CARTELS, PATENT POOLS AND THE INCENTIVE EFFECT OF COMPETITION

LISA MAGDALENA FEY

12 December 2014

CARTELS, PATENT POOLS AND THE INCENTIVE EFFECT OF COMPETITION

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

2014

vorgelegt von Lisa Magdalena Fey

Referent:	Prof. Dr. Klaus M. Schmidt
Korreferent:	Prof. Dr. Martin G. Kocher
Mündliche Prüfung:	29. April 2015
Promotionsabschlussberatung:	13. Mai 2015

DANKSAGUNG

An dieser Stelle möchte ich allen Personen danken, die zum Gelingen dieser Arbeit beigetragen haben.

Zuerst bedanke ich mich herzlich bei meinem Erstbetreuer Klaus Schmidt für die fachliche Betreuung und Unterstützung während der gesamten Promotion. Außerdem möchte ich meinem Zweitgutachter Martin Kocher für seine hilfreichen Kommentare zu meiner Arbeit danken. Florian Englmaier danke ich, dass er die Rolle des Drittgutachters übernommen hat.

Durch das Stipendium des Max-Planck-Instituts für Innovation und Wettbewerb und meiner Stelle am Lehrstuhl für Wirtschaftstheorie der LMU hatte ich das Glück, viele nette Kollegen zu haben, die mich auf meinem Weg zur Promotion begleitet haben. Diese gemeinsame Zeit hat nicht nur meine Arbeit bereichert, sondern auch Spaß gemacht. Vielen Dank dafür. Insbesondere möchte ich mich bei Philipp Schautschick und Julia Molestina ganz herzlich für jegliche Unterstützung und die tolle gemeinsame Zeit bedanken. Meiner Koautorin Carmen Thoma gilt mein Dank für die gute Zusammenarbeit und die Durchführung der Experimente. Außerdem möchte ich den Teilnehmern von Seminaren, Konferenzen und der Summer School für ihr Interesse an meiner Arbeit und ihren hilfreiche Kommentaren danken.

Dank für die finanzielle Förderung geht an das Max–Planck–Institut für Innovation und Wettbewerb und an die Deutsche Forschungsgemeinschaft. Beim Chief Economist Team der DG Competition bedanke ich mich für die Möglichkeit, europäische Wettbewerbspolitik hautnah mitzuerleben.

Besonders danke ich meiner Familie und meinen Eltern, Regine und Rüdiger, die mich immer gefördert haben ohne zu fordern und mir ihr vollstes Vertrauen geschenkt haben. Danke, Gerson, dass du immer für mich da bist.

Lisa Fey

CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

> *'The provisions of European Union law on cartels ... must be interpreted as not precluding a person who has been adversely affected by an infringement of European Union competition law and is seeking to obtain damages from being granted access to documents relating to a leniency procedure. ... It is, however, for the courts and tribunals of the Member States, on the basis of their national law, to determine the conditions under which such access must be permitted or refused by weighing the interests protected by European Union law.'*

With these words, the European Court of Justice closed the judgment in the case *Pfleiderer AG v. Bundeskartellamt* in 2011.[1] Already before the decision in the *Pfleiderer* case, EU courts had dealt with the tension between a victim's right to claim damages for infringement of EU competition law and the effectiveness of the public enforcement of competition rules by the European Commission (EC) and national antitrust authorities. Infringements of EU competition law such as cartels cause serious harm not only to the economy as a whole, but also to the customers of those who commit the infringements. These victims of infringements are entitled by EU law to compensation for the harm caused. However, only recently one could read about private parties claiming damages for losses due to cartels in the newspapers.

So far, shortcomings in the applicable legal frameworks have made it extremely costly and difficult to bring an action for damages. As a result, only few claims were brought before national courts. However, public attention has increased recently because these shortcomings in the legal frameworks regulating the interaction between private and public enforcement of competition law resulted in several court cases and finally in a directive on antitrust damages actions which was signed into law in November 2014 (European Union, 2014b).

By the judgment delivered in the *Pfleiderer* case, the European Court of Justice (ECJ) held that there are no existing common rules governing the right to access cartel documents in private follow-on damages actions. Obtaining relevant evidence has been identified as the main obstacle for potential claimants in their attempt to prove their harm. The key issue related to the access to cartel documents concerns statements that have been made by wrongdoers in order to seek leniency from fines. 'Weighing the interests

1 Case C-360/09, *Pfleiderer AG v. Bundeskartellamt* [2011] ECR I-5161.

protected by European Union law' refers to the following challenge: On the one hand, these voluntarily made, detailed leniency statements provide a useful source of evidence for the victims and therefore can facilitate actions for damages, fostering private enforcement. On the other hand, the disclosure of leniency statements for follow-on actions for damages can reduce the attractiveness of the leniency programmes that have become one of the most effective tools for cartel detection. In other words, the objective of private enforcement—full compensation for victims—and the objectives of public enforcement—detection and disclosure of cartels—could be at odds.

The first chapter of this dissertation provides an economic analysis of the interaction between *Leniency Programmes and Private Actions for Damages*. Within a theoretical framework, I show how private damages claims following a cartel decision affect the objectives of the public enforcement of competition law —detection and deterrence of cartels. In an infinitely repeated game I analyse firms' incentives to compete, to collude and keep their cartel secret, or to collude and later apply for leniency. The antitrust authority tries to enforce a competitive market by investigating firms and proving collusion. It also provides a leniency programme that offers a reduced fine for firms which voluntarily cooperate and report their participation in a cartel. If a firm is found to be guilty of colluding, it does not only has to pay a fine imposed to the antitrust authority, it may also be exposed to private damages payments. I distinguish the exposure to damages payments on the basis of whether a firm cooperates with the antitrust authority or not. Intuitively, the exposure to damages payments affects a firm's strategy on collusion and participation in the leniency programme.

I find that if private enforcement is strengthened in such a way that firms that are found guilty of collusion and that did not participate in a leniency programme are exposed to higher damages payments, a firm's profit from collusion decreases. Additional to this deterring effect, firms in a cartel might change their strategy from keeping their cartel secret to revealing in exchange for a reduction in fine. These results speak for increasing the exposure to damages for non-leniency firms because a stronger enforcement of damages claims against these firms supports the objectives of the public enforcement.

However, I find that the effect of increasing the exposure to damages payments for firms that revealed their cartel—the leniency firms—has two conflicting effects on deterrence. On the one hand, damages payments may reduce the incentives to collude, thereby incentivizing better compliance with competition law. On the other hand, increasing the exposure to damages payments for leniency firms can stabilize a cartel's agreement, which in turn makes collusion more profitable. Surprisingly, this cartel stabilizing effect has not been considered so far. The effectiveness of the leniency programme is undermined by higher expected damages payments as applying for leniency becomes less profitable.

The results of my model show that the interaction between private and public enforcement depends on which cartel members are exposed to the private damages claims following a cartel decision. Additionally, private enforcement does not affect the objectives of public enforcement—deterrence and disclosure—equally, but can support one and jeopardize the other.

In June 2014, the ECJ decided upon another aspect of private damages claims following a cartel decision. In the *Kone AG and Others v. ÖBB-Infrastruktur AG* case[2], the ECJ ruled that victims of cartels should also be allowed to seek damages from cartel members for loss resulting from 'umbrella pricing'. Under the 'umbrella' of a cartel, non-cartel members can set their own prices higher than they would otherwise have been able to without the cartel.

This aspect of cartel pricing shows how similar cartels and patent pools—which are the focus of chapter 2—are, even though their impact on prices and welfare can be completely opposite. A patent pool can be considered a group of firms which jointly fix a price for their product. But as opposed to a cartel, a patent pool of complementary patents has a pro-competitive effect if it reduces total royalty rates compared to individual pricing. One problem of patent pools concerns their stability. As in the case of a cartel, non-participating firms under the umbrella of the patent pool can set their royalty higher than they would otherwise have been able to without the patent pool. They can free-ride on the patent pool and profit from the effect that the patent pool reduces total royalties without joining the patent pool.

The second chapter, *On the Stability of Patent Pools*, raises the question as to how free-riding on a patent pool by firms which license their patents individually affects the pool's stability. A patent pool bundles patents for the purpose of joint licensing. Patent pools operate in an environment comprising three systems—the competition rules, the patent system and the standardisation process. Most jurisdictions look favourably on patent pools including only complementary patents as drivers of innovation. Although the first patent pool had come into existence as early as 1856 in the sewing machine industry (Lampe and Moser, 2010), the number of patent pools increased only after the U.S. Department of Justice acknowledged the potential pro-competitive benefit of patent pools in 1995. Today, most patent pools develop around an already established standard. Essential patents are required for complying with a technical standard and are therefore complementary. The bundling of complementary patents can reduce total royalties compared to a disintegrated market in which each patent owner sets its royalty indi-

2 Case C-557/12, *Kone AG and Others v. ÖBB-Infrastruktur AG* [2014]; judgment of 5 June 2014.

vidually. An additional advantage of patent pools is that they simplify or even only enable the implementation of a standard. Because the number of patents declared essential and incorporated in (technological) standards has increased extremely over the past few decades, the costs of negotiating individual licences for each patent can be too high for patent owners as well as for licensees.

For example, in the 1990s the core international digital video compression standard, required for virtually all digital television including DVD, faced a patent thicket. Blocking patents, hold-up behaviour and a huge number of patents by many patent owners made it almost impossible to use the standard. The creation of patent pools facilitated licensing and market adoption. Today, this standard is one of the most successful consumer electronic standards. In the last decade, patent pools have also formed in industries not related to compatibility standards or platform technologies. The 'Golden Rice Pool' bundles patents for a genetically engineered strain of rice, the 'Medicines Patent Pool' aims to improve generic low-cost production of key HIV therapies while 'Librassay' makes patents in the field of molecular diagnostics available through a single license.

Even though a patent pool reduces transaction costs and the complements problem of excessive high royalties, it also entails a major problem. Participation in a patent pool is voluntary, which is why the patent pool needs to be incentive compatible in order to attract patent owners. The bundling of complementary patents not only reduces the royalties paid by the licensees, but it also increases profits of the patent owners compared to individual licensing. But because all standard-essential patents are needed in order to use the standard's technology, patent holders can decide not to join the patent pool and license their patent individually. The reduction in the total royalty due to the bundling of patents in the pool allows the essential patent owners outside the patent pool to increase their royalty.

I analyse the stability of a patent pool using the concept of farsighted stability. According to this concept, agents are farsighted in the sense that they do not only correctly anticipate changes in royalties and in profits, but also foresee changes in the size of the patent pool following a deviation. Until now, the stability of patent pools has only been analysed using the concept of myopic stability, in which agents are unable to foresee other agents' reactions following a deviation. My results show that although free-riding can be profitable for a patent owner, the patent pool participation rate can be considerably larger if agents are assumed to be farsighted compared to myopic. I provide an algorithm to define the farsighted stable set of patent pool outcomes and apply the algorithm to a model of linear demand and price leadership of the patent pool. I show that grand patent pools, in which all owners of essential patents join one patent pool, can be in the set of farsightedly stable outcomes. A complete break-up of a patent pool is never farsightedly stable. These results are not restricted to the analysis of the stability of patent pools, but can also be applied to other fields that deal with coalitional stability such as team formation, political agreements and cartels.

While the first two chapters employ theoretical models to analyse firms' incentive to behave cooperatively or non-cooperatively in cartels and patent pools, the third chapter deals with *The Incentive Effect of Competition*—a joint work with Klaus Schmidt and Carmen Thoma. This chapter attempts to answer if the degree of competition affects the incentives to invest effort with the help of laboratory experiments. In particular, we are interested to find out whether firms invest more effort when they are in a competitive market than when they are in a monopolistic market, even though the monetary incentives to invest are in equilibrium the same in both markets.

