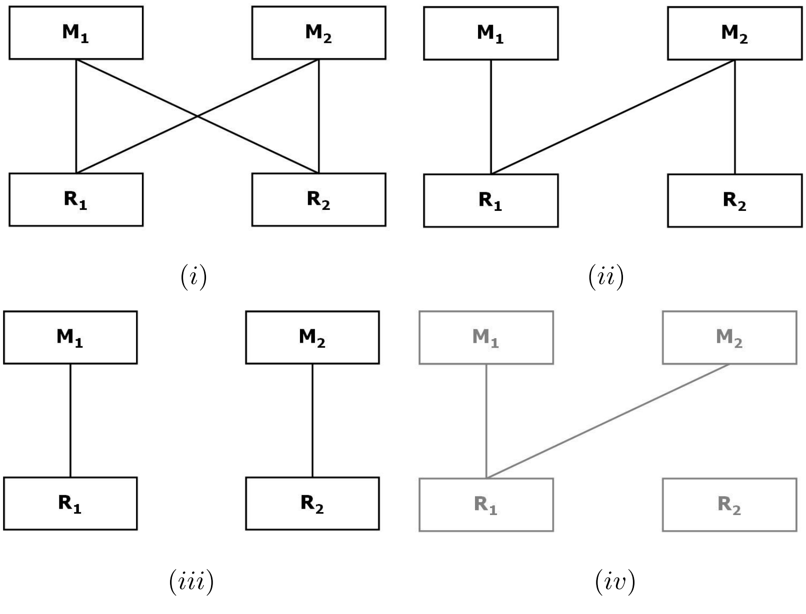
Thus, $wQ_w^* + Q^*$ is positive, regardless of the mode of competition, the vertical structure and the investment regime. Hence, it always holds that $w_F(F) > 0$. Q.e.d.

# Appendix C

## C.1 Preliminaries.

$(I)$ **Preliminaries: Distribution Systems.** The following graphs illustrate the four different distribution systems, with $M_1$ and $M_2$ representing the manufacturers and $R_1$ and $R_2$ representing the retail firms. Distribution system $(iv)$ is excluded from our analysis.

Figure C.1: Distribution Systems




$(II)$ **Preliminaries: Equilibrium Values.** To avoid very long expressions, we define the following polynomials:

$$A(K,d) \equiv 2K + d^2 - 1,$$

$$B(K,d) \equiv Kd^2 - 2K - d^2 + 1,$$

$$C(K,d) \equiv -d^2K + 2dK + 4K + d^3 + 2d^2 - d - 2,$$

$$D(K,d) \equiv -5d^2K + 8K - d^4 + 5d^2 - 4,$$

$$E(K,d) \equiv 3dK + 4K + d^3 + 2d^2 - d - 2,$$

$$F(K,d) \equiv 8 - 8d^2 - 16K + 8d^2K - d^4K$$

$$G(K,d) \equiv d^4K - 6d^2K + 8K + 4d^2 - 4$$

$$H(K,d) \equiv d^3K - 2d^2K - 4dK + 8K + 4d^2 - 4$$

$$I(K,d) \equiv d^3K + 2d^2K - 4dK - 8K - 4d^2 + 4$$

$$J(K,d) = 2d^3K + 5d^2K - 2dK - 8K - 4d^2 + 4$$

$$L(K,d) = d^6K^2 - 11d^4K^2 + 40d^2K^2 - 48K^2 + 10d^4K - 50d^2K + 40K - 8d^4 + 16d^2 - 8$$

Moreover, from the second order conditions and the non-negativity constraints we know that $B < 0$. This implies $A > 0$, $C > 0$, $D > 0$, $E > 0$, $F < 0$, $I < 0$, and $J < 0$. Using all SOCs and non-negativity conditions, we can restrict the parameter space to $K > 4(1-d^2)/(8-4d-2d^2+d^3)$, in order for the model to be well defined. This also implies $G$, $H > 0$. The equilibrium values are given in Table C.1.

Table C.1: Equilibrium Values

| | (N/N) | (E/N) | (E/E) |
|---|---|---|---|
| $w_1$ | $\frac{1-d}{2-d}$ | $\frac{(1-d)C}{D}$ | $\frac{(1-d)I}{(2-d)J}$ |
| $w_2$ | $\frac{1-d}{2-d}$ | $\frac{(1-d)E}{D}$ | $\frac{(1-d)I}{(2-d)J}$ |
| $p_1$ | $\frac{1-d}{2-d}$ | $\frac{(1-d)(A+K)C}{AD}$ | $\frac{2(1-d)L}{(2-d)HJ}$ |
| $p_2$ | $\frac{1-d}{2-d}$ | $\frac{(1-d)E}{D}$ | $\frac{2(1-d)L}{(2-d)HJ}$ |
| $q_1$ | $\frac{1}{(2-d)(1+d)}$ | $\frac{KC}{(1+d)AD}$ | $-\frac{(2+d)KG}{(1+d)HJ}$ |
| $q_2$ | $\frac{1}{(2-d)(1+d)}$ | $-\frac{EB}{(1+d)AD}$ | $-\frac{(2+d)KG}{(1+d)HJ}$ |
| $\theta_1$ | 0 | $\frac{(1-d)C}{AD}$ | $-\frac{4(1-d)G}{(2-d)HJ}$ |
| $\theta_2$ | 0 | 0 | $-\frac{4(1-d)G}{(2-d)HJ}$ |
| $\pi_{R1}$ | 0 | $\frac{(1-d)K\cdot C^2}{2(1+d)A\cdot D^2}$ | $-\frac{(1-d)KFG^2}{(2-d)^2(1+d)H^2J^2}$ |
| $\pi_{R2}$ | 0 | 0 | $-\frac{(1-d)KFG^2}{(2-d)^2(1+d)H^2J^2}$ |
| $\pi_{M1}$ | $\frac{1-d}{(2-d)^2(1+d)}$ | $\frac{(1-d)K\cdot C^2}{(1+d)A\cdot D^2}$ | $\frac{(1-d)(d+2)K\cdot I\cdot G}{(d-2)(d+1)H\cdot J^2}$ |
| $\pi_{M2}$ | $\frac{1-d}{(2-d)^2(1+d)}$ | $-\frac{(1-d)BE^2}{(1+d)AD^2}$ | $-\frac{(1-d)(d+2)KIG}{(2-d)(d+1)HJ^2}$ |

$(III)$ **Preliminaries: Framework.** The strategic effects, given the situation when only one manufacturer adopts ER, are defined according to the description in Section 3.3. The definition of the effects, given the situation when both manufacturers adopt ER, are defined as follows:

$(i)$ **Double Markup Effect.** The formal definition of the double markup effect for the case when both firms adopt ER ($N/N \to E/E$) is slightly different from the case when only one firm adopts ER ($N/N \to E/N$). The reason is that the respective outcome is not only influenced by one manufacturer's exclusivity decision, but by both manufacturers' exclusivity decisions. Hence, the definition of the double markup effect now includes one additional element capturing the second brand's retail markup and is given by $f_i(E/E \mid w_j = w_j^{N/N}, p_j = p_j^{N/N}, \theta_i = \theta_j = 0) + f_i(E/E \mid w_i = w_i^{N/N}, p_i = p_i^{N/N}, \theta_i = \theta_j = 0) - f_i\,(N/N) \equiv f_i(E/E \mid w_i = w_j = w^{DM}, p_i = p_j = p^{DM}, \theta_i = \theta_j = 0)$. $w^{DM}$ and $p^{DM}$ represent wholesale resp. retail prices resulting from the double markup effect. Moreover, notice that for some values (e.g., all prices), the second element of this expression equals zero. Thus, for these values the double markup effect is given by the same definition as for $(N/N \to E/N)$.

$(ii)$ **Competition Softening Effect**. The effect is given by $f_i\,(E/E \mid \theta_i = \theta_j = 0) - f_i(E/E \mid w_i = w_j = w^{DM}, p_i = p_j = p^{DM}, \theta_i = \theta_j = 0)$.

$(iii)$ **Investment Effect.** The effect is given by $f_i\,(E/E) - f_i\,(E/E \mid \theta_i = \theta_j = 0)$.

In Tables C.2 and C.3, we report the signs of these effects on the equilibrium values.

Table C.2: Composition of the Total Effect: N/N⇒E/N

| N/N⇒E/N | Double Markup | Competition Softening | Investment | Total |
|---|---|---|---|---|
| $w_1$ | 0 | + | + | + |
| $w_2$ | 0 | + | + | + |
| $p_1$ | + | + | + | + |
| $p_2$ | 0 | + | + | + |
| $\theta_1$ | 0 | 0 | + | + |
| $\theta_2$ | 0 | 0 | 0 | 0 |
| $\pi_{R1}$ | + | + | + | + |
| $\pi_{R2}$ | 0 | 0 | 0 | 0 |
| $\pi_{M1}$ | - | + | + | + / - |
| $\pi_{M2}$ | 0 | + | + | + |
| $CS$ | - | - | + | +/- |
| $PS$ | +/- | + | + | +/- |
| $Welfare$ | - | - | + | +/- |

Table C.3: Composition of the total effect: N/N⇒E/E

| N/N⇒E/E | Double Markup | Competition Softening | Investment | Total |
|---|---|---|---|---|
| $w_1$ | 0 | + | + | + |
| $w_2$ | 0 | + | + | + |
| $p_1$ | + | + | + | + |
| $p_2$ | + | + | + | + |
| $\theta_1$ | 0 | 0 | + | + |
| $\theta_2$ | 0 | 0 | + | + |
| $\pi_{R1}$ | + | +/- | + | + |
| $\pi_{R2}$ | + | +/- | + | + |
| $\pi_{M1}$ | - | +/- | + | +/- |
| $\pi_{M2}$ | - | +/- | + | +/- |
| $CS$ | - | - | + | +/- |
| $PS$ | +/- | +/- | + | +/- |
| $Welfare$ | - | - | + | +/- |

$(IV)$ **Preliminaries: Sturm's theorem.** Sturm's theorem provides the basis for most of the proofs in this appendix.[56] In this section, we first introduce Sturm's theorem and then we give a small example on how this theorem works: Given equation

$$f(x) = a_0x^n + a_1x^{n-1} + \cdots + a_{n-1}x + a_n, \tag{C.1}$$

where the coefficients $a_i$ are real numbers and $a_0 \neq 0$, let $N(x)$ be the number of sign changes (disregarding vanishing terms) in the sequence of functions:

$$f_0 = f(x) = g_0(x)f_1(x) - f_2(x), \quad f_1 = f'(x) = g_1(x)f_2(x) - f_3(x), \quad f_2 = g_2(x)f_3(x) - f_4(x), \ldots$$

where for $i > 1$ each $f_i(x)$ is $(-1)$ times the remainder obtained on dividing $f_{i-2}(x)$ by $f_{i-1}(x)$ and $f_n(x) \neq 0$ is a constant. Then the number of real roots of eq. (1), located between two real numbers $a$ and $b$ ($b > a$) excluding the own roots of expression (C.1), is equal to $N(a) - N(b)$.
Sturm's theorem provides a simple algorithm to determine the number of real roots for each real polynomial in any given interval $(a, b)$. Thus, if a real polynomial has no real roots in interval $(a, b)$, it is sufficient to evaluate this polynomial at an arbitrary number in this interval, in order to determine its sign.[57] We use a simple example to illustrate how Sturm's theorem works: Assume, we are looking for the sign of $8 - 6d - 2d^3 + d^4$ for $d\epsilon\,(0, 1)$. Thus, the chain of Sturm's functions is given by: $f_0 = 8 - 6d - 2d^3 + d^4$, $f_1 = -6 - 6d^2 + 4d^3$, $f_2 = -29 + 18d + 3d^2$, $f_3 = 111 - 82d$ and $f_4 = -1$. Now, we can examine the changes in the signs:

| $d$ | $f_0$ | $f_1$ | $f_2$ | $f_3$ | $f_4$ | $N(d)$ |
|---|---|---|---|---|---|---|
| 0 | + | - | - | + | - | 3 |
| 1 | + | - | - | + | - | 3 |

Thus, the examined expression has zero roots. Hence, the expression is positive.

# C.2 Proofs.

## C.2.1 Proof of Proposition 3.1.

In order to prove Proposition 3.1, we use the following definitions from above:

$K > \underline{K} = \frac{4(1-d^2)}{8-4d-2d^2+d^3}$, $\quad d \in (0, 1)$, $\quad A(.) > 0$, $\quad B(.) < 0$, $\quad C(.) > 0$ $\quad D(.) > 0$, $\quad H(.) > 0$, $J(.) < 0$.

**Retail prices:**

[56] In the description of Sturm's theorem we follow Korn and Korn (1968).
[57] Sturm's theorem was firstly announced 1829 (Sturm (1829)). The proof can be found in Khovanskii and Burda (2008).