It appears to be a recurrent phenomenon that firms increase their efforts if the degree of competition increases unexpectedly. The spate of cost-cutting in the oil industry after the 1986 price crash (Borenstein and Farell, 2000), the advent of the most technologically progressive period in the US after the Great Depression (Field, 2003) and the sharp productivity increase in the Great Lakes iron ore production after the Brazilian market entry (Schmitz Jr, 2005) are examples of the effect of competition on productivity and innovation. In the last example, the Great Lakes iron ore producers faced no competition for nearly a century. In the early 1980s, Brazilian iron ore producers were unexpectedly offering iron ore at lower prices in the Great Lakes region. In response, the production process in the Great Lakes iron ore industry underwent a change, labour productivity doubled, material productivity rose by 50% and capital productivity increased within a few years, after years of little change before the Brazilian market entry.

The connection between competition and innovation has long been the interest of economists, dating back to Schumpeter (1942) and Arrow (1962). Theoretical models on the relationship between competition and innovation offer mixed results and reveal the counteractive effects of competition and innovation. Moreover, the interdependence of competition and innovation is also problematic in empirical studies because the causal relationship remains unclear. Most empirical studies find that innovation increases linearly with competition (Geroski, 1994; Nickell, 1996; Blundell et al., 1999) or that innovation increases with competition and at some point decreases again (Scherer, 1967; Aghion et al., 2005). This non-linear relationship can emerge because the rents from innovation depend on the level of the innovativeness and competitiveness of the industry.

Even though a large body of literature addresses the issue of competition and innovation, its focus is on the monetary incentives to invest. Surprisingly, no research has been devoted to the question as to how competition affects the incentives to invest independent of the monetary incentives which might vary depending of the degree of competition and the innovativeness of an industry. We analyse this question with the help of laboratory experiments, a method that allows us to control for the degree of competition and the monetary incentives to invest.

In the first experiment, subjects decide how much of their given budget they invest in a risky R&D project. The project's probability of success increases with their investment. Subjects are either in a monopoly, duopoly or an oligopoly treatment. In the monopoly treatment, a subject's payoff depends only on its project success, whereas in the competitive treatments a subject's payoff depends on its own project's success as well as on the success of their competitor(s) who invest simultaneously. Our results reveal that subjects in the competitive treatments invest significantly more than the subjects in the monopoly treatment, even though the Nash equilibrium investment is the same across treatments.

To investigate which aspect of competition incentivizes the subjects to invest more, we conduct a second experiment. Letting subjects invest sequentially allows us to align the complexity and risk of the investment in a monopoly and a duopoly treatment. Our results show that a higher degree of complexity and the uncertainty about the competitor's decision are possible drivers of the higher investment in the competitive treatments which we observed in the first experiment. In the experiment with sequential decisions, the average investments do not differ across treatments. But the fact that subjects in the duopoly treatment compete against another subject still impacts the investment decision. We observe that with competition, subjects invest more if their expected payoff decreases exogenously. A decrease in their payoff seems to motivate higher investments. Subjects in the monopoly treatments in contrast are discouraged from investing in the same situation. This difference can only be explained by the incentive effect of competition, because the relation between cost of investment and probability of success is in both treatments unaffected by the exogenous shock. The results of Chapter 3 indicate that the relationship between competition and innovation does not only depend on the monetary incentive to invest, which has been the focus of the literature so far, but that there is also an incentive effect of competition independent of monetary incentives.

Each of the three chapters is self-contained, having its own introduction and appendix. Consequently, each chapter can be read independently of the other two. A consolidated bibliography of all chapters can be found at the end of the dissertation.

1

LENIENCY PROGRAMMES AND PRIVATE ACTIONS FOR DAMAGES

1.1 INTRODUCTION

De jure there is no interaction between the private and public enforcement of competition law. Nevertheless, the interaction between leniency programmes and cartel damages claims has produced several court cases and broad discussions over the recent years. In particular, cartel damages actions that follow an AA's decision may give rise to several problems. One of these problems is at the focus of this chapter—the interaction between private follow-on claims for damages and leniency programmes.

Very recently, on 26 November 2014, the 'Directive of the European Parliament and of the Council on certain rules governing actions for damages under national law for infringements of the competition law provisions of the Member States and of the European Union' was signed into law (European Commission, 2014; European Union, 2014b). This directive came into existence after long discussions about the coexistence of private and public enforcement of competition law in the EU.[1]

The European Commission (EC) found that shortcomings in the applicable legal frameworks so far make it excessively costly, if not impossible, for victims of cartels to obtain relevant evidence to bring an action against the cartelists.[2] The access to case documents for potential claimants on the one hand facilitates damages claims, but on the other hand gives rise to problems concerning the public enforcement of competition law. Leniency programmes are an often-used tool of public enforcement and require the firms to make detailed leniency statements in order to get reductions from

1 A Green Paper (European Commission, 2005) was followed by a White Paper (European Commission, 2008), which led to the publication of a Proposal for a Directive by the European Commission in June 2013 (European Commission, 2013e). A modified version was adopted by the European Parliament in April 2014 (European Parliament, 2014), followed by the final adoption by the Council in November 2014 (European Union, 2014b). For the full overview of the history and the documents accompanying of the European discussion, see http://ec.europa.eu/competition/antitrust/actionsdamages/index.html.

2 Until now, most of the private actions for damages were brought by large businesses. The harm caused by competition law infringements is often widely spread and each victim has a low-value damage (European Commission, 2013b). The EC recommends that some form of collective redress mechanism should be available in all EU Member States to improve the change for compensation of consumers and SMEs (European Commission, 2013a,d).

fines. Owing to the system of joint and several liability[3] and the unlikely event that leniency applicants appeal, revealing firms are in a different position than non-revealing firms in follow-on damages claims as they may become the primary target of damages claims.

In this chapter I analyse the effect of follow-on damages claims on cartel deterrence and cartel disclosure. I study how facilitating damages actions affects the public enforcement of competition law. I develop a theoretical model in which symmetric firms decide whether to compete, to collude and keep their cartel secret or to collude and later apply for leniency as part of their strategy. To analyse the effect of damages payments on the cooperation with the AA (AA) and on collusion, I distinguish between the exposures to damages payments for revealing firms and for non-revealing firms.

The results of my model have several interesting implications for the design of the interaction of private damages claims and leniency programmes. First, my model provides insights into the effect that private enforcement has on the incentives to collude or to compete in a market additional to public enforcement. Second, it shows how private damages payments affect the incentives to report a cartel under legal frameworks which differ in the exposure to damages for revealing and non-revealing colluding firms.

I find that an increase in the exposure to damages payments for firms which are found guilty and which did not cooperate with the AA decreases the value of collusion. Additional to this deterring effect, higher expected cost in case of collusion increases the incentives to disclose the cartel to the AA. A stronger enforcement of damages claims against firms which did not reveal their cartel supports the objectives of the public enforcement, namely deterrence and disclosure of cartels. An increase in the exposure to damages payments for firms which revealed their cartel to the AA has two opposite effects on deterrence. On the one hand, the expected costs of collusion increase and this may deter firms from collusion. On the other hand, it stabilizes a cartel's agreement never to reveal and this in turn makes collusion more profitable. Surprisingly, this cartel-stabilizing effect has not been considered so far. The effect on the incentives to cooperate with the AA is unambiguous: Higher expected damages payments for revealing firms reduce the incentives to apply for leniency because revealing becomes less profitable.

My analysis uses the basic framework developed by Motta and Polo (2003), which considers the effect of leniency programmes on cartel deterrence and cartel detection. I modify the timing and expand the model by damages to analyse the interaction of leniency programmes and cartel damages actions.

3 Under the rule of joint and several liability, a person who was harmed by several wrongdoers can claim total damages from one, several or all liable wrongdoers, regardless of their individual share of the harm caused.

The economic literature on leniency programmes[4] builds upon the literature on law enforcement and shows that self-reporting and leniency policies can have positive effects by reducing costs and preventing crimes (see for example Kaplow and Shavell, 1994, and Kofman and Lawarrée, 1996). The paper by Motta and Polo (2003) is the first paper that discusses leniency programmes in a dynamic setting in a multi-agent environment. In this model, symmetric firms interact repeatedly and choose whether or not to collude, playing grim trigger strategies. The AA reviews the industry with some probability and colluding firms can decide if they want to cooperate with the AA which reduces their fine. Firms report information as part of a strategy. On the one hand, lenient treatment of cartel members reduces the expected fine and this increases the incentives for collusion. On the other hand, leniency programmes reduce the cost of prosecution and make enforcement more effective. Motta and Polo (2003) show that if the AA reallocates resources from prosecution to detection, the positive effect tends to dominate the negative effect. Private actions for damages and their interactions with leniency programmes are not part of the model of Motta and Polo (2003).

Several other papers show that leniency programmes may have counterproductive side effects and that programme characteristics such as fines, rewards and the timing of reductions granted have to be designed carefully (Spagnolo, 2004; Buccirossi and Spagnolo, 2006; Aubert et al., 2006; Harrington, 2008; Motchenkova and Leliefeld, 2010; Chen and Rey, 2013).

My research question also relates to the literature on private and public enforcement of competition law. So far, the legal and economic literature has focused on the comparison of private and public enforcement of competition law or on the comparison of the EU and the US legal system of private and public enforcement of competition law.[5] My analysis in contrast

4 Spagnolo (2008) gives a good overview of the literature of leniency policies.

5 For a detailed overview of private enforcement of competition law, see for example Komninos (2008); Basedow (2007); Basedow et al. (2011). Wils (2009) proposes a separate-task-approach for the public and private enforcement of competition law in the EU and lists issues at which both interact. Segal and Whinston (2007) survey the economic issues of public vs. private enforcement in different jurisdictions. They analyse advantages and costs of private enforcement compared to public enforcement in deterring anti-competitive behaviour. Their discussion of economic issues of the optimal enforcement mix follows the US perspective, in which private enforcement pursues punitive objectives additionally to the fines imposed by the public authority. Peyer and Hüschelrath (2013) analyse the optimal enforcement mix of public and private enforcement for different anticompetitive conducts. Segal and Whinston (2007) and Peyer and Hüschelrath (2013) both focus on the comparison and the optimal mix of the two enforcement mechanisms. Similarly, McAfee et al. (2008) compare the welfare effects of public and private enforcement. They assume that private claimants may act strategically and may have informational advantages to the public authority. Therefore, private enforcement is only welfare increasing if courts are sufficiently precise. This comparison of the effectiveness of the two mechanisms and their advantages and disadvantages is again mainly of interest in the analysis of the US system of private and public enforcement of competition law.

focuses on the interaction of private and public enforcement of competition law. The model which I consider is different from the models which compare public and private enforcement as I do not introduce private enforcers as additional strategic players (as in McAfee et al., 2008). My model analyses the most common form of private enforcement in the EU, in which private enforcement builds upon public enforcement and claimants file actions for damages following the decision of the public authority.[6]

Marra and Sarra (2010) analyse how the incompleteness of competition laws influences the incentives of individuals to turn to court following a competition law infringement. In their model, the incompleteness of law introduces uncertainty that influences the behaviour of plaintiffs as well as that of defendants. They assume that the law remains incomplete until the first relevant court judgment and that follow-on litigants are able to exploit the first-movers effort. To stimulate private enforcement of competition law, Marra and Sarra (2010) propose direct measures such as the increase in available information and indirect measures such as filling legislative gaps and additional incentives for first movers in private enforcement. Although my model also allows for the incompleteness of law, I do not distinguish between stand-alone and follow-on claimants and their incentives to bring a claim. In my model, I analyse the effect of the exposure to damages claims on a cartelist's incentives to collude and cooperate with the AA. A cartelist's effective exposure to damages payments can vary between zero and total harm caused by the cartel. These variations can either be explained by an exemption by law to pay full damages or by the incompleteness of law. Owing to this incompleteness, claimants may have a lower probability of being fully compensated and cartelists are exposed to damages payments which are lower than the harm they have caused.