- $p_i^{N/E} - p_i^{N/N} = \frac{2d(1-d^2)K}{(2-d)D(.)} > 0$
- $p_i^{N/E} - p_i^{E/N} = \frac{(1-d)K(3d^2K-4K+d^4-3d^2+2)}{A(.)D(.)} \Rightarrow sgn(p_i^{N/E} - p_i^{E/N}) = sgn(3d^2K - 4K + d^4 - 3d^2 + 2)$.
  This polynomial is decreasing in $K$:
  $$3d^2K - 4K + d^4 - 3d^2 + 2|_{K=\underline{K}} = -(1-d^2)d\left(8 - 6d^2 - 2d^3 + d^4\right)(2-d)^{-2}(2+d)^{-1} < 0$$
  $$\Rightarrow 3d^2K - 4K + d^4 - 3d^2 + 2 < 0 \Rightarrow p_i^{N/E} - p_i^{E/N} < 0$$
- $p_i^{E/E} - p_i^{E/N} = \frac{(1-d)(2L(.)A(.)\cdot D(.)-(2-d)(A(.)+K)C(.)H(.)J(.))}{(2-d)A(.)D(.)H(.)J(.)} = -\frac{(1-d)dK\Lambda(.)}{(2-d)A(.)D(.)H(.)J(.)}$
  This difference is larger than zero if and only if $\Lambda(.) > 0$.
  $$\begin{aligned}
  \Lambda_{KKK}(.) &= \left(1-d^2\right)\left(768\left(1-d^2\right) + 1536 + 432d^4 + 6d^5\right) + (1-d)\left(288d\left(1-d^2\right) + 96d\right) \\
  &\quad +36d^8 + 66d^5 + 384d^4 > 0 \\
  \Lambda_{KK}(.)|_{K=\underline{K}} &= [(32+96d)\left(1-d^2\right) + (1-d)\left(12d\left(1-d^2\right) + 20d + 2d^6\right) + 32d^4 + 21d^5 + d^6] \\
  &\quad 2(1-d^2)(2+d) > 0 \Rightarrow \Lambda_{KK}(.) > 0 \\
  \Lambda_K(.)|_{K=\underline{K}} &= \frac{(1-d^2)^2 d\left[\left(1-d^2\right)\left(192-48d^2+10d^4+d^5\right)+(1-d)\left(24d\left(1-d^2\right)+40d\right)+22d^4+23d^5\right]}{(2-d)^2} > 0 \\
  &\quad \Rightarrow \Lambda_K(.) > 0 \\
  \Lambda(.)|_{K=\underline{K}} &= \frac{4(4-d)(1-d)^4d^2(1+d)^3(d^2-2d-4)(d^3+2d^2-4)}{(2-d)^4(2+d)} > 0 \Rightarrow \Lambda(.) > 0 \Rightarrow p_i^{E/E} - p_i^{E/N} > 0
  \end{aligned}$$

Q.e.d.

**Wholesale prices:**

- $w_i^{E/N} - w_i^{N/N} = \frac{(1-d^2)d^2K}{(2-d)D(.)} > 0$
- $w_i^{N/E} - w_i^{E/N} = \frac{(1-d^2)dK}{D(.)} > 0$
- $w_i^{E/E} - w_i^{N/E} = \frac{(1-d^2)d^2K\left(4-2d-5d^2+2d^3+d^4-4K+d^2K\right)}{(2-d)D(.)J(.)}$
  $\Rightarrow w_i^{E/E} - w_i^{N/E} > 0 \Leftrightarrow d^2K - 4K + d^4 + 2d^3 - 5d^2 - 2d + 4 < 0 \Leftrightarrow K > \frac{d^4+2d^3-5d^2-2d+4}{4-d^2}$.

Q.e.d.

**Investment:**

- $\theta_i^{N/E} - \theta_i^{N/N} = 0$
- $\theta_i^{E/N} - \theta_i^{N/N} = \theta_i^{E/N} = \frac{(1-d)C(.)}{A(.)D(.)} > 0$
- $\theta_i^{E/E} - \theta_i^{E/N} = \frac{(1-d)(-4G(.)A(.)D(.)-(2-d)C(.)H(.)J(.))}{(2-d)A(.)D(.)H(.)J(.)} = -\frac{(1-d)dK\Theta(.)}{(2-d)A(.)D(.)H(.)J(.)}$

$$\Rightarrow \; \theta_i^{E/E} - \theta_i^{E/N} > 0 \;\Leftrightarrow\; \Theta(.) > 0$$

$$\begin{aligned}
\Theta_{KK}(.) &= \left(1-d^2\right)\left(64\left(1-d^3\right)+128d\left(1-d\right)+192+48d^4+14d^5\right) \\
&\quad +4d^8+18d^5+32d^4>0 \\
\Theta_K(.)|_{K=\underline{K}} &= d\tfrac{1-d^2}{2-d}\left(4+2d-d^2\right)\left[8\left(1-d^2\right)+\left(1-d\right)\left(40-20d^2\right)+d^4+2d^5\right]>0 \\
&\Rightarrow \; \Theta_K(.)>0 \\
\Theta|_{K=\underline{K}} &= 4(4-d)(1-d)^3d^2(1+d)^2(d^2-2d-4)(d^3+2d^2-4)(2-d)^{-3}(2+d)^{-1}>0 \\
&\Rightarrow \; \Theta(.)>0 \;\Rightarrow\; \theta_i^{E/E}-\theta_i^{E/N}>0
\end{aligned}$$

Q.e.d.

**Retail profits:**

- $\pi_R^{N/E} - \pi_R^{N/N} = 0$
- $\pi_R^{E/N} - \pi_R^{N/N} = \frac{(1-d)K[C(.)]^2}{2(1+d)A(.)[D(.)]^2} > 0$
- $\pi_R^{E/E} - \pi_R^{E/N} = \frac{(1-d)K\left(-2A(.)[D(.)]^2F(.)[G(.)]^2-(2-d)^2[C(.)]^2[H(.)]^2[J(.)]^2\right)}{2(2-d)^2(1+d)A(.)[D(.)]^2[H(.)]^2[J(.)]^2} = \frac{(d-1)dK^2\Sigma(.)}{2(2-d)^2(1+d)A(.)[D(.)]^2[H(.)]^2[J(.)]^2}$
  $\Rightarrow \pi_R^{E/E} - \pi_R^{E/N} > 0$
  This difference is larger than zero if and only if $\Sigma(.) < 0$.

$$
\begin{aligned}
\Sigma_{K^5}(.) \quad &= \quad 480d^{17} - 3360d^{16} - 17640d^{15} + 82560d^{14} + 249600d^{13} - 873600d^{12} \\
&\quad -1856640d^{11} + 5191680d^{10} + 8087040d^{9} - 18923520d^{8} - 21288960d^{7} \\
&\quad +43253760 + 33177600d^{5} - 60456960d^{4} - 28016640d^{3} + 47185920d^{2} \\
&\quad +9830400d - 15728640 \overset{Sturm's\, Theorem}{<} 0 \\
\Sigma_{K^4}(.)|_{K=\underline{K}} \quad &= \quad -48(d-2)^2(d-1)d(d+1)(d+2)^2[(d-1)[(1-d^2)(3456-2336d^2) \\
&\quad +422d^4(1-d)+248d^4]+(d^2-1)[(1-d^2)(2432-1696d^2+626d^4) \\
&\quad +606d^4+33d^8+4d^9]-41d^8-43d^9] < 0 \Rightarrow \Sigma_{K^4}(.) < 0 \\
\Sigma_{KKK}(.)|_{K=\underline{K}} \quad &= \quad -6(1-d^2)^2d^2(2+d)\{(1-d)\left[4044+(1-d)\left(\left(1-d^3\right)\left(5460+4d^6\right)\right.\right. \\
&\quad +1148d^6\left(1-d\right)\left(1-d^2\right)\left(41435+46476d+549d^6\right) \\
&\quad +419d+2587d^4+16950d^5+2620d^6+20d^{10})]+261\} < 0 \\
&\quad \Rightarrow \Sigma_{KKK}(.) < 0 \\
\Sigma_{KK}(.)|_{K=\underline{K}} \quad &= \quad \tfrac{4(1-d^2)^3d^3}{(2-d)^2}\{(d-1)\{(1-d)\left[\left(1-d^2\right)((1-d)(3948d+d^{11})\right. \\
&\quad 50295+28382d-15410d^3+2028d^5+541d^6)+12611d^4 \\
&\quad +728d^5+1511d^6+72d^9+29d^{10}+d^{11}]+1844\}-45\} < 0 \\
&\quad \Rightarrow \Sigma_{KK}(.) < 0 \\
\Sigma_{K}(.)|_{K=\underline{K}} \quad &= \quad -16\tfrac{4-d}{(2-d)^4(2+d)})(1-d)^5d^4(1+d)^4(4-2d^2-d^3)\{(1-d)(160-76d^2) \\
&\quad +(1-d^2)(224-140d^2+15d^4)+3d^4(1-d^3)+14d^4+d^8\} < 0 \\
&\quad \Rightarrow \Sigma_{K}(.) < 0. \\
\Sigma(.)|_{K=\underline{K}} \quad &= \quad -32\tfrac{(4-d)^2(1-d)^7}{(2-d)^6(2+d)^2}d^5(1+d)^5(4-d^2+2d)(4-d^3-2d^2)^2 < 0 \\
&\quad \Rightarrow \Sigma(.) < 0. \\
&\quad \Rightarrow \pi_R^{E/E} - \pi_R^{E/N} > 0.
\end{aligned}
$$

Q.e.d.

## C.2.2 Proof of Proposition 3.2.

In order to prove this proposition, it is sufficient to show that there exist parameter values for $d$ and $K$ satisfying the respective equilibrium conditions.

$(i)$ Both manufacturers do not adopt exclusive retailing, $\pi_{Mi}^{N/N}/\pi_{Mi}^{E/N} > 1$ and $\pi_{Mi}^{N/E}/\pi_{Mi}^{E/E} >$

1. Notice that the latter condition is needed to ensure that the type ($i$) equilibrium is unique. Suppose $d = 0.85$ and $K = 1.8$. As can be easily shown, these values satisfy the equilibrium conditions. Hence, the $N/N$ distribution system constitutes an unique equilibrium.

| M1\M2 | Exclusivity | Non-exclusivity |
|---|---|---|
| Exclusivity | 0.110, 0.110 | 0.060, 0.122 |
| Non-exclusivity | 0.122, 0.060 | 0.061, 0.061 |

($ii$) One manufacturer adopts exclusive retailing and the other manufacturer does not adopt exclusive retailing, ${}^{\pi_{Mi}^{E/N}}/{}_{\pi_{Mi}^{N/N}} > 1$ and ${}^{\pi_{Mi}^{N/E}}/{}_{\pi_{Mi}^{E/E}} > 1$. The latter condition ensures that the second manufacturer is not willing to adopt exclusivity given the first one has done so. Suppose that $d = 0.85$ and $K = 1.2$. As can be easily shown these values satisfy the equilibrium conditions:

| M1\M2 | Exclusivity | Non-exclusivity |
|---|---|---|
| Exclusivity | 0.125, 0.125 | 0.065, 0.126 |
| Non-exclusivity | 0.126, 0.065 | 0.061, 0.061 |

There are two identical asymmetric equilibria of type E/N given $d = 0.85$ and $K = 1.2$.

($iii$) Both manufacturers adopt exclusive retailing, ${}^{\pi_{Mi}^{E/E}}/{}_{\pi_{Mi}^{N/E}} > 1$ and ${}^{\pi_{Mi}^{E/N}}/{}_{\pi_{Mi}^{N/N}} > 1$. The later condition ensures that the equilibrium of type ($iii$) is unique. Suppose that $d = 0.85$ and $K = 0.6$. As can be easily shown these values satisfy the equilibrium conditions:

| M1\M2 | Exclusivity | Non-exclusivity |
|---|---|---|
| Exclusivity | 0.202, 0.202 | 0.086, 0.143 |
| Non-exclusivity | 0.143, 0.086 | 0.061, 0.061 |

Given $d = 0.85$ and $K = 0.6$, it is a dominant strategy for both firms to adopt exclusivity. Thus, the E/E regime constitutes an unique equilibrium.

($iv$) Finally, multiple equilibria of type ($i$) and ($iii$) exist for some parameter combinations. That is, ${}^{\pi_{Mi}^{N/N}}/{}_{\pi_{Mi}^{E/N}} > 1$ and ${}^{\pi_{Mi}^{E/E}}/{}_{\pi_{Mi}^{N/E}} > 1$. Suppose $d = 0.5$ and $K = 1$. As can be easily shown these values satisfy the equilibrium conditions:

| M1\M2 | Exclusivity | Non-exclusivity |
|---|---|---|
| Exclusivity | 0.237, 0.237 | 0.142, 0.226 |
| Non-exclusivity | 0.226, 0.142 | 0.148, 0.148 |

For these values both firms have no dominant strategy. If the competitor decides to adopt ER, it is also profitable to adopt ER. Therefore, the N/N distribution system constitutes an unique equilibrium. Q.e.d.