An empirical analysis of the costs and benefits of private enforcement is difficult because the full costs and benefits are hard to observe. There are only few empirical studies on the private enforcement of EU competition law due to the lack of systematic data collection.[7]

The problems of uncertainty caused by the current legal rules on the interaction of private and public enforcement of competition law have resulted in several court cases and broad discussion among legal practitioners and scholars. Nevertheless, to my knowledge no economic model addressed the topic

6 Calcagno (2012) analyses stand-alone private damages actions in a framework similar to McAfee et al. (2008).

7 A problem in addition to the lack of data collection on private enforcement cases is the fact that many follow-on cases are settled before they reach court and therefore do not show up in the statistics. Rodger (2006a,b, 2009a, 2013, 2009b) give an overview of UK private enforcement cases until 2012. Peyer (2012) analyses the existence of private antitrust litigation in Germany and finds that actions for damages are rare but injunctive reliefs are widely used.

of the interaction between leniency programmes and private cartel damages claims. I try to fill this gap and shed light on the effect of cartel damages payments on firms' incentives to collude and on the incentives to cooperate with the AA once a cartel has been set up.

This chapter is organized as follows. Section 1.2 gives a comprehensive overview of the legal background of private and public enforcement of competition law and the most relevant court cases in the EU. These cases initiated the debate about the interaction of private enforcement of competition law and leniency programmes with the focus on the special role of leniency applicants. Section 1.3 sets up the model of private and public enforcement of competition law. Section 1.4 analyses the effect of the exposure to damages payments on the incentives to collude and to report a cartel. Section 1.5 concludes.

1.2 PRIVATE AND PUBLIC ENFORCEMENT OF EU COMPETITION LAW

1.2.1 *Objectives, Legal Framework and Problems*

Competition law enforcement pursues three main objectives. The first one is injunction, that is to stop the infringement of the law and to deter future infringement. The second objective is compensation, that is to reimburse the victims of the infringement for the harm suffered. The third objective is to punish the infringer. These three objectives can be pursued by the combination of private and public enforcement of competition law. In the EU, private and public enforcement are seen as complementary tools. Whereas the public enforcement aims to punish and deter illegal actions, the objective of the private enforcement is to guarantee 'full and fair compensation for victims once a public authority has found and sanctioned an infringement' (European Commission, 2013a, p.2). In the US, private enforcement also includes a punitive element by awarding treble damages due to the lack of a strong public agency. The majority view of scholars is that both private and public enforcement are needed in order to achieve the injunctive, compensatory and punitive objectives of competition law.

EU competition rules are primarily enforced by the EC and the national AAs in the public interest. Additionally, Articles 101 and 102 TFEU have direct effect so that victims of infringement can privately claim damages for breaches of Articles 101 and 102 TFEU before national courts in civil actions.[8] In 2001, the European Court of Justice (ECJ) emphasized the importance of the private enforcement of competition law and justified the right to compensation for anti-competitive behaviour. In the *Courage* judgment, para.26, the ECJ stated that '[t]he full effectiveness of Article 85 of the Treaty [now 101 TFEU] and, in particular, the practical effect of the prohibition laid down in Article 85(1) would be put at risk if it were not open to any individual to claim damages for loss caused to him by a contract or by conduct liable to restrict or distort competition'.

Private actions for damages for an infringement of competition law can be either follow-on or stand-alone actions. Follow-on actions are lawsuits which are brought in wake of a public investigation. In several jurisdictions of the EU Member States, a probative value of national AA decisions exists for subsequent actions for damages, i.e. claimants do not have to prove the illegal conduct. Furthermore, the EU has adopted a rebuttable presumption that cartel infringements cause harm.[9] Stand-alone private actions for damages are initiated independently and are more complex and difficult to litigate for the claimants because of the lack of an existing evidence for the illegal conduct. As a result, a relatively high proportion of private antitrust enforcement actions in the EU are follow-on claims (Renda et al., 2007, p.40). Because private enforcement in most cases builds upon public enforcement of competition law, a smooth interaction of both is desirable.

The current legal framework in the EU for damages actions in cases of competition law infringements has not proved satisfactory because individuals encounter difficulties in obtaining compensation for their harm. Even though the EU law guarantees the right to compensation, actions for compensation are generally adjudicated by national courts and it is therefore for the domestic legal systems to define rules on the exercise of the right to compensation.To date, most victims of infringement remain uncompensated.

8 The European Court of Justice announced that this right is guaranteed by primary EU law (Case C-453/99, *Courage Ltd. v. Crehan* [2001] ECR I-6297, para.26; joined Cases C-295/04 to C-298/04, *Vincenzo Manfredi and Others v. Lloyd Adriatico Assicurazioni SpA and Others* [2006] ECR I-6619, para.60; Case C-360/09, Case C-360/09, *Pfleiderer AG v. Bundeskartellamt* [2011] ECR I-5161, para.36; Case C-199/11, *Europese Gemeenschap v. Otis NV and Others*). Civil actions for damages are generally adjudicated to national courts of the EU Member States and it is a matter of the national courts to lay down detailed rules. The international jurisdiction of the national court is often determined by Council Regulation (EC) No 44/2001 of 22 December 2000 on jurisdiction and the recognition and enforcement of judgments in civil and commercial matters, OJ L 12, 16.1.2001, p. 1. This Regulation has been recently replaced by Regulation (EU) No 1215/2012 of 12 December 2012 on jurisdiction and the recognition and enforcement of judgments in civil and commercial matters, OJ L 351, 20.12.2012, p. 1, which for the most part will enter into force on 10 January 2015.

9 European Union (2014b, Art.17) provides a rebuttable presumption with regard to the existence of harm in cartel infringements.

Only 25% of antitrust infringements found by the EC in the last seven years have been followed by civil actions. From 2006–2012 only 15 out of 54 final cartel and antitrust prohibition decisions taken by the EC were followed by actions for damages in the Member States. In the same period only 52 actions for damages were brought in seven Member States (European Commission, 2013a, p.1).[10]

Two problems are seen as the main reason for the low rate of private enforcement. First, the diversity of the national rules governing the compensation of competition law infringements creates legal uncertainty for potential victims as well as for potential defendants. Second, victims find it difficult to obtain relevant evidence to proof their harm. Concerning the first shortcoming, a study commissioned by the EC found that legislation and handling of damages actions in the EU are of 'astonishing diversity and total underdevelopment' (Waelbroeck et al., 2004, p.11). Another report carried out for the EC finds that only in 10 EU Member States private antitrust litigation exists but 'seems very sparse and related to isolated streams of cases' (Renda et al., 2007, p.9). Furthermore, the study finds that the conditions for private enforcement of competition law have not improved significantly since 2004. Parallel to the EC's discussions about a reform of the legislation for more effective civil redress, several Member States have experienced an increase in private damages actions. Germany, the UK and the Netherlands have become the favourite forums for antitrust litigation. The reason for this focus is that some features of these jurisdictions are seen as plaintiff-friendly and the EC considers the procedural rules for antitrust damages actions to be more effective than in other countries (European Commission, 2013c, para.52).

Three factors play an important role in determining whether and how victims of competition law infringements are compensated. The first factor is the *existence of a right* for compensation for victims of antitrust violations. In most jurisdictions the victim's right for compensation exists and includes compensation for the harm suffered as well as compensation for the gain of which it has been deprived. If the right for compensation exists, the second important factor is whether certain groups of infringers are *exempted* from damages claims by law. If all cartel members are jointly and severally liable for the damages caused by the cartel, a victim can ask full compensation from any of the cartel members. There can be several exemptions from this rule, such as to partially exempt leniency participants. To privilege revealing firms in relation to victims is seen as problematic in the EU because it

10 Given that there is no centralized register for the private enforcement of EU competition law which involves litigation before 28 national courts, the EC notes that these figures should be considered as a rough indicator.

infringes the primary law principle of effectiveness.[11] A possibility to exclude revealing firms from the full burden of damages claims by law is to privilege them in relation to their non-revealing co-infringers. The final Directive (European Union, 2014b, Art.11) restricts the civil liability of the leniency applicants and of small and medium-sized enterprises to claims by its direct and indirect purchasers or providers unless victims are unable to obtain full compensation from the other infringers. Furthermore, certain groups can be partially exempted from damages payments by restricting the amount of contribution which co-infringers are allowed to recover from them.[12]

The third factor is the possibility of victims to *effectively exercise* their right for compensation. The right can be significantly restricted by high costs and/or high legal uncertainty and procedural difficulties. The second important problem of private enforcement is the access to evidence, which is seen as the key aspect of any civil damages action to prove an infringement and to quantify the harm suffered (Atlee et al., 2013). In general, to assess and proof the harm, the actual position of the injured party has to be compared with a hypothetical position in which the infringement did not occur. The costly analysis of this counterfactual scenario is difficult without crucial pieces of evidence which is often in the hands of the infringers or the AA. Over the past years, a special tension has arisen over the right of victims to gain access to documents provided to the EC on a voluntary basis in effort to seek leniency from fines. Leniency programmes define rules which offer full or partial immunity from fines to firms which commit or committed infringements of the competition rules and cooperate with the AA.[13] These rules were first adopted in the US in 1978 and are now in place in almost all European countries.[14]

Fine reduction and immunity from fines granted in leniency programmes 'have become essential instruments to enforce competition rules at both EU and national level' (European Commission, 2013a, p.3).[15] Private and public enforcement interact if actions for damages have an influence on cartel

11 The ECJ expressed its concerns about restricting the civil liability of leniency participants at the expense of the injured parties in Case C-536/11, *Bundeswettbewerbsbehörde v. Donau Chemie AG and Others*, para.47.

12 European Union (2014b, Art.11(5)) restricts the amount of contribution of an immunity recipient to the amount of the harm it caused to its direct and indirect purchasers or providers.

13 In the UK, the leniency programme also protects employees from personal sanctions. If an employee agrees on activities that infringe the competition rules, he commits a criminal offence.

14 In the EU, the leniency programme rules are defined in European Union (2006).

15 From 2008 to 2011, 21 out of 24 EC cartel decisions and from 2010 to 2011, 31 out of 51 national competition authorities cartel decisions were based on leniency applications (European Commission, 2013c, p.20).

deterrence and detection. The EC is concerned that the disclosure of leniency documents will undermine the procedure's effectiveness and attractiveness. Leniency applicants could be more cautious in their submissions and statements to reduce the risk that these statements are used against them in follow-on civil actions. These undertakings may have an increased exposure to damages in follow-on claims and may therefore be disadvantaged over companies that did not cooperate with the AA. The uncertainty about the exposure of damages claims could deter the company from revealing, faced with the disclosure of the information it provides to third parties. Furthermore, the EC fears that the disclosure may undermine the decision making process, hinder public enforcement proceedings and could reveal the competition authority's investigation strategy (European Commission, 2013e, para.4.2).

A crucial point in overcoming the obstacle of proving the harm is the provision of relevant information. Of particular interest for this study is the decision of the AA concerning the disclosure of internal documents in general and the leniency statements in particular.[16] Depending on the type of information which the AA discloses, the focus of follow-on damages claims can be either on the revealing or on the non-revealing firms.

In the recent past the EC has systematically denied access to case files asserting that leniency statements should not be used against the leniency applicants in private actions for damages. On the one hand, the Leniency Notice of the EC guarantees that leniency statements will not be disclosed by the EC to complainants or other third parties without consent (European Union, 2006, para.33). On the other hand, the Leniency Notice clearly states that participating in a leniency programme cannot protect an undertaking from civil law consequences (European Union, 2006, para.39). This contradiction is further complicated by Regulation 1049/2001 of the European Parliament and the Council regarding public access to European Parliament, Council and Commission documents. According to this regulation, claimants seeking redress for infringement of competition law are able to address an information request to the EC in order to obtain evidence directly from the regulators' files.

16 In the final Directive (European Union, 2014b, Art.6), the EC's proposal to generally exclude leniency and settlement documents from disclosure has been adopted.