### C.2.3 Proof of Proposition 3.3.

The proof consists of two steps:

($i$) The N/N-equilibrium occurs if and only if it is unprofitable for both manufacturers to adopt ER given the other manufacturer has not adopted ER. Without ER no investment occurs. Hence, the profits in the N/N equilibrium with asymmetric brands are equal to those in the N/N equilibrium with symmetric brands.
Moreover, the profits in the E/N equilibrium (more efficient firm adopts exclusivity)with asymmetric brands are identical to those with symmetric brands. The more efficient manufacturer adopts ER and hence, investment occurs only in its brand. By definition, the investment cost of the more efficient manufacturer is identical to the investment cost with symmetric brands. Thus, the more efficient firm's incentives not to adopt exclusivity given its competitor has not done so, remain unchanged.
In addition, profits in the N/E equilibrium (less efficient firm adopts exclusivity) are lower than in the E/N equilibrium due to a smaller investment effect (i.e. higher investment cost). Hence, given that it is not profitable for the more efficient manufacturer to adopt exclusivity, it is also not profitable for the less efficient manufacturer.
Hence, the outcome is identical to the scenario with symmetric brands. Q.e.d.

($ii$) The E/N-equilibrium occurs only when the following two conditions are satisfied:

1. Manufacturer 1 has an incentive to adopt exclusivity when its competitor has not adopted it.

2. Manufacturer 2 has not an incentive to adopt exclusivity when its competitor has adopted it.

We have seen in ($i$) that the incentive described under 1. is the same with symmetric as well as with asymmetric brands. Thus, we have to show that the incentive under 2. is larger with asymmetric than with symmetric brands. It is sufficient to show that $\pi_{M2}^{E/E}$ is lower with asymmetric than with symmetric brands. Notice that the double markup effect as well as the competition softening effect are identical in both cases and the investment effect is decreasing in the investment cost. As manufacturer 2 has a larger investment cost in the case with asymmetric brands, its profit is smaller than in the symmetric case. This argument follows in algebraic form:

Let the investment cost of retailer 1 be $K\left(\frac{\theta_{11}^2}{2}+\frac{\theta_{12}^2}{2}\right)$ and of retailer 2 $(K+\Delta)\left(\frac{\theta_{11}^2}{2}+\frac{\theta_{12}^2}{2}\right)$. We want to show that $\pi_{M2}^{E/E}$ is decreasing in $\Delta$. $\pi_{M2}^{E/E}$ is given by

$$\pi_{M2}^{E/E}=\frac{(2+d)G(K,d)M(K,\Delta,d)[P(K,\Delta,d)]^2}{(2-d)(1+d)Q(K,\Delta,d)[R(K,\Delta,d)]^2}$$

We already know that$G(K,d)>0\,\forall d\in(0,1)\wedge K>\frac{4\left(1-d^2\right)}{8-4d-2d^2+d^3}$

$$\Rightarrow sgn(\frac{\partial\pi_{M2}^{E/E}(K,\Delta,d)}{\partial\Delta})=sgn(\frac{\partial(M(K,\Delta,d)[P(K,\Delta,d)]^2/Q(K,\Delta,d)[R(K,\Delta,d)]^2)}{\partial\Delta})$$

Therefore, we have to determine the sign of

$$\frac{\partial\left[M(K,\Delta,d)[P(K,\Delta,d)]^2\right]}{\partial\Delta}Q(K,\Delta,d)[R(K,\Delta,d)]^2 - \frac{\partial\left[Q(K,\Delta,d)[R(K,\Delta,d)]^2\right]}{\partial\Delta}M(K,\Delta,d)[P(K,\Delta,d)]^2.$$

If this term is negative, the profit of the second manufacturer decreases in $\Delta$. This term can be rewritten as $8(1-d)^2(1+d)P(.)R(.)Z(.)$. In order to show this, we have to determine the signs of $P(.)$, $R(.)$ and $Z(.)$.

We start by examining the sign of $P(d,K,\Delta)$:

$$\begin{aligned}
P_\Delta(.) &= 32-48d^2+4d^3+16d^4-4d^5-K(4-d^2)^2(4+d-2d^2)\\
\Rightarrow P_{\Delta K}(.) &= -(4-d^2)^2(4+d-2d^2)\\
P_\Delta(.)|_{K=\underline{K}} &= -4(-1+d)d(1+d)(-6-d+3d^2)<0 \Rightarrow P_\Delta(.)<0\,\forall\Delta\\
P(.)|_{\Delta=0} &= -16+32d^2-16d^4+64K+8dK-92d^2K-4d^3K+28d^4K-4d^5K\\
&\quad -64K^2-16dK^2+64d^2K^2+8d^3K^2-20d^4K^2-d^5K^2+2d^6K^2\\
(P(.)|_{\Delta=0})_{KK} &= -2(2-d)^2(2+d)^2(4+d-2d^2)<0\\
(P(.)|_{\Delta=0})_K|_{K=\underline{K}} &= 4d(1-d^2)(-10-d+5d^2)<0 \Rightarrow (P(.)|_{\Delta=0})_K<0\\
(P(.)|_{\Delta=0})|_{K=\underline{K}} &= \tfrac{32(-1+d)^3d^2(1+d)^2}{(-2+d)^2(2+d)}<0 \Rightarrow P(.)|_{\Delta=0}<0 \Rightarrow P(.)<0
\end{aligned}$$

for any $d$, $K$, $\Delta$ from our domain. Next, we examine the sign of $R(d,K,\Delta)$.

$$\begin{aligned}
R_\Delta(.) &= 32-52d^2+20d^4+K[(-2+d)(2+d)(-4-d+2d^2)(-4+d+2d^2)]\\
\Rightarrow R_{\Delta K}(.) &= (-2+d)(2+d)(-4-d+2d^2)(-4+d+2d^2)<0\\
R_\Delta(.)|_{K=\underline{K}} &= -\tfrac{4(-1+d)^2d(1+d)\left(-8-d+4d^2\right)}{-2+d}<0 \Rightarrow \tfrac{\partial R(.)}{\partial\Delta}<0\,\forall\Delta\\
R(.)|_{\Delta=0} &= (-4+4d^2+8K-2dK-5d^2K+2d^3K)J(K,d)\\
\Rightarrow sgn[R(d,K,\Delta)|_{\Delta=K}] &= -sgn[-4+4d^2+8K-2dK-5d^2K+2d^3K]\\
(R(d,K,\Delta)|_{\Delta=K})_K &= 8-2d-5d^2+2d^3>0 \,\wedge\, (-4+4d^2+8K-2dK-5d^2K+2d^3K)|_{K=\underline{K}}\\
&= -\tfrac{4(-1+d)^2d(1+d)}{(-2+d)(2+d)}>0\\
&\Rightarrow -4+4d^2+8K-2dK-5d^2K+2d^3K>0 \Rightarrow R(.)<0
\end{aligned}$$

for any $d$, $K$, $\Delta$ within our domain. In order to complete the proof, we have to show that

$Z(d, K, \Delta)$ is always negative:

$$\begin{aligned}
Z_{\Delta\Delta}(.) &= 2(d-2)X(d,k) \\
X_{\Delta\Delta\Delta}(.) &= 6(2-d)^3(2+d)^4(4+d-2d^2)(16-15d^2+d^3+3d^4) > 0 \\
X_{KK}(.)|_{K=\underline{K}} &= \left[21d^4+3(1-d)d^4+(1-d^2)(224-72d-80d^2+37d^3+4d^4)\right] \\
&\quad 4d(4-d^2)(1-d^2)(2+d)^2 > 0 \Rightarrow X_{KK}(.) > 0 \\
X_K(.)|_{K=\underline{K}} &= 16d^2\left(1-d^2\right)^2\left(4-d^2\right)(128-42d-181d^2+52d^3+72d^4-16d^5-7d^6) > 0 \\
&\Rightarrow X_K(.) > 0 \\
X(.)|_{K=\underline{K}} &= 32(1-d)d^3\left(1-d^2\right)^3\left(48+10d-45d^2-3d^3+10d^4\right)(2-d)^3 > 0 \\
&\Rightarrow X(.) > 0 \Rightarrow Z_{\Delta\Delta}(.) < 0\, for\, any\, \Delta \\
Z_{\Delta}(.)|_{\Delta=0} &= 2(-4+4d^2+8K-2dK-5d^2K+2d^3K)\Xi(K,d)
\end{aligned}$$

We have already shown that $(-4+4d^2+8K-2dK-5d^2K+2d^3K) > 0$. Thus, it holds that

$$\begin{aligned}
sgn[\tfrac{\partial Z(d,K,\Delta)}{\partial\Delta}|_{\Delta=K}] &= sgn[\Xi(K,d)] \\
\Xi_{KKK}(.) &= 6(-2+d)^3(2+d)^4(16-15d^2+d^3+3d^4) < 0 \\
\Xi_{KK}(.)|_{K=\underline{K}} &= -4d(2-d)(1-d^2)(2+d)^2(128-2d-127d^2+2d^3+28d^4+2d^5) < 0 \\
&\Rightarrow \Xi_{KK}(.) < 0 \\
\Xi_K(.)|_{K=\underline{K}} &= -4d^2(1-d^2)^2(2+d)(156-80d-129d^2+51d^3+16d^4)(2-d)^{-1} < 0 \\
&\Rightarrow \tfrac{\partial\Xi(.)}{\partial K} < 0 \\
\Xi(.)|_{K=\underline{K}} &= 48(1-d)^4d^3(1+d)^3(-10-d+5d^2)(2-d)^{-3} < 0 \\
&\Rightarrow \Xi(.) < 0 \Rightarrow \tfrac{\partial Z(.)}{\partial\Delta}|_{\Delta=0} < 0 \Rightarrow \tfrac{\partial Z(.)}{\partial\Delta} < 0 \\
Z(.)|_{\Delta=0} = &= \Omega(d,K)I(d,K)(-4+4d^2+8K-2dK-5d^2K+2d^3K)
\end{aligned}$$

We have already shown that $I(.) < 0$ and $-4+4d^2+8K-2dK-5d^2K+2d^3K > 0$.

Therefore,

$$
\begin{aligned}
sgn[Z(d,K,\Delta)|_{\Delta=0}] &= -sgn[\Omega(d,K)] \\
\Omega_{KKK}(.) &= 6(-2+d)^2(2+d)^2(16-15d^2+d^3+3d^4)>0 \\
\Omega_{KK}(.)|_{K=\underline{K}} = &= -4(-1+d)d(1+d)(2+d)(48-28d-33d^2+18d^3+2d^4)>0 \\
&\Rightarrow \Omega_{KK}(.)>0 \\
\Omega_{K}(.)|_{K=\underline{K}} = &= -48d^2(1-d)(1-d^2)^2(-3+d+d^2)(2-d)^{-2}>0 \Rightarrow \tfrac{\partial\Omega(.)}{\partial K}>0 \\
\Omega(.)|_{K=\underline{K}} &= -\tfrac{96(-1+d)^5d^3(1+d)^3}{(-2+d)^4(2+d)}>0 \Rightarrow \Omega(.)>0 \Rightarrow Z(.)|_{\Delta=0}<0 \Rightarrow Z(.)<0 \\
&\Rightarrow \tfrac{\partial \pi_{M2}^{E/E}}{\partial\Delta}<0
\end{aligned}
$$

for any $d$, $K$ and $\Delta$ from our domain. Q.e.d.

### C.2.4 Proof of Proposition 3.4.

This proof consists of three parts:

1. We show that $CS^{E/E} > CS^{N/N}$ if $K < \tilde{K} = \frac{4(3+d)-2d^2(5+d)+2(1+d)\sqrt{4(3+d)-2d^2(5+d)+2(1+d)}}{(4-d^2)^2}$.
2. We show that $CS^{E/E} > CS^{E/N}$ if $K < \tilde{K}$.
3. We show that no asymmetric equilibrium exists if $K < \tilde{K}$.

**ad 1.** Notice that the E/E and the E/N equilibrium are symmetric. Thus, it holds that $CS^{E/E} > CS^{N/N}$ if $Q^{E/E} > Q^{N/N}$ is true. This is the case if the following condition is fulfilled:
$\frac{(1-d)(16+16d-16d^2-16d^3-48K-40dK+32d^2K+28d^3K+4d^4K+32K^2+16dK^2-16d^2K^2-8d^3K^2+2d^4K^2+d^5K^2)}{(2-d)(1+d)H(.)J(.)} > 0$

$\Leftrightarrow K^2(32+16d-16d^2-8d^3+2d^4+d^5)+K(-48-40d+32d^2+28d^3+4d^4)+16+16d-16d^2-16d^3<0$

Solving this inequality and taking the SOC ($K > \underline{K}$) into account this expression is fulfilled for any $K < \tilde{K}$. Q.e.d.