1.2.2 *Recent EU and Member States Court Cases on Access to Information in Follow-on Damages Actions*

A broad discussion about the access to information in follow-on damages actions emerged after the June 2011 *Pfleiderer* ruling of the ECJ.[17] In 2008, the German Federal Cartel Office imposed fines on manufacturers of decor paper for price fixings and capacity agreements. Pfleiderer, a customer of these companies, requested full access to the cartel files in order to bring an action for damages. The Federal Cartel Office refused the request whereupon Pfleiderer brought an action against the refusal before the Local Court in Bonn. The Local Court referred the question whether access to leniency documents should be provided to the ECJ. The ECJ ruled that in absence of any binding EU regulation on this special issue the national courts have to decide on the basis of national law whether access to leniency documents should be granted, thereby balancing the interests on a case by case basis. The ECJ emphasized that the right to claim damages for infringement of competition law discourages illegal conduct and therefore fosters effective competition. Nevertheless, the ECJ feared that the integrity of the public enforcement process could be jeopardized if leniency applicants are at risk of damages claims on the basis of voluntarily submitted documents. The Local Court denied the access to leniency documents because in their opinion the latter effect outweighed the former effect.

In the *Donau Chemie* ruling[18], the ECJ held that European Union Law, in particular the principle of effectiveness, precludes a provision of national law that deprives third parties of all rights to access a cartel file. Prior to this case the Bundeswettbewerbsbehörde (Austrian Federal Competition Authority) ordered Donau Chemie and Others in a final judgment to pay a fine due to cartel agreements. Thereupon, the Verband Druck- und Medientechnik (VDMT, Austrian Union of Print and Media Technology) was seeking access to the file relating to the proceedings between the Bundeswettbewerbsbehörde and Donau Chemie and Others in order to assess the nature and amount of potential loss suffered by the VDTM members. Austrian Law provides that defendants have to consent the access to the file, which Donau Chemie and Others did not. The ECJ took issue with this national rule. Even though it is for the Member States to establish and apply the national rules in the absence of binding EU competition law rules, Austrian law was found to effectively bar claimants from their EU right to seek compensation for cartel harm.

---

17 Case C-360/09, *Pfleiderer AG v. Bundeskartellamt* [2011] ECR I-5161.
18 Case C-536/11, *Bundeswettbewerbsbehörde v. Donau Chemie AG and Others* [2013].

Following the ECJ decisions, the EU Member States have weighted the effective application of Articles 101 and 102 TFEU and the right to claim damages for loss caused differently. This legislative divergence is given by different national rules on the access to evidence and also by the lack of adequate rules in some Member States. The ECJ's decision to weight the interests on a case by case basis and the diversity of national rules has led to inequalities and uncertainty concerning the conditions for possible claimants to exercise their right to compensation as well as for possible defendants to be held liable for infringement of competition law.

The German Courts refused access to leniency documents. In the judgment of the *Pfleiderer* case, access was refused because the purpose of the inquiry appeared to be put at risk. In *Roasted Coffee*, the Higher Regional Court in Düsseldorf rejected the disclosure of leniency documents holding that the confidential treatment of the leniency applications outweighs the information interest of the claimants.[19]

The UK courts, however, ruled differently. In *National Grid* the claimant considered to bring a follow-on damages claim against the participants of the *Gas Insulated Switchgear* cartel[20] in which ABB was granted immunity from fines by the EC. National Grid applied for the disclosure of information at the English High Court[21] which included information provided by ABB to the EC on a voluntary basis to seek immunity from fines. Following this request the English High Court invited the EC to submit observations on several questions. The EC answered that the principles of the ECJ ruling in *Pfleiderer* cover leniency programmes of both the national AAs and the EC and that the issue of access therefore has to be decided by national rules. Hereupon the English High Court decided that a number of passages from the confidential version of the EC's decision and limited passages of other documents should be disclosed.

In the recent *EnBW* case[22] the ECJ decided that the EC may reject the request by a plaintiff in a national follow-on proceeding for documents produced in an EU cartel case.[23] In line with its recent decisions in *Bitumen*[24]

19 In 2009 the Bundeskartellamt fined several coffee roasters for price fixing (Case B11-18/08) after a leniency application has sparked off the investigation. In 2011 several customers of the fined coffee roasters asked for access to the case files. Decision of the Higher Regional Court in Düsseldorf: OLG Düsseldorf, BB 2012, 2459-2462.

20 Case COMP/F/38.899, Gas Insulated Switchgear C(2006) 6762 final.

21 *National Grid Electricity Transmission Plc v. ABB Ltd & Ors* [2012] EWHC 869 (Ch).

22 EnBW claimed that it is a victim of the Gas Insulated Switchgear Cartel and sought access to the case documents in 2007. The EC rejected the request and EnBW appealed the decision before the General Court which set aside the EC's refusal. The EC in turn appealed.

23 Case C-365/12 P, *European Commission v. EnBW Energie Baden-Württemberg AG* [2014].

24 Case T-380/08, *Kingdom of the Netherlands v. European Commission* [2013].

and *CDC*[25] the court ruled that the EC cannot presume that these documents fall under the exemption of the Transparency Regulation but has to analyse each document. Overall, these cases demonstrate the legal uncertainty of potential claimants and defendants and how differently has been decided on the access to documents over time and in different EU Member States.

1.3 THE MODEL

The model uses the framework developed by Motta and Polo (2003), who analyse the effect of a leniency programme on cartel participation and detection. Additionally, my model allows for private enforcement of competition law. Firms which are found guilty by the AA have to compensate the victims of the cartel.[26] I introduce two parameters which measure the exposure to damages claims for revealing and for non-revealing firms. This allows me to compare private enforcement regimes which differ in the wrongdoers' exposure to follow-on damages claims.[27]

Everything described below is common knowledge to all agents. I analyse an economy with several symmetric industries. Each industry comprises a group of firms and each firm can either collude or compete in its industry. For tractability reasons I assume that firms are symmetric. Firms take into account the enforcement activity of the AA, which will review one industry at a time. The AA can prove collusion with some probability, in this case firms pay a fine to the AA. A leniency programme exists, offering reduced fines for leniency firms. If firms are found guilty, they also have to pay damages which depend on the duration of the cartel and on the private enforcement regime.

25 Case T-437/08, *CDC Hydrogene Peroxide Cartel Damage Claims v European Commission* [2011].

26 The claim for damages is only one out of several remedies. Especially in cases of infringements in which the AA has not (yet) delivered a judgment, an injunctive relief may be cheaper to enforce for the victim than damages claims. Furthermore, consensual dispute resolution mechanisms of competition litigation such as out-of-courts-settlements, arbitration and mediation are options to avoid costly law suits. Declaration of nullity of contractual provisions is another possibility of private enforcement. With more settlements as well as with more actions for damages, the infringer's expected cost of collusion increases. The disclosure of information in settlement cases may raise similar problems with follow-on damages claims as the disclosure of leniency documents. The acknowledgement of the participation in a cartel and the cooperation with the AA in exchange for a simplified procedure and a reduction in fine may bring the settling parties in a weaker position in follow-on damages claims if the settlement documents are available for the claimants.

27 The effective exposure of convicted firms to damages payments depends on the existence of a right for compensation and the victims' possibilities to effectively exercise this right, which again heavily depends on access to leniency statements (see Section 1.2.1).

1.3.1 *Exposure to Damages*

A firms has to pay damages if it is found guilty either by cooperating with the AA (applying for leniency) or by being proved guilty without cooperation. A firms has to pay damages if it is found guilty either by cooperating with the AA (applying for leniency) or by being proved guilty without cooperation. Let D be the amount of damages that each firm would have to pay for one period of collusion without any restrictions. The factor $\beta_{LP} \in [0, 1]$ describes the effective exposure to damages D for leniency firms and the factor $\beta_{NLP} \in [0, 1]$ describes the effective exposure to non-revealing firms. In case there is no right for compensation or it is practically impossible to obtain compensation, $\beta_{LP} = \beta_{NLP} = 0$. In case of full exposure to damages claims, $\beta_{LP} = \beta_{NLP} = 1$. In this case a right for compensation exists and victims are able to exercise this right. Neither firms which cooperate with the AA nor firms which do not cooperate fall under an exemption and therefore each infringer has to pay full damages D. If a right for compensation exists and the focus of damages claims is on the non-revealing firms, $\beta_{LP} < \beta_{NLP}$.[28] On the other hand, if a right for compensation exists and the focus of damages claims is on the leniency firms, $\beta_{LP} > \beta_{NLP}$.[29] Even if all cartel participants are legally liable for damages, procedural issues may shift the focus on the leniency participants.[30]

28 A partial or total exclusion of immunity recipients can emerge due to a legal exclusion from damages claims. It may also result because of the information provision by the AA: If the AA denies claimants access to leniency files (which contain collected relevant evidence), it may be excessively difficult for the claimants to prove the harm caused by these firms. Claimants then focus their actions for damages on the firms which did not participate in a leniency programme. The shift of the focus of damages claims is possible because under a system of joint and several liability the victims of an infringement are able to recover their full damages from any of the infringers regardless of the individual share of the liability.

29 Even though $\beta_{LP} > \beta_{NLP}$ is possible, I assume the following restriction on the differences between damages payments: $\beta_{LP}D - \beta_{NLP}D < \delta V_{CR} - \delta\frac{\pi_N}{1-\delta} + F(1-r)$. The difference between the damages payments in case of participating in the leniency programme and not revealing is assumed to be lower than the difference between the value of the strategy CR minus the reduced fine and the value of the collusion profit minus the fine.

30 If for example the AA discloses all documents relating to the cartel investigation including the leniency statements, the risk of damages claims for the leniency participants is higher compared to the non-revealing cartel participants. The voluntarily submitted, detailed documents (including an admission to unlawful practices) provide a useful source of relevant evidence for claimants and put the leniency participants in a weak position in follow-on damages claims. Furthermore, through the cooperation with the AA the court's decision becomes final earlier for the revealing firms than for the non-revealing firms as the latter may appeal the decision.

1.3.2 *Public Enforcement*

The AA is able to commit to a set of policy parameters: The probability that it will review an industry, the probability to prove a cartel guilty and full and reduced fines. With probability $\alpha \in [0, 1]$ the AA reviews the firms in an industry. With probability $p \in [0, 1]$ the AA can prove collusion if firms do not reveal. The full fine F has to be paid by each firm which does not cooperate with the AA and is proved guilty. The reduced fine rF with $r \in [0, 1]$ is part of the leniency programme and has to be paid by each leniency firm.

The timing of the AA's actions is as follows. The AA observes the economy in period t. If there is no collusion, the AA does not review any industry.[31] If the AA observes collusion it reviews one industry of the economy in the following period $t + 1$; each industry gets reviewed with probability α. The firms are able to react to the review of the AA in this period. If firms make use of the leniency programme and reveal the cartel to the AA, the review stops and the colluding firms are found guilty. In this case the AA starts to observe the economy again in the following period. If no firm reveals the cartel to the AA, the AA tries to prove the cartel in the following period $t + 2$. The AA is successful with probability p and is not able to prove the cartel with probability $1 - p$. In both cases, the AA observes the economy again in the following period. If the AA proves the firms guilty either by the firms' confession or on its own, it is able to restore competition in this period.

1.3.3 *Firms' Strategies*

Firms play an infinitely repeated game. Their strategy consists of a market action and the revelation action. Firms decide whether they want to collude or to compete (market action) and whether they reveal their cartel once reviewed by the AA (revelation action).

For these decisions firms take into account the policy parameters set by the AA which are constant over the game. Furthermore, firms take into account the private enforcement parameters that define the exposure to damages payments if they collude and are found guilty. In case of several equilibrium strategies, firms coordinate on the Pareto-dominant strategy. Firms in this game play grim trigger strategies.[32] A firm's deviation from the market action as well as a deviation from the revelation action is regarded as a deviation from the strategy and is punished by the other firms by never colluding again.