**ad 2.** Notice that the investment effect on consumer surplus is stronger in the E/E than in the E/N equilibrium. As the investment effect is decreasing in $K$, Moreover, the effect of $K$ on consumer surplus is stronger in the E/E than in the E/N equilibrium. In the E/N equilibrium investment is only undertaken by the exclusive retailer. Hence, $K$ directly affects the quantity of the exclusive brand. However, the quantity of the non-exclusive brand is only indirectly affected. In contrast, both quantities are affected directly in the

E/E equilibrium. In other words, the difference in consumer surplus in both equilibria is increasing in $K$:

$$\begin{aligned}
\frac{\partial\left(CS^{E/E}(d,K)-CS^{E/N}(d,K)\right)}{\partial K} &= \frac{(1-d)\chi(d,K)}{[A(d,K)]^3[D(d,K)]^3[H(d,K)]^3[J(d,K)]^3} \\
\Rightarrow \frac{\partial\left(CS^{E/E}(d,K)-CS^{E/N}(d,K)\right)}{\partial K} < 0 &\quad\Leftrightarrow\quad \chi(.) < 0
\end{aligned}$$

Using Sturm's theorem, it can be shown that $\chi(.) < 0$ holds for any $d$, $K$ within our domain:

$$\begin{aligned}
\chi_{K^{10}}(.) &= \left(1-d^2\right)(-5130+(1-d)(-62703+(1-d)(-145710d^7-57577d^{10}-20831d^{11}+8494d^{12} \\
&\quad +1260d^{13}-520d^{14}+\left(1-d^2\right)\left(-145797d^2-194182d^3+88872d^5-114319d^6-142582d^7\right) \\
&\quad -166202\left(1-d^5\right)+(1-d)\left(-18362-382381d^3+360000d^5-103273d^7\right))))-9747+8559d<0 \\
\chi_{K^9}(.)|_{K=\underline{K}} &= -362880(1-d)(2+d)^4(1048576+7864320d-10158080d^2-11206656d^3+18980864d^4 \\
&\quad -20746240d^5-3653632d^6+64204800d^7-24083200d^8-67990528d^9+31040832d^{10} \\
&\quad +38386848d^{11}-18019808d^{12}-12651200d^{13}+5740476d^{14}+2509294d^{15}-1033931d^{16} \\
&\quad -320648d^{17}+105389d^{18}+31118d^{19}-6804d^{20}-1944d^{21}+384d^{22}) \overset{\text{Sturm's Theorem}}{<} 0 \\
&\quad \Rightarrow \chi_{K^9}(.) < 0 \\
\chi_{K^8}(.)|_{K=\underline{K}} &= 120960(1-d)^2d(1+d)(2+d)^3(2-d)^{-2}(-7340032-30146560d+57016320d^2 \\
&\quad +42270720d^3-76464128d^4+35938304d^5-32413696d^6-112777216d^7 \\
&\quad +148110336d^8+98087168d^9-137400192d^{10}-44632320d^{11}+63497024d^{12} \\
&\quad +12731248d^{13}-16717568d^{14}-2679720d^{15}+2717456d^{16}+442294d^{17}-302807d^{18} \\
&\quad -48374d^{19}+21419d^{20}+2998d^{21}-564d^{22}-216d^{23}+32d^{24}) \overset{\text{Sturm's Theorem}}{<} 0 \\
&\quad \Rightarrow \chi_{K^8}(.) < 0
\end{aligned}$$

$$
\begin{aligned}
\chi_{K^7}(.)|_{K=\underline{K}} &= 5040(-1+d)^3d^2(1+d)^2(2+d)^2(2-d)^{-4}(208666624+523239424d \\
&-1431044096d^2-649723904d^3+1702133760d^4-2441216d^5+567300096d^6 \\
&+97677312d^7-2405477376d^8+223821312d^9+1969144832d^{10} \\
&-206317312d^{11}-826604608d^{12}+54924128d^{13}+211237872d^{14}-3415200d^{15} \\
&-35656848d^{16}-421884d^{17}+3995722d^{18}+152135d^{19}-291579d^{20}-26497d^{21} \\
&+16876d^{22}+345d^{23}-154d^{24}-68d^{25}+8d^{26}) \overset{\text{Sturm's Theorem}}{<} 0 \Rightarrow \chi_{K^7}(.)<0 \\
\chi_{K^6}(.)|_{K=\underline{K}} &= -(2-d)^{-6}720(1-d)^4d^3(1+d)^3(2+d)(1148190720+1623719936d-6943670272d^2 \\
&-1522401280d^3+8220934144d^4+2014773248d^5-774782976d^6-5065863168d^7 \\
&-4622747648d^8+5247410176d^9+4049376256d^{10}-2562309888d^{11} \\
&-1816873216d^{12}+678837248d^{13}+503555264d^{14}-110289440d^{15} \\
&-86226880d^{16}+11722352d^{17}+9880928d^{18}-858008d^{19}-795262d^{20}+56696d^{21} \\
&+32777d^{22}+1211d^{23}-1726d^{24}+100d^{25}+8d^{26}) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \chi_{K^6}(.)<0 \\
\chi_{K^5}(.)|_{K=\underline{K}} &= (2-d)^{-8}1440(-1+d)^5d^4(1+d)^4(332922880+199491584d-1760821248d^2 \\
&-36962304d^3+2259894272d^4+627998720d^5-1291350016d^6-1559681024d^7 \\
&+308211712d^8+1385933824d^9+129782016d^{10}-645355392d^{11}-145858112d^{12} \\
&+179201344d^{13}+52903040d^{14}-30329632d^{15}-10084800d^{16}+3458848d^{17} \\
&+1137880d^{18}-285658d^{19}-81390d^{20}+16299d^{21}+4552d^{22} \\
&-1041d^{23}-26d^{24}+12d^{25}) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \chi_{K^5}(.)<0 \\
\chi_{K^4}(.)|_{K=\underline{K}} &= -192(2-d)^{-10}(2+d)^{-1}(-1+d)^6d^5(1+d)^5(1132986368-16515072d \\
&-5268635648d^2+867237888d^3+7730397184d^4+1038114816d^5 \\
&-6994022400d^6-3360485376d^7+4043362304d^8+3117941248d^9 \\
&-1270275584d^{10}-1575115008d^{11}+145991296d^{12}+462831872d^{13} \\
&+29444576d^{14}-81874432d^{15}-11125552d^{16}+9191840d^{17}+1427988d^{18} \\
&-720396d^{19}-73314d^{20}+35772d^{21}+578d^{22}-869d^{23}+78d^{24}-8d^{25} \\
&+d^{26}) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \chi_{K^4}(.)<0
\end{aligned}
$$

$$\begin{aligned}
\chi_{K^3}(.)|_{K=\underline{K}} &= (2-d)^{-12}(2+d)^{-2}192(-1+d)^7 d^6(1+d)^6(418643968-196476928d \\
&-1758494720d^2+647462912d^3+2949898240d^4-332296192d^5 \\
&-3090866176d^6-306096128d^7+1992954368d^8+565802240d^9 \\
&-791036288d^{10}-362372608d^{11}+180364800d^{12}+123434784d^{13} \\
&-20026032d^{14}-23989320d^{15}+364488d^{16}+2810316d^{17}+119628d^{18} \\
&-186354d^{19}-17010d^{20}+8591d^{21}+172d^{22}+56d^{23}-63d^{24} \\
&+6d^{25}) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \chi_{K^3}(.)<0 \\
\chi_{K^2}(.)|_{K=\underline{K}} &= -(2-d)^{-14}(2+d)^{-3}768(-4+d)(-1+d)^9 d^7(1+d)^8 \\
&(507904-532480d-933888d^2+761344d^3+909312d^4-431360d^5 \\
&-495936d^6+82240d^7+150576d^8+5712d^9-21104d^{10} \\
&-4340d^{11}+2044d^{12}+242d^{13}-13d^{14}-32d^{15}+4d^{16}) \\
&(-4-2d+d^2)(-4+2d^2+d^3) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \chi_{K^2}(.)<0 \\
\chi_{K}(.)|_{K=\underline{K}} &= \tfrac{512(-4+d)^2(-1+d)^{11}d^8(1+d)^9(-4-2d+d^2)^2(-4+2d^2+d^3)^2}{(2-d)^{16}(2+d)^4} \\
&[53d^4+12d^5+10d^8+(1-d)(1728-584d^2)+41d^4(1-d^3) \\
&+(1-d^2)(1472-1224d^2+90d^4)]<0 \Rightarrow \tfrac{\partial\chi(.)}{\partial K}<0 \\
\chi(.)|_{K=\underline{K}} &= -\tfrac{6144(4-d)^3(1-d)^{13}d^9(1+d)^{10}(4+2d-d^2)^3(4-2d^2-d^3)^3}{(2-d)^{18}(2+d)^5}<0 \\
&\Rightarrow \chi(.)<0 \\
&\Rightarrow \tfrac{\partial\left(CS^{E/E}(d,K)-CS^{E/N}(d,K)\right)}{\partial K}<0
\end{aligned}$$

for any $d$, $K$ from our domain. Using these results, we can proof the original statement: If $CS^{E/E} > CS^{N/N}$ holds, the same logic applies to the size of the consumer surplus in the E/N equilibrium. We know that $CS^{E/E} > CS^{N/N}$ holds if $K$ is sufficiently small (see the condition above). For the remainder of this proof, we divide our parameter space into two subspaces:

*(i)* $0 < d < 0.5$

*(ii)* $0.5 \leq d < 1$

**ad** $(i)$**.** Suppose that $K = 1 + d/2$. This implies that $0 < 32d^2 + 48d^3 + 24d^4 - 20d^5 - 8d^6 - 2d^7 - d^8 + d^9 + \frac{d^{10}}{4}$ for $d \in (0, 0.5)$.

$$\begin{aligned}\left(CS^{E/E} - CS^{E/N}\right)|_{K=1+d/2} \quad = \quad & (1-d)d^2 8^{-1}(1+d)^{-1}(1+d+d^2)^{-2}(-4-2d+d^2+2d^3)^{-2}(8+d^4)^{-2} \\ & (-8-12d+9d^3+2d^4)^{-2}(32768+262144d+843776d^2+1236992d^3 \\ & +65536d^4-2930688d^5-5085184d^6-3376128d^7+1018880d^8 \\ & +3631872d^9+2476224d^{10}-12800d^{11}-1026432d^{12}-530624d^{13} \\ & +75048d^{14}+176824d^{15}+50584d^{16}-18520d^{17}-16249d^{18} \\ & -3812d^{19}+32d^{20}+144d^{21}+16d^{22})) \overset{Sturm's\,Theorem}{>} 0\end{aligned}$$

This difference is decreasing in $K$. Thus, it holds that $CS^{E/E} > CS^{E/N}$ for $d$ between 0 and $\frac{1}{2}$ and $K < 1 + d/2$.

**ad** $(ii)$ Suppose now that $K = 3/2 - d/2$. Using Sturm's Theorem this implies that

$$0 \overset{Sturm's\,Theorem}{<} 128 - 320d + 96d^2 + 240d^3 - 76d^4 - 96d^5 + 22d^6 + 20d^7 - \frac{15d^8}{4} - \frac{3d^9}{2} + \frac{d^{10}}{4}$$

$$\begin{aligned}(CS^{E/E} - CS^{E/N})|_{K=3/2-d/2} \quad = \quad & (2-d)^{-2}(1+d)^{-1}(2-d+d^2)^{-2}(-8-3d+3d^2+2d^3)^{-2} \\ & (-16+20d-6d^2-5d^3+d^4)^{-2}(-16+8d+5d^2-5d^3+2d^4)^{-2} \\ & (-29360128+103809024d-50135040d^2-166428672d^3 \\ & +177827840d^4+95567872d^5-206496768d^6+7089664d^7 \\ & +143738048d^8-62955392d^9-56805760d^{10}+56995824d^{11} \\ & +2648800d^{12}-25435624d^{13}+9554739d^{14}+4915108d^{15} \\ & -4818244d^{16}+417792d^{17}+992954d^{18}-407896d^{19}-41316d^{20} \\ & -14853d^{22}+68536d^{21}-2044d^{23}+1552d^{24}-272d^{25}+16d^{26}) \\ & \tfrac{1}{8}(1-d) \overset{Sturm's\,Theorem}{>} 0\end{aligned}$$

This difference is decreasing in $K$. Thus, it holds that $CS^{E/E} > CS^{E/N}$ for $d$ between 1/2 and 1 and $K < 3/2 - d/2$. Q.e.d.