31 I assume that there are no type I judicial errors.
32 See Friedman (1971) for grim trigger strategies.

I define three strategies: One non-collusive strategy (NC) and two collusive strategies—collude and reveal (CR) and collude and not reveal (CNR).[33] In strategy NC, firms never collude. Playing the strategy CR, firms collude from period t on as long as no deviation occurs. Each firm's profit from colluding is π_M in this period. If the AA does not review the industry in the following period $t+1$, a firm's profit from colluding is again π_M. If instead the AA reviews the industry, firms cooperate with the AA and the AA imposes the reduced fine rF on the firms. In this period $t+1$, a firm's profit is that of a competitive industry, $\pi_N < \pi_M$. Additionally, each firm has to pay damages $\beta_{LP}D$, with β_{LP} defining the exposure to damages D. If neither a deviation from the market action nor a deviation from the revelation action occurred, firms continue to play CR in the following period $t+2$.

Playing the strategy CNR, firms collude from period t on as long as no deviation occurs. Each firm's profit is π_M in this period. In period $t+1$ firms continue to collude and each firm's profit is π_M, independent of whether the AA reviews the industry or not. In period $t+2$ the AA tries to prove the cartel. If the AA proves the firms guilty, the AA imposes a fine F on the colluding firms. Each firm has to pay damages payments $\beta_{NLP}2D$, with β_{NLP} defining the exposure to damages. The damages payments are doubled because firms collude for two periods. If the AA proves the firms guilty, each firm's profit is π_N in period $t+2$. If the AA cannot prove the firms guilty in $t+2$, each firm's profit in this period is π_M. As long as no deviation from the market action and the revelation action occurred, firms continue playing CNR in period $t+3$.

Whenever a deviation from the strategy occurs, firms will never cooperate again and will behave competitively from the next period onwards. By deviating from collusion, a firm obtains a payoff $\pi_D > \pi_M$ in the deviation period but in all following periods each firm receives only π_N.

33 Motta and Polo (2003) also define the strategies NC, CR and CNR. In my model, firms playing the strategies CR and CNR are not only exposed to fines by the AA but also to private damages payments, which vary depending on the revelation action. Additionally, I modify the timing and firms' profits in order to analyse the effect of private actions for damages on firms' incentives. The timing of the game in my model is different to the timing in Motta and Polo (2003) in order to allow for periods of collusive profits in case of a cartel. In the model by Motta and Polo (2003), firms which collude and reveal never obtain the high profits from collusion if the AA reviews their industry, because firms reveal in the single collusion period if reviewed and therefore obtain competitive profits in this period. It seems unreasonable to me that customers of the cartel are harmed by the cartel even though the cartelists only agreed upon colluding but in no period actually colluded (or obtained collusive profits). The timing of the game in my model is so that firms which agree on the strategy CR at least collude in one period and thereby harm consumers. See Section 1.3.4 for details on the timing of the game.

1.3.4 *Timing of the Game*

The timing of the game is as follows (see Figure 1.1). First, the AA sets its policy parameters and firms observe these parameters as well as the private enforcement parameters. In period t firms choose their strategy and decide whether or not they deviate from the market action. The AA observes the economy. If firms collude, the AA reviews each industry with probability α in period $t+1$. It at least one firm makes use of the leniency programme and reveals the cartel, the AA forces all firms of the leniency applicant's industry to compete in this period. The cartel is found guilty and the revealing firm(s) has (have) to pay the reduced fine rF to the AA and the damages payments $\beta_{LP}D$ to the claimants. The game restarts at period t.

If no firm reveals the cartel in period $t+1$, the AA continues its work in the reviewed industry and tries to prove the cartel in period $t+2$. With probability p the AA is successful, in this case each firm of the industry is found guilty and has to pay the fine F to the AA and the damages payments $\beta_{NLP}2D$ to the claimants. The AA forces these firms firms to compete in period $t+2$. With probability $1-p$ the AA fails to prove the cartel. In this case firms obtain collusive profits in period $t+2$. The game restarts at period t.[34]

Remember that all firms and all industries are symmetric. The Pareto-dominating equilibrium strategy is the same for each firm given the policy and enforcement parameters. In equilibrium no firm has an incentive to deviate from the agreed strategy. Therefore the duration of the game depends on the equilibrium strategy. If firms choose the strategy CR, the game restarts after period $t+1$ whereas its restarts after period $t+2$ if firms choose the strategy CNR. Note that the AA reviews one industry each time in case there is collusion. In case one colluding industry is not reviewed, another industry is reviewed. In case the AA started a review and no firm reveals, it takes the AA another period to try proving the cartel before the game

34 In my model, firms decide whether or not to reveal information to the AA after the AA has reviewed the industry of the firm. According to EU rules, it is not possible to gain immunity or reductions from fines after the EC has submitted its statement of objections to the alleged firms (European Union, 2006, para. 14 and para. 29). A statement of objections is a formal step in the antitrust investigation and is not issued unless the EC believes that it can make out the case and justify a prohibition. Hence, the statement of objections is a product of considerable earlier investigative work. According the EU law, an application for leniency is not possible after the EC has send out its statement of objection. In my model, the 'review' should therefore not be interpreted as the issue of a statement of objection. If the AA reviews an industry this should rather be interpreted as an event that makes it more likely that the AA has concerns about that industry. For example, this event can be an investigation in an industry close by the relevant industry or the involvement of one cartel participant in another illegal conduct. See also Miller (2009, fn 11).

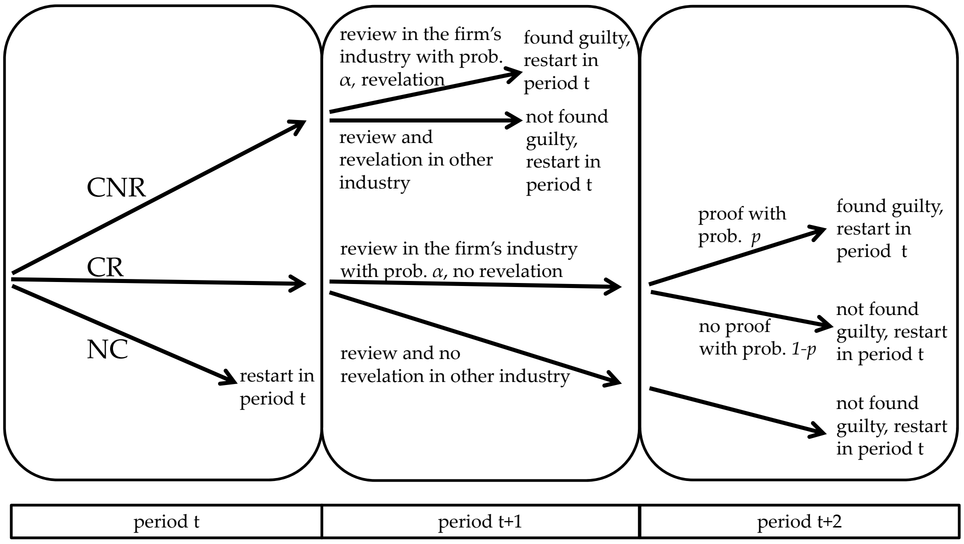

Figure 1.1: Timing of the game

restarts.[35] If there was no deviation from the agreed strategy, firms start colluding in the period following the proof by self-reporting or by the AA. If a deviation occurred, firms behave competitively forever from the following period onwards.

1.3.5 *Equilibria of the Game*

Whereas in the NC equilibrium a cartel never occurs, in the CR and the CNR equilibria firms agree to collude. Two conditions need to hold for CNR and CR to be equilibria: First, firms choose their agreed market action and collude. Second, firms choose their agreed revelation action if the AA starts to review their industry. The applied equilibrium concept is subgame perfection. In case of two subgame perfect equilibria (SPE), firms choose the strategy that maximizes their profit.

In the NC equilibrium a deviation to collusion is not profitable because each firm's payoff from no collusion is higher than the expected payoff from collusion. From period t on, there is full cartel deterrence. In the CR equilibrium a firm's profit is highest if it colludes and reveals once the AA starts a review whereas in the CNR equilibrium it is more profitable for a colluding firm not to reveal once the AA reviews the industry.

35 If firms choose the strategy CNR and an industry is not reviewed in period $t+1$, this industry may be reviewed at earliest in period $t+3$.

Collude and Reveal (CR)

The strategy CR is an SPE if each firm does not have an incentive to deviate from the strategy. Neither a deviation in period t from the market action to *no collusion* nor a deviation after being reviewed in period $t+1$ from the revelation action to *not reveal* must be profitable. The value of the CR strategy for a firm is

$$V_{CR} = \pi_M + \delta\left[\alpha(\pi_N - rF - \beta_{LP}D) + (1-\alpha)\pi_M\right] + \delta^2 V_{CR} \tag{1}$$

which can be rewritten to

$$V_{CR} = \frac{\pi_M - \delta\left[\alpha(rF + \beta_{LP}D + \pi_M - \pi_N) - \pi_M\right]}{1-\delta^2}\ . \tag{2}$$

The value of the strategy CR consist of the collusive profit in period t plus the expected profit from period $t+1$ discounted by the factor $\delta \in (0,1)$. In period $t+2$ the value of the strategy CR has to be added to the expected profit of periods t and $t+1$, because in period $t+2$ the firm continues to play CR.[36]

A firm does not have an incentive to deviate after a review took place in period $t+1$ from its revelation action *reveal* to *not reveal* because not revealing if all other firms reveal increases the fine from rF to F and leads to competitive payoffs forever on.[37] Deviating in period t from the market action of *collusion* to *no collusion* can be profitable because firms obtain a high deviation profit and do not expose themselves to fines and damages payments if they behave competitively. A firm's value of a deviation from CR to NC is

$$V_D = \pi_D + \delta\frac{\pi_N}{1-\delta}\ . \tag{3}$$

The strategy CR is an SPE if $V_{CR} > V_D$, or, expressed in terms of α, if

$$\alpha < \alpha_{CR} = \frac{(1-\delta)(\pi_M - \delta\pi_N - (1-\delta)\pi_D)}{\delta(\pi_M - \pi_N + rF + \beta_{LP}D)}\ . \tag{4}$$

Lemma 1.1. *For given policy parameters* (F, r, α) *and the private enforcement parameter* (β_{LP})*, the strategy CR is an SPE if* $\alpha < \alpha_{CR}$.

36 If the strategy CR is profitable in period t it is also profitable in period $t+2$. In period $t+2$ the game restarts if CR is the dominant equilibrium strategy.

37 See [29] for the assumption on differences in damages payments in order to exclude the case that a deviation pays off just because the damages payments in case of revealing are much higher than the damages payments from not revealing.

Lemma 1.1 follows from the inequality $V_{CR} > V_D$ and shows that if the review probability is below α_{CR} it is profitable for firms to choose CR, whereas a deviation from collusion is profitable if $\alpha > \alpha_{CR}$. Intuitively, it is profitable for firms to collude and reveal once reviewed if the probability of a review is low because firms obtain a high profit from collusion but the probability of having to pay the reduced fine is low. The threshold α_{CR} is independent of the proof probability p because firms always reveal before the AA tries to prove the cartel when playing the strategy CR. A CR-SPE exists if $\alpha_{CR} > 0$, or $\delta > \frac{\pi_D - \pi_M}{\pi_D - \pi_N}$. To focus on the interesting case in which CR can be an equilibrium strategy, I assume $\alpha_{CR} > 0$. An increase in the costs in case of a proof of the collusive behaviour (r, F, β_{LP}, D) as well as an increase of the alternative profits (π_D, π_N) decrease the threshold α_{CR}. CR becomes an equilibrium strategy for higher review probabilities if π_M increases.