**ad** 3**.** We have already shown that if the above mentioned condition is binding, it holds that $CS^{N/N} > CS^{E/N}$. Now, we show that no asymmetric equilibrium exists under this condition.

First, consider the incentives of a manufacturer to adopt exclusivity given the other manufacturer has not adopted exclusivity. These incentives are decreasing in $K$. Notice that

$K$ does not affect profits in the N/N equilibrium. However, it has a negative impact on the profit in the E/N equilibrium. Thus, the difference between profits in both equilibria is decreasing in $K$.
Second, consider the incentives of a manufacturer to adopt exclusivity given the other manufacturer has adopted exclusivity. These incentives are decreasing in $K$ as $K$ affects profits in the E/E equilibrium directly while in the E/N equilibrium profits are only affected indirectly. Thus, the difference between the non-exclusive manufacturer's profit in the E/N equilibrium and the profit in the E/E equilibrium is increasing in $K$. The algebraic proof follows:

$\frac{\partial(\pi_1^{E/N}-\pi_1^{N/N})}{\partial K} = \frac{(-1+d)^2 C(.)}{[A(.)]^2[D(.)]^3}(-8-4d+18d^2+9d^3-12d^4-6d^5+2d^6+d^7+32K+16dK-46d^2K-17d^3K+17d^4K+d^5K-3d^6K-32K^2-16dK^2+20d^2K^2-2d^3K^2-9d^4K^2)$

Consider now the second derivative with respect to $K$ of the last term in this expression:

$$-64-32d+40d^2-4d^3-18d^4<0$$

Evaluating the first derivative at $K$'s lower bound gets us:

$$-\frac{(-1+d)d(1+d)\left(-128-80d+32d^2-24d^4-7d^5+3d^6\right)}{(-2+d)^2(2+d)}<0$$

As this expression is negative, the first derivative is negative for any $K$. Again, we evaluate this expression at the lower bound of $K$:

$$\frac{(-1+d)^2d^2(1+d)^2(-128-96d-48d^2+4d^4-4d^5-2d^6+d^7)}{(-2+d)^4(2+d)^2}<0$$

As this expression is negative, the incentive to adopt exclusivity, if the competitor has not adopted exclusivity, is decreasing in $K$. The effect of $K$ on the incentives not to adopt exclusivity given the other manufacturer has adopted exclusivity is given by:

$$\frac{\partial(\pi_2^{E/N}-\pi_2^{E/E})}{\partial K}=\frac{(1-d)^2\varpi(d,K)}{(2-d)[A(d,K)]^2[D(d,K)]^3[H(d,K)]^2J(d,K)]^3}\Rightarrow\frac{\partial(\pi_2^{E/N}-\pi_2^{E/E})}{\partial K}>0\Leftrightarrow\varpi(.)<0$$

$$\begin{aligned}
\varpi_{K^8}(.) &= 40320(2-d)^2(2+d)^4(-131072+98304d+311296d^2-307200d^3-227328d^4 \\
&+403456d^5-23552d^6-292288d^7+125632d^8+128384d^9-75968d^{10} \\
&-34584d^{11}+21200d^{12}+5165d^{13}-2914d^{14}-292d^{15}+168d^{16}) \overset{Sturm's\,Theorem}{<} 0 \\
\varpi_{K^7}(.)|_{K=\underline{K}} &= -5040(1-d^2)d(2+d)^3(2490368-2228224d-4980736d^2+5406720d^3 \\
&+2267136d^4-5056512d^5+2019328d^6+2285568d^7-2754176d^8-545088d^9 \\
&+1315264d^{10}+101360d^{11}-315416d^{12}-26708d^{13}+40218d^{14}+5127d^{15} \\
&-3190d^{16}-428d^{17}+152d^{18}) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \varpi_{K^7}(.)<0 \\
\varpi_{K^6}(.)|_{K=\underline{K}} &= 720(2-d)^{-2}(1-d^2)^2d^2(2+d)^2(-20185088+20643840d+34832384d^2 \\
&-38346752d^3-12771328d^4+21049344d^5-12476416d^6+1000960d^7 \\
&+14889216d^8-4535936d^9-7092288d^{10}+1371344d^{11}+1910096d^{12} \\
&-113332d^{13}-300544d^{14}-4376d^{15}+27280d^{16}+1855d^{17}-1334d^{18} \\
&-204d^{19}+56d^{20}) \overset{Sturm's\,Theorem}{>} 0 \Rightarrow \varpi_{K^6}(.)>0 \\
\varpi_{K^5}(.)|_{K=\underline{K}} &= -120(1-d^2)^3(2-d)^{-4}d^3(2+d)(92274688-104857600d-145457152d^2 \\
&+154927104d^3+76447744d^4-42135552d^5-5560320d^6-44448768d^7 \\
&-18159616d^8+36814848d^9+14847104d^{10}-11526656d^{11}-5530688d^{12} \\
&+1817520d^{13}+1038472d^{14}-148612d^{15}-116292d^{16}+5176d^{17}+7974d^{18} \\
&-51d^{19}-210d^{20}-36d^{21}+8d^{22}) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \varpi_{K^5}(.)<0 \\
\varpi_{K^4}(.)|_{K=\underline{K}} &= -(2-d)^{-6}96(1-d^2)^4d^4(65536000-81166336d-102531072d^2+108441600d^3 \\
&+86843392d^4-30713856d^5-55618560d^6-25549824d^7+19732992d^8 \\
&+24935744d^9-1266560d^{10}-9296064d^{11}-1178128d^{12}+1773000d^{13} \\
&+370332d^{14}-208484d^{15}-49628d^{16}+15309d^{17}+3837d^{18}-641d^{19} \\
&-216d^{20}+36d^{21}) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \varpi_{K^4}(.)<0
\end{aligned}$$

$$\begin{aligned}
\varpi_{K^3}(.)\,|_{K=\underline{K}} &= -(2-d)^{-8}(2+d)^{-1}24(1-d^2)^5 d^5(119013376-158990336d-198967296d^2 \\
&+229949440d^3+221495296d^4-126754816d^5-170844160d^6+9434112d^7 \\
&+79060992d^8+25422080d^9-20823424d^{10}-13156992d^{11}+2726944d^{12}99664d^{14} \\
&+3030064d^{13}-199664d^{14}-388688d^{15}+6936d^{16}+33292d^{17}-1294d^{18}-1649d^{19} \\
&+200d^{20}+2d^{21}) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \varpi_{K^3}(.)<0 \\
\varpi_{K^2}(.)\,|_{K=\underline{K}} &= -(2-d)^{-10}(2+d)^{-2}32(1-d^2)^6 d^6(33816576-48726016d-62046208d^2 \\
&+85196800d^3+73228288d^4-68294656d^5-56822784d^6+25639680d^7 \\
&+29120256d^8-2739648d^9-9091136d^{10}-1166048d^{11}+1740272d^{12} \\
&+395040d^{13}-217696d^{14}-52732d^{15}+21940d^{16}+1758d^{17}-1031d^{18} \\
&+37d^{19}+8d^{20}) \overset{Sturm's\,Theorem}{<} 0 \Rightarrow \varpi_{K^2}(.)<0 \\
\varpi_{K}(.)\,|_{K=\underline{K}} &= 384(2-d)^{-12}(2+d)^{-3}(4-d)^2(1-d)^8 d^7(1+d)^7(-4-2d+d^2) \\
&(-4+2d^2+d^3)^2(896-512d-960d^2+256d^3+392d^4-28d^5 \\
&-24d^6-7d^7+2d^8)<0 \Rightarrow \varpi_K(.)<0 \\
\varpi(.)|_{K=\underline{K}} &= 1536(4-d)^3(1-d)^{10}d^8(1+d)^8(2-d)^{-14}(2+d)^{-4}(-4-2d+d^2)^2 \\
&(-4+2d^2+d^3)^3<0 \Rightarrow \varpi(.)<0,
\end{aligned}$$

for any $d$, $K$ from our domain of definition. Therefore, the difference in profits of non-exclusive manufacturer in E/N regime and profit of manufacturer in E/E regime is increasing in $K$. In order to complete this non-existence proof, we divide our parameter space into three subspaces:

- Consider $d < 0.5$ and $K = 1$.

  $$1 < \tilde{K} \Rightarrow 0 < -(2-d)^2 d(2+d)(-8+4d^2+6d^3+d^4)$$

  The incentive of manufacturer 1 to adopt exclusivity given manufacturer 2 has not done so is given by:

  $$-\frac{(1-d)d^2(8-8d-d^2-2d^3-7d^4+2d^5+d^8)}{(2-d)^2(1+d)(2-d^2)^2(1+d^2)(2+d^2)^2} < 0$$

  From the previous analysis we know that this difference is decreasing in $K$. Therefore, for $d < 0.5$ and $K > 1$ no asymmetric equilibrium exists. Consider now the incentives not to adopt exclusivity given the competing manufacturer has done so:

$$(1+d)^{-1}(2-d^2)^{-2}(1+d^2)^{-1}(2+d^2)^{-2}(4-4d+2d^2+d^3)^{-1}(-4-2d+d^2+2d^3)^{-2}$$

$$(1-d)d^2(2-d)^{-1}(-128-320d-32d^2+464d^3+592d^4+64d^5-436d^6-536d^7$$

$$-228d^8+160d^9+232d^{10}+92d^{11}-15d^{12}-32d^{13}-13d^{14}+d^{16}) \overset{Sturm's\,Theorem}{<} 0$$

As this is negative, no positive incentive to adopt $ER$ exists. From the previous analysis we know that this difference is increasing in $K$. Therefore, for $d < 0.5$ and $K < 1$ no asymmetric equilibrium exists.

- Consider now the second subsection, where $0.5 \leq d < 0.75$ and $K = 1 + d/10$. For $1 + \frac{d}{10} < \tilde{K}$ it holds that

$$\frac{1}{100}(2-d)^2 d(2+d)(640+48d-416d^2-704d^3-172d^4-22d^5-d^6)0 \overset{Sturm's\,Theorem}{>} 0$$

The incentive of manufacturer 1 to adopt exclusivity given its competitor has not done so is given by:

$$-(1-d)\tfrac{d}{2}(1600+8640d-4736d^2-4360d^3-6596d^4-7406d^5+674d^6+748d^7+1119d^8$$

$$+1000d^9)(2-d)^{-2}(1+d)^{-1}(5+d+5d^2)^{-1}(-40-8d+5d^3+10d^4)^{-2} \overset{Sturm's\,Theorem}{<} 0$$

We know from the previous analysis that this difference is decreasing in $K$. Hence, given $0.5 \leq d < 0.75$ and $K > 1 + d/10$ no asymmetric equilibrium exists. Consider now the incentives not to adopt $ER$ given the competitor has adopted $ER$:

$$(1-d)\tfrac{d}{2}(2-d)^{-1}(1+d)^{-1}(5+d+5d^2)^{-1}(40-32d+16d^2+8d^3+d^4)^{-1}(-40-8d+5d^3+10d^4)^{-2}$$

$$(-40-28d+8d^2+25d^3+2d^4)^{-2}(51200000-304640000d^2-334080000d^3+274764800d^4$$

$$+899090944d^5+540852224d^6-453013376d^7-1044911360d^8-673223392d^9+121484528d^{10}$$

$$+486807040d^{11}+306455472d^{12}+21145876d^{13}-81353138d^{14}-48840906d^{15}-6462016d^{16}$$

$$+3835231d^{17}+1490522d^{18}+221176d^{19}+15240d^{20}+400d^{21}) \overset{Sturm's\,Theorem}{<} 0$$

We know from the previous analysis that this difference is increasing in $K$. Thus, for $0.5 \leq d < 0.75$ and $K < 1 + d/10$ no asymmetric equilibrium exists.

Hence, for $d < 0.75$, no asymmetric equilibrium exists.