Collude and Not Reveal (CNR)

The strategy CNR is an SPE if neither a deviation in period t from the market action of *collusion* to *no collusion* nor a deviation in period $t+1$ from the revelation action of *not reveal* to *reveal* is profitable. The value of the strategy CNR is

$$\begin{aligned} V_{CNR} = &\pi_M + \delta\pi_M + \delta^2\alpha\left[p(\pi_N - F - \beta_{NLP}2D) + (1-p)\pi_M\right] \\ &+ \delta^2(1-\alpha)\pi_M + \delta^3 V_{CNR} \end{aligned} \tag{5}$$

which can be rewritten to

$$V_{CNR} = \frac{\pi_M(1+\delta) + \delta^2\left[\pi_M - p\alpha(\pi_M - \pi_N + F + \beta_{NLP}2D)\right]}{1-\delta^3} . \tag{6}$$

If all firms play CNR, each firm obtains the collusive profit in period t and $t+1$ because no firm reveals. In case the AA reviews the industry of a firm, this firm's expected profit in period $t+2$ depends on whether or not the AA proves the cartel guilty. In case the AA reviews another industry, the firm continues to obtain the collusive profit in period $t+2$. In period $t+3$ the game restarts.[38]

Two constraints must be satisfied for a CNR-SPE. First, a deviation in period t from the market action *collude* to *not collude* is never profitable. Second, a deviation after being reviewed in period $t+1$ from the revelation

38 If the strategy CNR is a dominant SPE, firms collude and the AA reviews one industry for sure. If CNR is a dominant SPE, firms do not reveal and the AA tries to prove the cartel in period $t+2$. The game then restarts in period $t+3$, different to the case if CR is a dominant SPE, in which case the game stops with the revelation of the cartel in $t+1$ and restarts in period $t+2$.

action *not reveal* to *reveal* is never profitable. In the following I will derive the conditions for both constraints.

Collude and not reveal is preferred over deviating in period t to *no collusion* if $V_{CNR} > V_D$, or, expressed in terms of α, if

$$\alpha < \alpha_{NC} = \frac{(1+\delta+\delta^2)(\pi_M - (1-\delta)\pi_D - \delta\pi_N)}{\delta^2 p(\pi_M - \pi_N + F + \beta_{NLP}2D)} \ . \tag{7}$$

The threshold α_{NC} is a downward sloping curve in the $(\alpha - p)$-space as shown in the example of Figure 1.2. If either the proof probability p or the review probability α or both are low, it is more profitable to collude and not reveal than to behave competitively in period t. If the review probability is high (or even 100%) it may still be profitable to collude and not reveal if it is very unlikely that the AA is able to proof the illegal behaviour (p low). The same holds true for high values of the proof probability. Even though the AA proves the cartel with a high probability, the strategy CNR may still yield a higher payoff than deviating from collusion if the probability of a review (which initiates the prosecution) is low. If the costs in case of proof of the cartel (F, β_{NLP}, D) increase or if the competitive profit increases, the threshold α_{NC} decreases. If the profit from collusion increases, it is profitable for higher α and p to choose the strategy CNR.

For the second constraint to hold, a firm must prefer not to reveal after the AA has started to review the industry in period $t+1$. The value of deviating from the revelation action *not reveal* to *reveal* once the AA has reviewed the industry is given by

$$V_R|review = \frac{\pi_N}{1-\delta} - rF - \beta_{LP}D \ . \tag{8}$$

The value of playing the action *not reveal* once reviewed is given by

$$V_{NR}|review = \pi_M + \delta\left[p(\pi_N - F - \beta_{NLP}2D) + (1-p)\pi_M\right] + \delta^2 V_{CNR} \ . \tag{9}$$

If firms do not reveal the cartel, each firm continues to have the collusive profit in period $t+1$. The expected profit of the following period $t+2$ depends on whether or not the AA proves the cartel guilty. In period $t+3$ firms continue to play CNR. Equation (9) can be rewritten to

$$\begin{aligned} V_{NR}|review =& \pi_M + \delta\left[p(\pi_N - F - \beta_{NLP}2D) + (1-p)\pi_M\right] + \frac{\delta^2}{1-\delta^3} \\ & \left[\pi_M(1+\delta) + \delta^2\left[\pi_M - p\alpha(\pi_M - \pi_N + F + \beta_{NLP}2D)\right]\right] \ . \end{aligned} \tag{10}$$

Not revealing after the AA reviews the industry is optimal if $V_{NR}|review > V_R|review$ or

$$\alpha < \alpha_R = \frac{(1+\delta+\delta^2)\left[\pi_M - \pi_N + (1-\delta)(rF + \beta_{LP}D) - \delta p(1-\delta)(\pi_M - \pi_N + F + \beta_{NLP}2D)\right]}{\delta^4 p(\pi_M - \pi_N + F + \beta_{NLP}2D)}\,. \tag{11}$$

The threshold α_R is downward sloping in the $(\alpha - p)$-space as shown in the example of Figure 1.2. If $\alpha < \alpha_R$, it is not profitable to reveal the cartel once the AA has started to review the industry. If either the proof probability p or the review probability α or both are low, not revealing the cartel is more profitable than a deviation to revealing. If the costs in case of proof of the cartel (r, F, β_{NLP}, D) increase or the competitive profit increases, the threshold α_R decreases.

Both constraints ($\alpha < \alpha_{NC}$ and $\alpha < \alpha_R$) have to be satisfied for CNR to be an SPE. A firm will only choose the strategy CNR if the review probability α is lower than the review probability that makes the firm indifferent between colluding and deviating in period t and between revealing and not revealing once it is under review in period $t+1$. The following Lemma summarizes the results from Equations (7) and (11):

Lemma 1.2. *For given policy parameters* (F, r, p, α) *and enforcement parameters* $(\beta_{LP}, \beta_{NLP})$*, the strategy CNR is an SPE if* $\alpha < \min\{\alpha_{NC}, \alpha_R\}$*.*

Figure 1.2 shows a possible example of the position of the downward-sloping functions α_R and α_{NC}. α_R and α_{NC} intersect at most once in $p \in [0, 1]$. Let p_B define the intersection of α_R and α_{NC}. For high α (or low p), α_{NC} is always to the left of α_R. Intuitively, if $\alpha = 1$, firms know for sure in period t already that they will get reviewed in period $t+1$. For CNR to be an SPE, α_{NC} has to bind. The incentive constraint to choose *not revealing* after a review in period $t+1$ cannot be stricter than α_{NC} because firms knew already in period t that they will be reviewed for sure.

The constraint to reveal once under review can only be binding if α_R and α_{NC} intersect in $p \in [0, 1]$, which is the case if $p_B < 1$ or $r < r_B$.[39] If the reduction in the fine is too little ($r > r_B$), α_R is never binding and once a firm decided for CNR in period t, a deviation to *reveal* in period $t+1$ is never profitable.

39 See Appendix for the derivation of r_B.

CNR and CR: Dominant Subgame Perfect Equilibria

Lemmata 1.1 and 1.2 define the conditions for a CR-SPE and a CNR-SPE. Figure 1.2 shows an example of the SPE, depending on α and p. For all (α, p)-combinations in the white area, NC is the equilibrium. For all (α, p)-combinations in the dotted area, CR is an SPE. The grey area shows all (α, p)-combinations for which CNR is an SPE. The grey and the dotted area overlap so that for some α, p both CNR and CR are SPE. In this case firms are assumed to choose the revelation action that maximizes their profit. The strategy CNR dominates the strategy CR if $V_{CNR} > V_{CR}$ or

$$p < p_{CNR} = \frac{(1+\delta+\delta^2)(\pi_M - \pi_N + rF + \beta_{LP}D)}{\delta(1+\delta)(\pi_M - \pi_N + F + \beta_{NLP}2D)} \ . \tag{12}$$

Lemma 1.3. *If both strategies CR and CNR are subgame perfect equilibria, CNR dominates CR if* $p < p_{CNR}$.

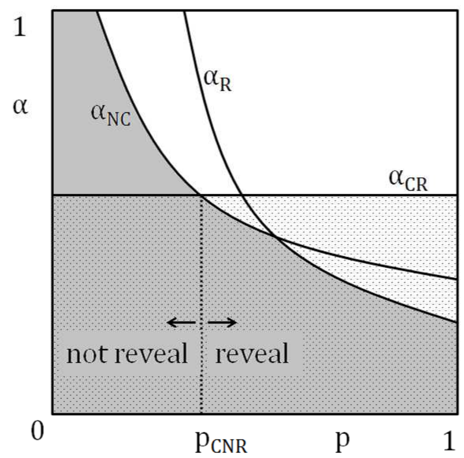

Figure 1.2: CR and CNR equilibria

Not revealing is more profitable than revealing if the probability of proof is low. p_{CNR} is the cut-off value of the proof probability p at which not revealing is equally profitable as revealing once reviewed. Figure 1.2 shows the intersection of the horizontal line α_{CR} (below which CR is an SPE) with the downward sloping curve α_{NC} (below which CNR is preferred to deviating from collusion) at p_{CNR}. The following proposition summarizes the dominant SPE of the game. Figure 1.A1 in the Appendix shows examples of SPE, depending on the position of the threshold-curves.

Proposition 1.1. *Given the policy parameters* (F, r, α, p) *and the enforcement parameters* $(\beta_{LP}, \beta_{NLP})$*, the dominant SPE in the repeated game are defined as follows in the* $(\alpha - p)$*-space.*

(i) The strategy not collude (NC) is the unique equilibrium strategy for $\alpha > \min\{\alpha_{NC}, \alpha_R\} \wedge \alpha > \alpha_{CR}$.

(ii) The strategy collude and reveal (CR) is the dominant SPE for $\alpha > \min\{\alpha_{NC}, \alpha_R\} \wedge \alpha < \alpha_{CR}$ *and for* $\alpha < \min\{\alpha_{NC}, \alpha_R\} \wedge p \in [p_{CNR}, 1]$.

(iii) The strategy collude and not reveal (CNR) is the dominant SPE for $\alpha < \min\{\alpha_{NC}, \alpha_R\} \wedge p \in [0, p_{CNR}]$.

Proof. Follows from Lemmata 1.1, 1.2 and 1.3. □

Leniency programmes can have an anti-competitive and a pro-competitive effect as shown by Motta and Polo (2003). CR can be an equilibrium for values of α and p at which firms would not collude absent a leniency programme (dotted white area in Figure 1.2). In these cases collusion would not be profitable without the possibility to reveal and to receive a reduction in fines. Only the reduction in fine makes it profitable to collude and to reveal the cartel once reviewed by the AA. On the other hand, a leniency programme can have a pro-competitive effect. If $p > p_{CNR}$, the leniency programme induces firms to choose CR instead of CNR for some values of α, p and thereby increases cartel detection (dotted grey area to the right of p_{CNR}).

1.4 THE IMPACT OF THE PRIVATE ENFORCEMENT REGIME ON DETERRENCE AND DISCLOSURE

Depending on the private enforcement regime, firms in my model can be more or less exposed to damages payments.[40] The exposure to damages influences the values of the strategies CR and CNR and the threshold values α_{CR}, α_R, α_{NC} and p_{CNR} which determine the equilibria. The following Lemmata 1.4 to 1.7 summarize the results of the comparative statics analysis of changes in the private enforcement parameters β_{NLP} and β_{LP}. The intuition of the results is given in Sections 1.4.1 and 1.4.2.

Lemma 1.4 (α_{CR})**.** *An increase in the exposure to damages for revealing firms* β_{LP} *decreases the threshold* α_{CR}*, below which CR is more profitable than a deviation to not collude.*

40 See [28] on partial exclusions from damages payments by law and effectively and [30] on the relationship between the exposure to damages and the disclosure of leniency statements.