- Finally, consider the last subsection, that is, $0.75 \leq d < 1$. In addition, suppose that $K < 1408/1000 - 408d/1000$. The latter implies that

$$\tfrac{1}{15625}(2-d)^2(2+d)(185232-402848d+9384d^2+243040d^3$$

$$+73452d^4-51236d^5-12750d^6+2601d^7) \overset{Sturm's\,Theorem}{>} 0$$

Now, consider the incentives to not adopt exclusivity given the competing manufacturer has adopted $ER$:

$$(1-d)\,(-2+d)^{-1}(1+d)^{-1}(227-102d+125d^2)^{-1}(-908+1112d-352d^2-278d^3+51d^4)^{-1}$$

$$(908-56d-482d^2-97d^3+102d^4)^{-2}(-908+408d+255d^2-255d^3+125d^4)^{-2}(15738720504451584$$

$$-31026772800625920d-16508458186889600d^2+57675869217678016d^3+823226689552768d^4$$

$$-48456960603325984d^5+16259005070184112d^6+14133753170213392d^7-16350914893485352d^8$$

$$+6309091534897108d^9+5541810617834892d^{10}-5959840533879032d^{11}+409043007808180d^{12}$$

$$+1641500886532907d^{13}-911172926276052d^{14}-418921140473363d^{15}+352649497192055d^{16}$$

$$-105007538527782d^{17}-75443462220731d^{18}+35466154432341d^{19}+4900095065961d^{20}$$

$$-3980342487375d^{21}+422825062500d^{22})\overset{Sturm's\,Theorem}{<}0$$

We know from the previous analysis that this difference is increasing in $K$. Therefore, for $0.75 \leq d < 1$ and $K < 1408/1000 - 408d/1000$ no asymmetric equilibrium exists.

Thus, for $K < \tilde{K}$ no asymmetric equilibrium exists. Q.e.d.

### C.2.5 Proof of Proposition 3.5.

This proof consists of four parts:

1. We show that $W_K^{E/N}, W_K^{E/E} < 0$.
2. We determine a condition under which welfare increases with exclusivity.
3. We show that there exist E/E and E/N equilibria under this condition.
4. We show that for exclusive retailing to be welfare enhancing, retail investment must be more cost efficient the weaker the competition is.

**ad 1.** The intuition behind this is simple. Consider that only the investment effect depends on the cost of investment. Moreover, the investment effect is positive for welfare. Since this effect is stronger the smaller $K$ is, welfare under both regimes is decreasing in $K$. This can also be shown algebraically:

First, consider welfare in the E/N equilibrium: We have already shown that consumer surplus as well as profits of the exclusive manufacturer are decreasing in $K$. Moreover, the profit of the exclusive retailer is also decreasing in $K$. Thus, we only have to show that the profit of the non-exclusive manufacturer is decreasing in $K$:

$$\frac{\partial \pi_{M2}^{E/N}}{\partial K} = \frac{(1-d)^2\, dE(.)v(.)}{[A(.)]^2[D(.)]^3}$$

with

$$
\begin{aligned}
\upsilon_{KK}(.) &= 64+32d-48d^2-8d^3+14d^4>0 \\
\upsilon_K(.)|_{K=\underline{K}} &= -2(1-d^2)d\left(-4-2d+d^2\right)\left(16-4d-6d^2+d^3+2d^4\right)(2-d)^{-2}(2+d)^{-1}>0 \\
&\Rightarrow \upsilon_K(.)>0 \\
\upsilon(.)|_{K=\underline{K}} &= \tfrac{d^2(1-d^2)^2}{(2-d)^{-2}(2-d^2)^{-2}}G(.)\left(128-112d^2-16d^3+64d^4+12d^5-12d^6-2d^7+d^8\right)>0 \\
&\Rightarrow \upsilon(.)>0
\end{aligned}
$$

for any $d$, $K$ from our domain of definition. Thus, the profit of the non-exclusive manufacturer is decreasing in $K$ and so, $W_K^{E/N}<0$. Now consider $W^{E/E}$: We have already shown that consumer surplus as well as manufacturer profits are decreasing in $K$. Therefore, it remains to be shown that retail profits also decreases in $K$:

$$\frac{\partial \pi_R^{E/E}}{\partial K} = -\frac{8\,(1-d)^2\,(1+d)\,G(.)\tau(.)}{[G(.)]^3[J(.)]^3}$$

with

$$
\begin{aligned}
\tau_{KKK}(.) &= -3072+2304d+3840d^2-2496d^3-2112d^4+1008d^5+624d^6 \\
&\quad -180d^7-96d^8+12d^9+6d^{10}<0 \\
\tau_{KK}(.)|_{K=\underline{K}} &= -8(-2+d)(-1+d)d(2+d)^2(14-5d-17d^2+4d^3+5d^4)<0 \Rightarrow \tau_{KK}(.)<0 \\
\tau_K(.)|_{K=\underline{K}} &= 16(1-d)^3d^2(1+d)(2+d)\left(-11+2d+7d^2\right)(2-d)<0 \Rightarrow \tau_K(.)<0 \\
\tau(.)|_{K=\underline{K}} &= -\tfrac{192(1-d)^5d^3(1+d)^2}{(2-d)^3}<0 \Rightarrow \tau(.)<0
\end{aligned}
$$

for any $d$, $K$ from our domain of definition. Thus, the retail profit is decreasing in $K$ and so, $W_K^{E/E}<0$.

**ad 2.** Consider the difference between $W^{E/N}$ and $W^{N/N}$:

$$W^{E/N}-W^{N/N} = \frac{(d-1)\,S(d,K)}{2\,(2-d)^2\,(1+d)\,[A(.)]^2\,[D(.)]^2} > 0 \Leftrightarrow S(d,K)<0$$

with

$S(.) = 48+32d-200d^2-112d^3+331d^4+146d^5-275d^6-86d^7+119d^8+22d^9-25d^{10}-2d^{11}+2d^{12}-336K-176dK+1104d^2K+468d^3K-1371d^4K-426d^5K+787d^6K+152d^7K-195d^8K-18d^9K+9d^{10}K+2d^{12}K+848K^2+288dK^2-2068d^2K^2-492d^3K^2+1736d^4K^2+234d^5K^2-534d^6K^2-26d^7K^2+d^8K^2-4d^9K^2+17d^{10}K^2-896K^3-64dK^3+1472d^2K^3-56d^3K^3-644d^4K^3+82d^5K^3-39d^6K^3-22d^7K^3+47d^8K^3+320K^4-128dK^4-304d^2K^4+128d^3K^4-20d^4K^4-40d^5K^4+45d^6K^4$

The function $S(d,K)$ describes the threshold between the meshed and the non-meshed region in Figure 3.3. We have to show that under this condition welfare is increasing with exclusivity when both manufacturers adopt exclusivity. Consider therefore the difference between $W^{E/E}$ and $W^{N/N}$:

$$W^{E/E} - W^{N/N} = \frac{(d-1)\,T(d,K)}{(2-d)^2\,(1+d)\,[H(.)]^2\,[J(.)]^2} > 0 \Leftrightarrow T(d,K) < 0$$

with

$T(.) = 768 + 256d - 2816d^2 - 768d^3 + 3840d^4 + 768d^5 - 2304d^6 - 256d^7 + 512d^8 - 5376K - 1280dK + 16896d^2K + 3328d^3K - 19200d^4K - 3072d^5K + 9216d^6K + 1280d^7K - 1536d^8K - 256d^9K + 13568K^2 + 1280dK^2 - 36288d^2K^2 - 3072d^3K^2 + 34816d^4K^2 + 3456d^5K^2 - 14384d^6K^2 - 2096d^7K^2 + 2352d^8K^2 + 432d^9K^2 - 64d^10K^2 - 14336K^3 + 2048dK^3 + 32256d^2K^3 - 3200d^3K^3 - 27008d^4K^3 + 448d^5K^3 + 10784d^6K^3 + 760d^7K^3 - 2064d^8K^3 - 304d^9K^3 + 152d^10K^3 + 32d^11K^3 + 5120K^4 - 3072dK^4 - 9472d^2K^4 + 4352d^3K^4 + 7296d^4K^4 - 2432d^5K^4 - 2976d^6K^4 + 672d^7K^4 + 676d^8K^4 - 92d^9K^4 - 81d^10K^4 + 5d^11K^4 + 4d^12K^4$

In order to show that the first condition is stronger than the second, it is sufficient to find a $K$ for which the following condition is satisfied:

$\forall d \in (0,1): \; S(.) > 0 \;\wedge\; T(.) < 0$

In order to find a value for $K$ that satisfies this condition, we divide our parameter space into 7 subspaces, in each of which we find a $K$ satisfying the above-mentioned conditions. The subspaces with the corresponding values for $K$ are:

| | | | | |
|---|---|---|---|---|
| 1. | $d \in (0, 0.5)$ | $K$ | $=$ | $\frac{9}{10} + \frac{\sqrt{21}}{10} + \frac{117d}{20} - \sqrt{21}d$ |
| 2. | $d \in (0.5, 0.8)$ | $K$ | $=$ | $\frac{1}{3} + \frac{10d}{3}$ |
| 3. | $d \in (0.8, 0.9)$ | $K$ | $=$ | $-\frac{57}{5} + 18d$ |
| 4. | $d \in (0.9, 0.95)$ | $K$ | $=$ | $-40 + 50d$ |
| 5. | $d \in (0.95, 0.98)$ | $K$ | $=$ | $-\frac{785}{3} + \frac{850d}{3}$ |
| 6. | $d \in (098, 0.99)$ | $K$ | $=$ | $-1158 + 1200d$ |
| 7. | $d \in (0.99, 1)$ | $K$ | $=$ | $981125 - 1981000d + 1000000d^2$ |

By inserting the values for $K$ into $T(.)$ and $S(.)$ and by using of Sturm's theorem, we can show that $T(.) < 0$ and $S(.) > 0$.[58] This implies that welfare is increasing with exclusivity if investment is sufficiently efficient, i.e., $S(d,K) < 0$.

**ad 3.** Welfare is increasing with exclusivity if and only if one or both manufacturers are willing to adopt exclusivity. In order to prove this statement, it is sufficient to find parameter values for $d$ and $K$ satisfying the equilibrium conditions.

$(i)$ One manufacturer adopts exclusive retailing and the other manufacturer does not adopt exclusive retailing, $\pi_{Mi}^{E/N}/\pi_{Mi}^{N/N} > 1$ & $\pi_{Mi}^{N/E}/\pi_{Mi}^{E/E} > 1$. Suppose that $d = 0.85$ and $K = 1.2$. These values satisfy the conditions above:

[58] Note that these conditions are also satisfied for the endpoints of the intervals. The step-by-step proof can be provided upon request.

| | |
|---|---|
| $\pi_{Mi}^{E/N}/\pi_{Mi}^{N/N}$ | $\doteq 1.06$ |
| $\pi_{Mi}^{N/E}/\pi_{Mi}^{E/E}$ | $\doteq 1.01$ |
| $S(d,K)$ | $-149.11$ |

$(ii)$ Both manufacturers adopt exclusive retailing, $\pi_{Mi}^{E/E}/\pi_{Mi}^{N/E} > 1$ & $\pi_{Mi}^{E/N}/\pi_{Mi}^{N/N} > 1$. Suppose that $d = 0.85$ and $K = 0.6$. These values satisfy the conditions above:

| | |
|---|---|
| $\pi_{Mi}^{E/E}/\pi_{Mi}^{N/E}$ | $\doteq 1.42$ |
| $\pi_{Mi}^{E/N}/\pi_{Mi}^{N/N}$ | $\doteq 1.40$ |
| $S(d,K)$ | $\doteq -14.44$ |

**ad 4.** We have already shown that $W^{E/N} = W^{E/E}$ if and only if $S(.) = 0$. We can determine $K'(d)$ using the implicit function theorem:

$$K'(d) = -\frac{\frac{\partial S(.)}{\partial d}}{\frac{\partial S(.)}{\partial K}} = \frac{U(d,K)}{V(d,K)}$$

First, note that there is no $K < 1.1$ satisfying $S(.) = 0$. Thus,

$$\begin{aligned}
U_{K^4}(.) &= 3072 + 14592d - 9216d^2 + 1920d^3 + 4800d^4 - 6480d^5 > 0 \\
U_{KKK}(.)|_{K=1.1} &= -\tfrac{12}{5}(-1568 + 672d + 3804d^2 - 7320d^3 - 1175d^4 + 2385d^5 \\
&\quad -385d^6 + 940d^7) \overset{Sturm's\,T.}{>} 0 \Rightarrow \tfrac{\partial^3 U(.)}{\partial K^3} > 0\,\forall K \geq 1.1 \\
U_{KK}(.)|_{K=1.1} &= -\tfrac{2}{25}(-21312 + 29128d + 18936d^2 - 53440d^3 + 26775d^4 \\
&\quad -50400d^5 - 17255d^6 + 31220d^7 - 900d^8 + 4250d^9) \overset{Sturm's\,T.}{>} 0 \\
&\quad \Rightarrow U_{KK}(.) > 0\;\forall K \geq 1.1 \\
U_K(.)|_{K=1.1} &= \tfrac{1}{250}(114048 - 139632d + 102156d^2 - 4000d^3 - 216875d^4 \\
&\quad +434685d^5 - 26145d^6 + 44380d^7 + 60300d^8 - 116000d^9 \\
&\quad -6000d^{11} > 0 \Rightarrow \tfrac{\partial U(.)}{\partial K} > 0\;\forall K \geq 1.1 \\
U(.)|_{K=1.1} &= \tfrac{1}{5000}(428544 - 262656d + 1194768d^2 - 740280d^3 - 277950d^4 \\
&\quad +1243935d^5 - 716030d^6 + 1269320d^7 + 118800d^8 - 273500d^9 \\
&\quad +110000d^{10} - 252000d^{11}) > 0 \Rightarrow U(.) > 0\;\forall K \geq 1.1
\end{aligned}$$

Second, we examine the sign of $V(d,K)$ for $S(d,K)=0$:

$$V(.)|_{S(.)=0} > 0 \quad \Leftrightarrow \quad S(.) - \tfrac{V(.)K}{4} \equiv W(.) < 0$$

$$W_{KKK}(.) \quad = \quad -1344 - 96d + 2208d^2 - 84d^3 - 966d^4 + 123d^5 - \tfrac{117d^6}{2} - 33d^7 + \tfrac{141d^8}{2} < 0$$

$$W_{KK}(.)|_{K=1.1} \quad = \quad \tfrac{1}{20}(1+d)(-12608 + 16256d - 9040d^2 - 2648d^3 + 16116d^4 - 8730d^5$$

$$-3237d^6 + 1991d^7 - 420d^8 + 340d^9) < 0$$

$$\Rightarrow W_{KK}(.) < 0\ \forall K \geq 1.1$$

$$W_K(.)|_{K=1.1} \quad = \quad \tfrac{1+d}{400}(-52928 + 103616d - 148000d^2 + 51592d^3 + 67176d^4 - 62250d^5$$

$$+49233d^6 - 23059d^7 - 17940d^8 + 10780d^9 - 600\left(d^{10} - d^{11}\right)) < 0$$

$$\Rightarrow \tfrac{\partial W(.)}{\partial K} < 0\ \forall K \geq 1.1$$

$$W(.)|_{K=1.1} \quad = \quad \tfrac{1+d}{4000}(-57216 + 216192d - 418320d^2 + 249544d^3 - 105888d^4 - 40490d^5$$

$$+193401d^6 - 128003d^7 + 25480d^8 - 6560d^9 - 22600d^{10} + 14600d^{11})$$

$$\overset{Sturm's\ Theorem}{<} 0 \Rightarrow W(.) < 0\ \forall K \geq 1.1\ \Rightarrow V(.) > 0\ \forall K \geq 1.1 \Rightarrow K'(d) > 0$$

Q.e.d.

# Bibliography

Acer (2011): "Framework Guidelines on Capacity Allocation and Congestion Management for Electricity," *Agency for the Cooperation of Energy Regulators*, FG-2011-E-002.

Aghion, P., and P. Howitt (1992): "A Model of Growth Through Creative Destruction," *Econometrica*, 60, 323–351.

——— (1998): *Endogenous Growth Theory.* MIT Press, Cambridge, USA.

Alesina, A., S. Ardagna, G. Nicoletti, and F. Schiantarelli (2005): "Regulation and Investment," *Journal of the European Economic Association*, 3 (4), 791–825.

Allcott, H. (2011): "Rethinking Real Time Electricity Pricing," *Resource and Energy Economics*, 33 (4), 820–842.

Areeda, P., and L. Kaplow (1988): *Antitrust Analysis. Problems, text, cases.* Little Brown and Company.

Armstrong, M. (1999): "Competition in the Pay-TV Market," *Journal of the Japanese and International Economics*, 13, 257–280.

Arya, A., B. Mittendorf, and D. E. M. Sappington (2008): "Outsourcing, vertical integration, and price vs. quantity competition," *International Journal of Industrial Organization*, 26, 1–16.

Averch, H., and L. Johnson (1962): "Behavior of the firm under regulatory constraint," *American Economic Review*, 52 (5), 1052–1069.

Baldick, R., J. Bushnell, B. Hobbs, and F. Wolak (2011): "Optimal Charging Arrangements for Energy Transmission: Final Report," *Report Prepared for and Commissioned by Project TransmiT, Great Britain Office of Gas & Electricity Markets.*

Banerjee, S., and P. Lin (2003): "Downstream R&D, raising rivals' costs, and input price contracts," *International Journal of Industrial Organization*, 21, 79–96.

Beard, T. R., D. L. Kaserman, and J. W. Mayo (2001): "Regulation, Vertical Integration and Sabotage," *Journal of Industrial Economics*, 49, 319–333.

Bernheim, B. D., and M. D. Whinston (1998): “Exclusive Dealing,” *Journal of Political Economy*, 106 (1), 64–103.

Besanko, D., and M. K. Perry (1993): “Equilibrium Incentives for Exclusive Dealing in a Differentiated Products Oligopoly,” *RAND Journal of Economics*, 24 (4), 646–668.

——— (1994): “Exclusive dealing in a spatial model of retail competition,” *International Journal of Industrial Organization*, 12 (3), 297–329.

Bester, H., and E. Petrakis (1993): “The incentives for cost reduction in a differentiated duopoly,” *International Journal of Industrial Organization*, 11, 519–534.

Bolton, P., and P. Aghion (1987): “Contracts as a Barrier to Entry,” *American Economic Review*, 77 (3), 388–401.

Boom, A. (2009): “Vertically integrated Firms Investments in Electricity Generating Capacity,” *International Journal of Industrial Organization*, 27 (4), 544–551.

Borenstein, S. (2002): “The Trouble With Electricity Markets: Understanding California’s Restructuring Disaster,” *Journal of Economic Perspectives*, 16 (1), 191–211.

——— (2005): “The Long-Run Efficiency of Real-Time Electricity Pricing,” *The Energy Journal*, 26, 93–116.

——— (2007): “Customer risk from real-time retail electricity pricing: bill volatility and hedgeability,” *The Energy Journal*, 28, 111–130.

Borenstein, S., and S. Holland (2005): “On the efficiency of competitive electricity markets with time-invariant retail prices,” *The RAND Journal of Economics*, 36 (3), 469–493.

Boston Consulting Group (2006): “Profiting from Handset Customization,” *Opportunities for Action*.

Brocas, I. (2003): “Vertical integration and incentives to innovate,” *International Journal of Industrial Organization*, 21, 457–488.

Buehler, S. (2005): “The Promise and Pitfalls of Restructuring Network Industries,” *German Economic Review*, 6, 205–228.

Buehler, S., D. Gärtner, and D. Halbheer (2006): “Deregulating network industries: dealing with price-quality tradeoffs,” *Journal of Regulatory Economics*, 30, 99–115.

Buehler, S., and A. Schmutzler (2008): “Intimidating competitors - Endogenous vertical integration and downstream investment in successive oligopoly,” *International Journal of Industrial Organization*, 26, 247–265.

Buehler, S., A. Schmutzler, and M.-A. Benz (2004): "Infrastructure quality in deregulated industries: is there an underinvestment problem?," *International Journal of Industrial Organization*, 22, 253–267.

Bundesnetzagentur (2011): "Auswirkungen des Kernkraft-Moratoriums auf die Übertragungsnetze und Versorgungssicherheit. Bericht der Bundesnetzagentur an das Bundesministerium für Wirtschaft und Technologie," Bundesnetzagentur.

Bundesregierung (2008): "Entwurf eines Gesetzes zur Öffnung des Messwesens bei Strom und Gas für Wettbewerb," *Bundestag Drucksache*, 16/8306.

Bushnell, J. (1999): "Transmission Rights and Market Power," *The Electricity Journal*, 12 (8), 77–85.

Bushnell, J., and S. Stoft (1997): "Improving Private Incentives for Electric Grid Investment," *Ressource and Energy Economics*, 19, 85–108.

Chen, Y., and D. E. Sappington (2009): "Designing input prices to motivate process innovation," *International Journal of Industrial Organization*, 27 (3), 390–402.

——— (2010): "Innovation in vertically related markets," *Journal of Industrial Economics*, 58 (2), 373–401.

Chintagunta, P., H. Liu, and T. Zhu (2011): "Wireless Carriers' Exclusive Handset Arrangements: An Empirical Look at the iPhone," *NET Institute Working Paper*, 11-35.

Competition Commission (2007): "Working paper on supplier pricing to grocery retailers and wholesalers," .

Cramton, P., and A. Ockenfels (2011): "Economics and design of capacity markets for the power sector," *Working Paper, University of Maryland.*

Cramton, P., and S. Stoft (2006): "The Convergence of Market Designs for Adequate Generating Capacity," *White Paper, California Electricity Oversight Board.*

Crandall, R. (2007): *Opportunity 08: Independent Ideas for Americas Next President*chap. Extending Deregulation: Make the U.S. Economy More Efficient, pp. 249–261. Brookings Institution Press.

Cremer, H., J. Crémer, and P. D. Donder (2006): "Legal Vs. Ownership Unbundling in Network Industries," *CEPR Discussion Paper*, 5767.

Crew, M., C. Fernando, and P. Kleindorfer (1995): "The Theory of Peak-Load Pricing: A Survey.," *Journal of Regulatory Economics*, 8 (3), 215–248.

DE FONTENAY, C., J. GANS, AND V. GROVES (2010): "Exclusivity, competition and the irrelevance of internal investment," *International Journal of Industrial Organization*, 28(4), 336–340.

DEPARTMENT FOR ENERGY AND CLIMATE CHANGE, AND OFGEM (2010): "Smart Metering Implementation Programme: Prospectus," Discussion paper, Department for Energy and Climate Change.

DOBSON, P., A. FREDENBERG, J. GOYDER, P. REY, M. SLADE, AND D. O'BRIEN (2008): *The Pros and Cons of Vertical Restraints*. Konkurrensverket.

ECONOMIDES, N. (1998): "The incentive for non-price discrimination by an input monopolist," *International Journal of Industrial Organization*, 16, 271–284.

ECONOMIST (1999): "Britain's railways - The rail billionaires," Jul 1st, 1999.

——— (2000): "How not to run a railway," Nov 25th, 2000(8652).

——— (2001): "Britain off the rails," Mar 17th, 2001.

——— (2009a): "Smart grids - Clever, but unprincipled," Oct 8th, 2009.

——— (2009b): "Smart grids - Wiser wires," Oct 8th, 2009.

ELECTRICITY REGULATORY FORUM (2011): "Proposal for Target Model and Roadmap for Capacity Allocation and Congestion Management," Electricity Regulatory Forum.

EUROPEAN COMMISSION (2005): "Common Actions for Growth and Employment: The Community Lisbon Programme," COM(2005) 330 final.

——— (2007): "Report on Energy Sector Inquiry (Jan 10th 2007)," SEC (2006) 1724.

——— (2010): "Europe 2020 - A strategy for smart, sustainable and inclusive growth," COM(2010) 2020 final.

EUROPEAN COUNCIL (2011): "Conclusions of the European Council (4 February 2011)," EUCO 2/1/11 REV 1.

EUROPEAN PARLIAMENT (2009a): "Directive 2009/72/EC of the European Parliament and of the Council," *Official Journal of the European Union*, L 211/56.

——— (2009b): "Directive 2009/72/EC of the European Parliament and of the Council," *Official Journal of the European Union*, L 211/56.

EVANS, D., AND R. SCHMALENSEE (2002): *Innovation Policy and the Economy*chap. Some Economic Aspects of Antitrust Analysis in Dynamically Competitive Industries, pp. 1–50. MIT Press, Cambridge and London.

Fabra, N., and M. A. de Frutos (2011): “Endogenous capacities and price competition: The role of demand uncertainty,” *International Journal of Industrial Organization*, 29 (4), 399–411.

Fabra, N., N.-H. von der Fehr, and M. A. de Frutos (2011): “Market Design and Investment Incentives,” *Economic Journal*, 121, 1340–1360.

Fabrizio, K., N. Rose, and C. Wolfram (2007): “Do Markets Reduce Costs? Assessing the Impact of Regulatory Restructuring on US Electric Generation Efficiency,” *American Economic Review*, 97 (4), 1250–1277.

FERC (2011): “Assessment of Demand Response and Advanced Metering - Staff Report,” *Federal Energy Regulatory Commission*.

Frasco, G. (1991): *Exclusive dealing: A comprehensive case study*. University Press of America.

Frontier Economics (2006): “Current prices, anybody? - The costs and benefits of ‘smart’ electricity meters,” *Frontier Economics Bulletin*.

——— (2009): “Smart metering - A report prepared for Centrica,” *Frontier Economics*.

——— (2011): “Economic Potential of Smart Electricity Meters in Germany - Analysis commissioned by Yello Strom GmbH,” *Frontier Economics*.

Fumagalli, C., M. Motta, and T. Ronde (2009): “Exclusive dealing - the interaction between foreclosure and investment promotion,” CEPR Discussion Papers.

Gabszewicz, J., and S. Poddar (1997): “Demand Fluctuations and Capacity Utilization under Duopoly,” *Economic Theory*, 10 (1), 131–146.