Lemma 1.5 (α_{NC})**.** *An increase in the exposure to damages for non-revealing firms* β_{NLP} *decreases the threshold* α_{NC}*, below which CNR is more profitable than a deviation to not collude in period* t*.*

Lemma 1.6 (α_R)**.** *An increase in the exposure to damages for non-revealing firms* β_{NLP} *decreases the threshold* α_R*, below which CR is more profitable than a deviation to reveal in period* $t+1$*. An increase in the exposure to damages for revealing firms* β_{LP} *increases the threshold* α_{CR}*.*

Lemma 1.7 (p_{CNR})**.** *An increase in the exposure to damages for non-revealing firms* β_{NLP} *decreases the threshold* p_{CNR}*, below which CNR Pareto-dominates CR. An increase in the exposure to damages for revealing firms* β_{LP} *increases the threshold* p_{CNR}*.*

Proof. $\frac{\partial \alpha_{CR}}{\partial \beta_{LP}} < 0$, $\frac{\partial \alpha_{NC}}{\partial \beta_{NLP}} < 0$, $\frac{\partial \alpha_{R}}{\partial \beta_{NLP}} < 0$, $\frac{\partial \alpha_{R}}{\partial \beta_{LP}} > 0$, $\frac{\partial p_{CNR}}{\partial \beta_{NLP}} < 0$, $\frac{\partial p_{CNR}}{\partial \beta_{LP}} > 0$. □

1.4.1 *Exposure to Damages for Non-revealing Firms*

An increase in the exposure to damages for firms which do not cooperate with the AA has three effects. Figure 1.3 shows on an example the changes on the thresholds which define the equilibria of the game.

First, a ceteris paribus increase in the exposure to damages payments for non-revealing firms (β_{NLP}) decreases the value of the strategy CNR because the expected costs from collusion increase. Below the threshold α_{NC}, the

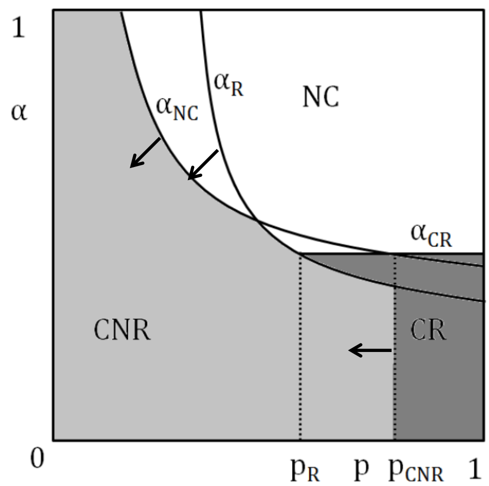

Figure 1.3: Increase in the exposure to damages claims for non-revealing firms

value of the CNR strategy is higher than the profit of a deviating from collusion. If the exposure β_{NLP} increases, the threshold α_{NC} decreases (Lemma

1.5). Second, the increase in the exposure to damages payments for non-revealing firms decreases the value of sticking to the strategy of *not reveal* once the AA has started a review. Revealing once the AA has reviewed the industry becomes more profitable for firms because it prevents the increased exposure to damages claims of non-revealing firms. The threshold α_R decreases (Lemma 1.6). The third effect of a higher exposure to damages claims for non-revealing firms concerns the threshold p_{CNR} above which CR Pareto-dominates CNR if both strategies are SPE. The strategy CR yields a higher profit than the strategy CNR if expected costs of the strategy CNR increase (Lemma 1.7). The following proposition summarizes the effects:

Proposition 1.2. *A ceteris paribus increase in the exposure to damages claims for non-revealing firms decreases the value of the strategy CNR and the value of sticking to the strategy CNR once reviewed by the AA. It follows that:*

(i) The number of policy parameter combinations (α, p) for which NC is an SPE increases.

(ii) The number of policy parameter combinations (α, p) for which a CR-SPE Pareto-dominates a CNR-SPE increases if $r < \bar{r}$.

(iii) The number of policy parameter combinations (α, p) for which CR is an SPE instead of CNR increases if $r < \min\{\bar{r}, \hat{r}\}$.

Proof. See Appendix.

If the exposure to damages for non-revealing firms increases, no collusion can be an SPE for review and proof probabilities at which we had an SPE with collusion before the increase in damages payments. Similar, CR can become a dominant SPE for review and proof probabilities at which the dominant SPE would be CNR without the increase of the damages payments. To summarize, the strategy CNR becomes less profitable compared to NC as well as to CR. An increase in the exposure to damages payments for non-revealing firms decreases collusion and increases the participation in the leniency programme. Encouraging private enforcement of competition law with the effect of higher exposure to damages for non-leniency firms supports the objectives of the public enforcement of competition law by making collusion without revealing less profitable compared to competition and compared to collusion with revealing.

1.4.2 *Exposure to Damages for Revealing Firms*

A ceteris paribus increase in the exposure to damages for revealing firms has three effects on the SPE of the game. Figure 1.4 shows on an example the changes of the thresholds which define the equilibria of the game.

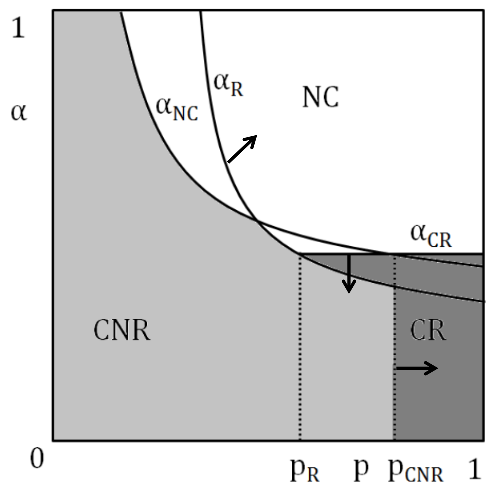

Figure 1.4: Increase in the exposure to damages claims for revealing firms

First, an increase of β_{LP} decreases the value of the strategy CR and makes a deviation from collusion more profitable. The value α_{CR}, which defines a threshold between the CR-SPE and the NC-SPE, decreases (Lemma 1.4).[41] Second, the value of a deviation once reviewed from *not reveal* to *reveal* decreases. The threshold α_R at which firms are indifferent between *not reveal* and *reveal* once reviewed increases (Lemma 1.6). Third, the threshold below which the strategy CNR Pareto-dominates CR increases. The strategy CR yields a lower profit than the strategy CNR if expected costs of the strategy CR increase (Lemma 1.7). Proposition 1.3 summarizes these results:

Proposition 1.3. *A ceteris paribus increase in the exposure to damages claims for revealing firms decreases the value of the strategy CR and the value of a deviation from not revealing to revealing once reviewed by the AA. It follows that:*

(i) The number of policy parameter combinations (α, p) *for which NC is an SPE instead of CR increases if* $r < \min\{\bar{r}, \hat{r}\}$ *(i.e. whenever a dominant CR-SPE exists).*

(ii) The number of policy parameter combinations (α, p) *for which NC is an SPE instead of CNR decreases if* $r < r_B \wedge r < \tilde{r}$ *(i.e. whenever* α_R *binding for a dominant CNR-SPE).*

(iii) The number of policy parameter combinations (α, p) *for which CNR Pareto-dominates CR increases if* $r < \bar{r}$.

41 The pro-collusive effect of the leniency programme can be reduced by the downward shift of α_{CR}. The region of parameters at which CR is an SPE, but NC would be an SPE in the absence of a leniency programme lies below α_{CR} and above $\min\{\alpha_{NC}, \alpha_R\}$.

Proof. See Appendix.

Increasing the exposure to damages claims for leniency firms does not have such clear cut effects on collusion as the increase in the exposure to damages claims for non-revealing firms. On the one hand, NC can become an SPE for review and proof probabilities at which the dominant SPE would be CR without higher damages payments. Higher total cost once a cartel is revealed makes the market action of CR less profitable compared to no collusion. On the other hand, CNR can become an SPE for some for review and proof probabilities at which NC would be the SPE without the increase in damages payments. Deviating from the revelation action *not reveal* once reviewed becomes less profitable and thereby reduces the incentive to deviate from CNR (to no collusion). The total effect on the number of policy parameter combinations (α, p) for which NC is an SPE is therefore not clear cut. There is no deterring effect of an increase in the exposure to damages for revealing firms if no dominant CR-SPE exists (α_{CR} is not binding for a dominant SPE, $r < \min\{\bar{r}, \hat{r}\}$). There is no pro-collusive effect if the revelation constraint α_R is not binding ($r > r_B \wedge r > \tilde{r}$). In all other cases, the total effect on the NC-SPE is ambiguous.

The effect on disclosure is unique: The number of policy parameter combinations (α, p) for which CNR Pareto-dominates CR increases as long as there are (α, p)-combinations for which both CNR and CR are SPE ($p_{CNR} < 1$ or $r < \bar{r}$).

To summarize, encouraging private enforcement of competition law with the effect of higher exposure to damages for firms which applied for leniency on the one hand is at odds with the objectives of the public enforcement of competition law by making revealing less profitable. On the other hand, higher exposure to damages for leniency firms can have a deterring effect on collusion, in this case private enforcement supports the objective of public enforcement of competition law.

1.5 CONCLUSION

In this chapter I show in an economic model how private enforcement of competition law interacts with the public enforcement of competition law. Actions for damages affect the incentives to collude and the incentives to apply for leniency. The exposure to damages payments of a convicted member of a cartel can be defined by law or effectively and can vary between cartel members who applied for immunity and members who did not apply for immunity. The exposure to damages payments affects the firms' incentives to collude and to reveal the cartel by changing the value of collusion and the value of reporting. In particular, an increase of the exposure to damages claims for non-revealing firms decreases the value of the strategy collude and not reveal and it decreases the value of sticking to this strategy after the AA has started an review of the industry. Because the strategy collude and not reveal becomes less profitable, deterrence of cartels as well as disclosure of cartels increase.

An increase of the exposure to damages claims for firms which received immunity from fines affects the incentives differently. Higher expected costs of revealing the cartel decrease the value of the strategy collude and reveal and the value of a deviation from not revealing to revealing once reviewed by the AA. Because the strategy collude and reveal becomes less profitable, firms can get deterred from colluding. But because a deviation from the strategy collude and not reveal, which leads to competition in the industry, becomes less profitable, it can also be the case that more firms collude instead of compete. Whether the first positive effect on deterrence outweighs the negative effect depends on the parameter of the model. If the reduction in fine for revealing is so low that revealing is not profitable for any antitrust policy, there is no effect on deterrence. If the reduction in fine is very generous, there is only the positive effect on deterrence. An increase of the exposure to damages claims for revealing firms clearly decreases the incentives of a cartel to cooperate with the AA.

The results of my model show that the exposure to damages payments and exemptions for leniency applicants have to be considered carefully. Simplifying damages claims against non-revealing firms increases disclosure and has a deterring effect. Private enforcement in this case supports the objectives of the public enforcement to deter and disclose cartels. Simplifying damages claims against revealing firms requires the AA to increase its efforts of review and proof in order to keep the leniency programme attractive, because firms' costs of revealing increase. Private enforcement in this case works against the public enforcement objective of disclosure of cartels. On the other hand, simplifying damages claims against revealing firms can have a deterring effect. Private enforcement may or may not strengthen the public enforcement objective of deterrence.

My results do not only apply to damages actions. Injunctive relief, declaration of nullity of contractual provisions and consensual dispute resolution mechanisms of competition litigation such as out-of-courts-settlements, arbitration and mediation are other remedies of private enforcement. All remedies decrease the expected profit from collusion. The disclosure of information in settlement cases may raise similar problems with follow-on damages claims as the disclosure of leniency documents. The acknowledgement of the participation in a cartel and the cooperation with the AA in exchange for a simplified procedure and a reduction in fines may bring the settling parties in a weaker position in follow-on damages claims if the settlement documents are available for the claimants.[42] Because of the similarity of the mechanisms and problems of settlement and leniency cases, my model can also be applied to settlement cases.

Finally, it would be interesting to extend my model by relaxing some assumptions. If the AA may make errors such as convicting a firm that is not guilty, follow-on actions for damages have to be paid by firms with a higher probability. Additionally, including stand-alone actions and class actions for damages would provide relevant insights on the effect on firms' incentives to collude and/or report the collusion. Private stand-alone actions allow private litigants to take action against infringements which the EC or the national AA would not pursue (because of limited resources) or have not pursued so far. The possibility of stand-alone private actions for infringements of competition law increases the expected cost of collusion. Allowing for stand-alone actions in my model would increase the expected damages payments which cartel members have to pay. Injunctive relief would decrease the profit from collusion. Furthermore, stand-alone actions may increase the probability that the AA is able to prove a cartel.