Gartner (2007): “Gartner Says Worldwide Mobile Phone Sales Grew 15 Per Cent in Third Quarter of 2007,” *Press Release*, Gartner Inc.

Gilbert, R., K. Neuhoff, and D. Newbery (2004): “Allocation Transmission to Mitigate Market Power in Electricity Networks,” *The RAND Journal of Economics*, 35 (4), 691–709.

Gilbert, R., and D. Newbery (1994): “The Dynamic Efficiency of Regulatory Constitutions,” *The RAND Journal of Economics*, 25 (4), 538–554.

Green, R. (2007): “Nodal pricing of electricity: how much does it cost to get it wrong?,” *Journal of Regulatory Economics*, 31 (2), 125–149.

Grossman, G., and E. Helpman (1989): “Product Development and International Trade,” *Journal of Political Economy*, 97, 1261–1283.

——— (1991): *Innovation and Growth in the Global Economy*. MIT Press, Cambridge, USA.

——— (1994): "Endogenous Innovation in the Theory of Growth," *Journal of Economic Perspectives*, 8, 23–44.

Guthrie, G. (2006): "Regulating Infrastructure: The Impact on Risk and Investment," *Journal of Economic Literature*, 44, 925–972.

Harbord, D., and M. Ottaviani (2001): "Contracts and Competition Contracts and Competition in the Pay-TV Market," *mimeo*.

Hogan, W. (1992): "Contract networks for electric power transmission," *Journal of Regulatory Economics*, 4 (3), 211–242.

——— (1999): "Restructuring the Electricity Market: Institutions for Network Systems," *Harvard University, Cambridge, MA*.

——— (2005): "On an Energy Only Electricity Market Design for Resource Adequacy," *Harvard University, Cambridge, MA*.

Hogan, W., J. Rosellón, and I. Vogelsang (2010): "Toward a combined merchant-regulatory mechanism for electricity transmission expansion," *Journal of Regulatory Economics*, 38 (2), 1–31.

Holland, S., and E. Mansur (2006): "The Short-Run Effects of Time-Varying Prices in Competitive Electricity Markets," *The Energy Journal*, 27, 127–155.

Höffler, F., and S. Kranz (2011a): "Imperfect Legal Unbundling of Monopolistic Bottlenecks," *Journal of Regulatory Economics*, 39 (3), 273–292.

——— (2011b): "Legal Unbundling Can Be a Golden Mean Between Vertical Integration and Ownership Separation," *International Journal of Industrial Organization*, 29 (5), 576–588.

Inderst, R., and T. Valletti (2009): "Price discrimination in input markets," *The RAND Journal of Economics*, 40 (1), 1–19.

Iyer, G., and J. M. Villas-Boas (2003): "A Bargaining Theory of Distribution Channels," *Journal of Marketing Research*, 40 (1), 80–100.

Joskow, P. (2007): *The New Energy Paradigm,*chap. Competitive Electricity Markets and Investment in New Generating Capacity, pp. 76–122. Oxford University Press.

Joskow, P., and J. Tirole (2000): "Transmission rights and market power on electric power networks," *The RAND Journal of Economics*, 31 (3), 450–487.

——— (2005): "Merchant Transmission Investment," *Journal of Industrial Economics*, 53 (2), 233–264.

——— (2006): "Retail electricity competition," *The RAND Journal of Economics*, 37 (4), 799–815.

Khovanskii, A., and Y. Burda (2008): "Degree of rational mappings, and the theorems of Sturm and Tarski," *Journal of Fixed Point Theory and Applications*, 3, 79–93.

Klein, B. (1988): "Vertical Integration as Organizational Ownership The Fisher Body General Motors Relationship Revisited," *Journal of Law, Economics and Organization*, 4, 199–213.

Korn, G. A., and T. M. Korn (1968): *Mathematical Handbook for scientists and engineers: Definitions, Theorems, and Formulas for Reference and Review*. McGraw-Hill Book Company, New York.

Kreps, D., and J. Scheinkman (1983): "Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes," *Bell Journal of Economics*, 14, 326–337.

Ledyard, J. (2008): *The New Palgrave Dictionary of Economics, Second Edition*chap. Market Failure. Palgrave Macmillan.

Lijsen, M. (2006): "The Real Time Price Elasticity of Electricity," *Energy Economics*, 29, 249–258.

Léautier, T. (2000): "Regulation of an electric power transmission company," *The Energy Journal*, 21 (4), 61–92.

Léautier, T.-O. (2011): "Is mandating "smart meters" smart?," *Toulouse School of Economics*.

Mandy, D. M., and D. E. M. Sappington (2007): "Incentives for sabotage in vertically related industries," *Journal of Regulatory Economics*, 31, 235–260.

Marvel, H. P. (1982): "Exclusive Dealing," *Journal of Law and Economics*, 25 (1), 1–25.

Masten, S. E., and E. A. Snyder (1993): "United States versus United Shoe Machinery Corporation On the Merits," *Journal of Law and Economics*, 36 (1), 33–70.

Mathewson, G. F., and R. A. Winter (1984): "An Economic Theory of Vertical Restraints," *RAND Journal of Economics*, 15, 27–38.

Milliou, C., and E. Petrakis (2007): "Upstream horizontal mergers, vertical contracts, and bargaining," *International Journal of Industrial Organization*, 25 (5), 963–987.

Milliou, C., E. Petrakis, and N. Vettas (2009): "(In)efficient trading forms in competing vertical chains," *mimeo*.

Motta, M. (2004): *Competition Policy: Theory and Practice*. Cambridge University Press, Cambridge, UK.

Murphy, F., and Y. Smeers (2005): "Generation Capacity Expansion in Imperfectly Competitive Restructured Electricity Markets," *Operations Research*, 53, 646–661.

National Economic Council (2009): "A Strategy for American Innovation: Driving Towards Sustainable Growth and Quality Jobs," September.

——— (2011): "A Strategy for American Innovation: Securing Our Economic Growth and Prosperity," September.

Neuhoff, K., R. Boyd, T. Grau, J. Barquin, F. Echavarren, J. Bialek, C. Dent, C. von Hirschhausen, B. Hobbs, F. Kunz, H. and Christian Nabe, G. Papaefthymiou, and C. Weber (2011b): "Renewable Electric Energy Integration: Quantifying the Value of Design of Markets for International Transmission Capacity," *DIW Discussion Papers*, 1166.

Neuhoff, K., B. Hobbs, and D. Newbery (2011a): "Congestion Management in European Power Networks: Criteria to Assess the Available Options," *DIW Discussion Papers*, 1161.

Newbery, D. (2000): *Privatization, Restructuring, and Regulation of Network Utilities*. MIT Press, Cambridge, USA.

Ng, C., and P. Seabright (2001): "Competition, Privatization and Productive Efficiency: Evidence from the Airline Industry," *The Economic Journal*, 111, 591–619.

Nicoletti, G., and S. Scarpetta (2003): "Regulation, Productivity and Growth: OECD Evidence," *Economic Policy*, 36, 9–72.

Ofgem (2010): "Project TransmiT: A Call for Evidence," *Office for Gas and Electricity Markets*, 119/10.

Olley, S., and A. Pakes (1996): "The dynamics of productivity in the telecommunications equipment industry," *Econometrica*, 64 (6), 1263–1297.

O'Neill, R., U. Helman, and B. Hobbs (2008): *Competitive Electricity Markets: Design, Implementation, Performance,*chap. The Design of U.S. Wholesale Energy and Ancillary Service Auction markets: Theory and Practice, pp. 179–244. Global Energy Policy and Economics Series, Elsevier.

O'Neill, R., U. Helman, B. Hobbs, and R. Baldick (2006): *Electricity Market Reform: An International Perspective,*chap. Independent system operators in the United States: History, lessons learned, and prospects, pp. 479–528. Global Energy Policy and Economics Series, Elsevier.

Oren, S. (2005): *Electricity Deregulation: Choices and Challenges,*chap. Generation Adequacy in Competitive Electricity Markets, pp. 388–414. University of Chicago Press.

Qui, L. D. (1997): "On the Dynamic Efficiency of Bertrand and Cournot Equilibria," *Journal of Economic Theory*, 75, 213–229.

Rasmusen, E. B., J. M. Ramseyer, and J. S. Wiley (1991): "Naked Exclusion," *American Economic Review*, 81 (5), 1137–1145.

Redpoint Energy (2011): "Modelling the Impact of Transmission Charging Options," *Redpoint Energy Ltd.*

Rey, P. (2003): *Advances in Economics and Econometrics Theory and Applications*chap. Towards a Theory of Competition Policy, pp. 82–132. Cambridge University Press, Cambridge, UK.

Rey, P., and J. Stiglitz (1995): "The role of exclusive territories in producers' competition," *The RAND Journal of Economics*, 26(3), 431–451.

Reynolds, S., and B. Wilson (2000): "Bertrand Edgeworth Competition, Demand Uncertainty, and Asymmetric Outcomes," *Journal of Economic Theory*, 92, 122–141.

Rious, V., J.-M. Glachant, and P. Dessante (2010): "Transmission Network Investment as an Anticipation Problem," *RSCAS Working Papers*, 2010/04.

Romer, P. (1990): "Endogenous Technological Change," *Journal of Political Economy*, 98, 71–102.

Sauma, E., and S. Oren (2009): "Do Generation Firms in Restructured Electricity Markets Have Incentives to Support Social-Welfare-Improving Transmission Investments?," *Energy Economics*, 31 (5), 676–689.

Sauma, E. E., and S. S. Oren (2006): "Proactive planning and valuation of transmission investments in restructured electricity markets," *Journal of Regulatory Economics*, 30, 358–387.

Schaber, K., F. Steinke, and T. Hamacher (2012): "Transmission grid extensions for the integration of variable renewable energies in Europe. Who benefits where?," *Energy Policy*, 43, 123–135.

Segal, I., and M. Whinston (2007): “Antitrust in Innovative Industries,” *American Economic Review*, 97 (5), 1703–1730.

Segal, I. R., and M. D. Whinston (2000): “Exclusive contracts and protection of investments,” *RAND Journal of Economics*, 31, 603–633.

Sibley, D. S., and D. L. Weisman (1998): “Raising rivals’ costs: The entry of an upstream monopolist into downstream markets,” *Information Economics and Policy*, 10, 451–470.

Singh, N., and X. Vives (1984): “Price and Quantity Competition in a Differentiated Duopoly,” *The RAND Journal of Economics*, 15, 546–554.

Smith, A. (1776): *An Inquiry into the Nature and Causes of the Wealth of Nations*. Methuen and Co., Ltd.

Spiller, P. T. (2005): *Handbook of Telecommunication Economics Vol. 2* chap. Institutional Changes in Emerging Markets: Implications for the Telecommunications Sector,, pp. 622–652. Elsevier North-Holland.

Sturm, C. F. (1829): “Mémoire sur la résolution des équations numériques,” *Bulletin des Sciences de Férussac*, 11, 419–422.

Subramanian, U. (2009): “Essays on competitive strategies in wireless markets,” Ph.D. thesis, University of Pennsylvania.

The World Bank (2006): *Doing Business 2007 - How to reform*. World Bank.

Tirole, J. (1988): *The Theory of Industrial Organization*. MIT Press, Cambridge, USA.

Valletti, T. M. (2003): “The theory of access pricing and its linkage with investment incentive,” *Telecommunications Policy*, 27, 659–675.

Valletti, T. M., and C. Cambini (2005): “Investments and Network Competition,” *The RAND Journal of Economics*, 36, 446–467.

Vives, X. (2001): *Oligopoly Pricing: Old Ideas and New Tools*. MIT Press, Cambridge, USA.

Vogelsang, I. (2001): “Price regulation for independent transmission companies,” *Journal of Regulatory Economics*, 20, 141–165.

Whinston, M. (2006): *Lectures on Antitrust Economics - The Cairoli Lectures*. MIT Press, Cambridge and London.

Winter, R. A. (1993): “Vertical Control and Price versus Nonprice Competition,” *The Quarterly Journal of Economics*, 108 (1), 61–76.

Wolak, F. (2011): "Measuring the Benefits of Greater Spatial Granularity in Short-Term Pricing in Wholesale Electricity Markets," *American Economic Journal: Papers and Proceedings*, 101 (3), 247–252.

Zöttl, G. (2011): "On Optimal Scarcity Prices," *International Journal of Industrial Organization*, 29 (5), 589–605.

# Eidesstattliche Versicherung

Ich versichere hiermit eidesstattlich, dass ich die vorliegende Arbeit selbständig und ohne fremde Hilfe verfasst habe. Die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sowie mir gegebene Anregungen sind als solche kenntlich gemacht.

Die Arbeit wurde bisher keiner anderen Prüfungsbehörde vorgelegt und auch noch nicht veröffentlicht.

München, 19. Juni 2012