42 European Union (2008) provides a summary of settlement cases in the EU. Interestingly, leniency participants who also commit to settle can expect an additional reduction in fine.

APPENDIX 1.A

Intersection of the Thresholds α_R, α_{NC} and α_{CR}

I first define the intersections of the functions α_R, α_{NC} and α_{CR} to simplify the description of the examples of SPE (see Figure 1.A1) and of the proofs of Propositions 1.2 and 1.3.

- $\alpha_{CR} = \alpha_{NC}$ at p_{CNR}, with $p_{CNR} < 1$ for

$$r < \bar{r} = \frac{F\delta(1+\delta) - D\left(-2\beta_{NLP}\delta(1+\delta) + \beta_{LP}\left(1+\delta+\delta^2\right)\right) - \pi_M + \pi_N}{F\left(1+\delta+\delta^2\right)} .$$

- $\alpha_{CR} = \alpha_R$ at p_R, with $p_R < 1$ for

$$\begin{aligned} r < \hat{r} = {} & \frac{1}{2F\left(-1+\delta^3\right)}\Big(-(F+2D\beta_{NLP})\delta + \delta^2(\pi_M - \pi_N) \\ & + 2(D\beta_{LP} + \pi_M - \pi_N) + \delta^4(F + 2D\beta_{NLP} + \pi_M - \pi_N) \\ & + \delta^3(-2D\beta_{LP} - \pi_M + \pi_N) - \delta\sqrt{1+\delta+\delta^2}\sqrt{}\Big(F^2(-1+\delta)^2 \\ & \left(1+\delta+\delta^2\right) + 4d^2\beta_{NLP}^2(-1+\delta)^2\left(1+\delta+\delta^2\right) + \delta(\pi_M - \pi_N) \\ & \Big(-4(-1+\delta)^2(1+\delta)\pi_D + \left(4+\delta-3\delta^2+\delta^3\right)\pi_M \\ & + \delta(-5+\delta(-1+3\delta))\pi_N\Big) - 4D\beta_{NLP}(-1+\delta)\delta\Big(2\left(-1+\delta^2\right)\pi_D \\ & + \pi_M + \pi_N - \delta((-1+\delta)\pi_M + \pi_N + \delta\pi_N)\Big) + 2F(-1+\delta) \\ & \Big(2D\beta_{NLP}\left(-1+\delta^3\right) - \delta\Big(2\left(-1+\delta^2\right)\pi_D + \pi_M + \pi_N \\ & - \delta\left((-1+\delta)\pi_M + \pi_N + \delta\pi_N\right)\Big)\Big)\Big)\Big) . \end{aligned} \tag{13}$$

- $p_{CNR} < p_R$ for $r > \tilde{r} = [\pi_M + \delta(1-\delta)(\pi_D - \pi_N) - \pi_N - \delta\beta_{LP}D]/F\delta$.
- $\alpha_R = \alpha_{NC}$ at p_B, with $p_B < 1$ for

$$r < r_B = \left[\delta\beta_{NLP}2D - \beta_{LP}D - \pi_M + \pi_N + \delta F + \delta^2(\pi_N - \pi_D)\right]/F. \tag{14}$$

Examples of SPE Depending on the Reduction in Fine

I discuss four examples of the position of the functions α_R, α_{NC} and α_{CR} which define the SPE to simplify the understanding of the propositions and the proofs. Figure 1.A1 illustrates these examples.

Example (i) shows an equilibrium outcome if the reduction in fine r is low. The horizontal line α_{CR} does not intersect with the downward sloping curves α_{NC} and α_R in $p \in [0,1]$, which means that $p_{CNR} > p_R > 1$ or $r > \hat{r}$ and $r > \bar{r}$. CR is an SPE if $\alpha < \alpha_{CR}$, but CR is dominated by CNR

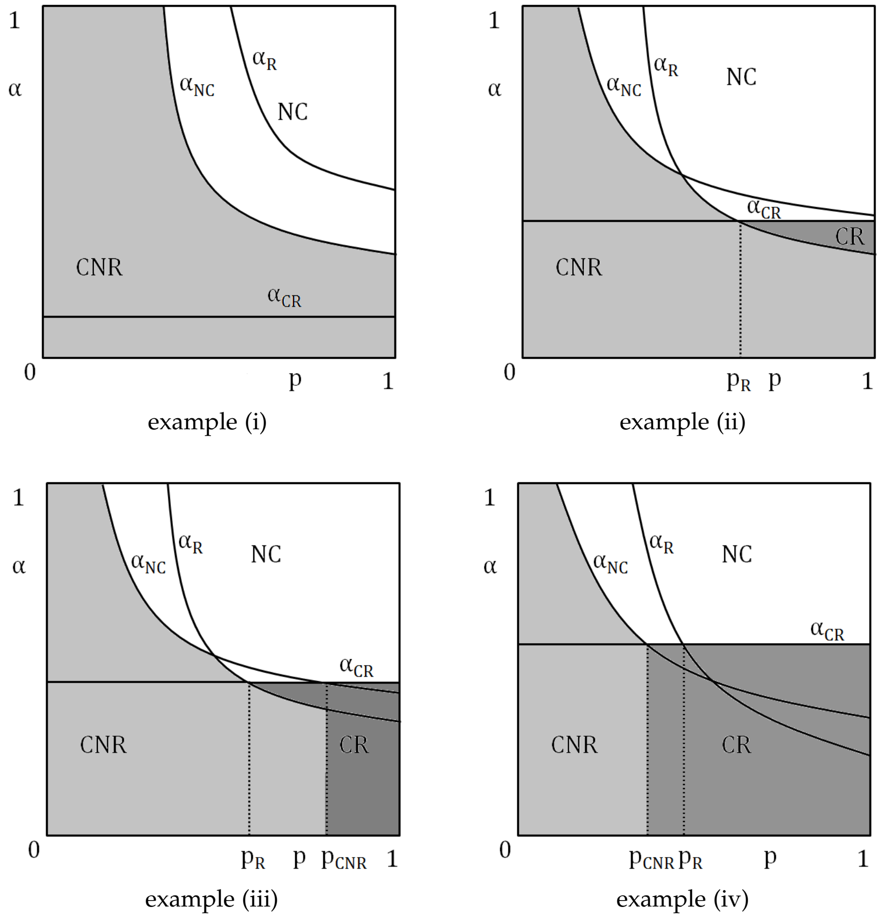

Figure 1.A1: The SPE depending on the fine reduction

because $p < 1 < p_{CNR}$. Because the reduction in fine for revealing firms is low, the incentives to collude and reveal are too low for all values of α and p. Therefore, cooperating with the AA is not an equilibrium action. In example (i), α_R is not binding (as discussed on page 29), which means that deviating from the revelation action is never profitable. This is the case if $r > r_B$.

In example (ii) the reduction in fine is higher as in example (i) such that $0 < p_R < 1 < p_{CNR}$ or $\hat{r} < r < \bar{r}$. The horizontal curve α_{CR} intersects α_R at p_R. CNR is the SPE below $\min\{\alpha_{NC}, \alpha_R\}$. CR is preferred to NC for all (α, p)-combinations below α_{CR}. CNR dominates CR for all values at which both strategies are SPE. The revelation constraint is binding, hence $r < r_B$. For high proof probabilities ($p > p_{CNR}$) and review probabilities below α_{CR}, collusion with revealing once reviewed is optimal. For lower proof probabilities the reduction in the fine is too low to make it profitable to reveal once reviewed compared to not revealing.

In example (iii) the reduction in fine is higher than in the previous examples such that we get $0 < p_R < p_{CNR} < 1$. α_{CR} intersects both α_R and α_{NC}. Because the reduction in fine for revealing firms is higher than in examples (i) and (ii), the CR-SPE yields higher profits than the CNR-SPE for proof probabilities $p > p_{CNR}$.

In example (iv) the reduction in fine is even higher, such that $0 < p_{CNR} < p_R < 1$. Therefore, revealing dominates not-revealing for lower values of the review and the proof probability than in the previous examples because the low fine for revealing firms makes it profitable for firms to reveal after colluding even if the proof and review probabilities are low.

Proof of Proposition 1.2

Lemmata 1.5 and 1.6 show that both functions α_{NC} and α_R decrease if β_{NLP} increases. $\min\{\alpha_{NC}, \alpha_R\}$ defines the threshold below which CNR is more profitable than NC for $p < \min\{p_R, p_{CNR}\}$. (For $p > \min\{p_R, p_{CNR}\}$, $\alpha_{CR} > \min\{\alpha_{NC}, \alpha_R\}$ and $\min\{\alpha_{NC}, \alpha_R\}$ does not define the threshold between the CNR-SPE and the NC-SPE. For an illustration of this case see Figure 1.A1, examples (ii)–(iv).) Hence, by the downward shift of α_{NC} and α_R, there are more (α, p)-combinations for which NC is an SPE.

By the downward shift of α_R, the number of (α, p)-combinations for which CR is an SPE instead of CNR increases if α_R defines a threshold between the CR-SPE and the CNR-SPE. $\min\{\alpha_{NC}, \alpha_R\}$ defines a lower bound for revealing for $p > p_R \wedge p_R < p_{CNR}$, which is the same as $r < \min\{\bar{r}, \hat{r}\}$. (See Figure 1.A1, examples (i) and (iv), for cases in which α_R does not define a lower bound for a dominant CR-SPE, because CR is never a dominant SPE or because CR dominates CNR for all $p > p_{CNR} > p_R$.)

Lemma 1.7 shows that p_{CNR}, which defines the threshold below which the CNR-SPE Pareto-dominates the CR-SPE, decreases with β_{NLP}. Therefore, if $p_{CNR} < 1$ (or $r < \bar{r}$), an increase of β_{NLP} increases the number of (α, p)-combinations for which CR is a dominant SPE instead of CNR. □

Proof of Proposition 1.3

α_{CR} is the threshold between the NC-SPE and the dominant CR-SPE if $\alpha_{CR} > \min\{\alpha_{NC}, \alpha_R\}$ (or $p > \min\{p_R, p_{CNR}\}$ or $r < \min\{\bar{r}, \hat{r}\}$). Lemma 1.4 shows that α_{CR} decreases with β_{LP}. A downward shift of the threshold between the SPE of CR and NC increases the number of (α, p)-combinations for which NC is an SPE instead of CR.

Lemma 1.6 shows that α_R increases with β_{LP}. α_R defines the threshold between the CNR and the NC-SPE if α_R is binding for a CNR-SPE, which is the case for $r < r_B$. For $\alpha_{CR} > \alpha_R$ (or $r > \widetilde{r}$), α_R does not define the threshold between the CNR-SPE and the NC-SPE. Therefore, the upward shift of the threshold α_R decreases the number of (α, p)-combinations for which NC is an SPE instead of CNR if $r < r_B \wedge r < \widetilde{r}$ (see Figure 1.A1, examples (ii) and (iii)).

Lemma 1.7 shows that p_{CNR}, which defines the threshold below which the CNR-SPE Pareto-dominates the CR-SPE, increases with β_{LP}. Therefore, if $p_{CNR} < 1$ (or $r < \bar{r}$), an increase of β_{LP} increases the number of (α, p)-combinations for which CNR is a dominant SPE instead of CR. $\square$

2 ON THE STABILITY OF PATENT POOLS

2.1 INTRODUCTION

The number of patents declared essential and incorporated in a technological standard has increased extremely during the past few decades. Because standards play a key role for the adoption and interoperability of technology, also mechanisms to make the patent inflation around standardization tractable gain importance.[1]

A patent pool is one of these mechanisms to coordinate the strategies of patent owners with respect to their licensing. A patent pool of standard-essential patents bundles the patents that are essential for the implementation of a standard and jointly markets these patents.[2] First, a patent pool addresses the need for transactional manageability if individual licensing is too costly. Because producers otherwise have to deal with a high number of patents to manufacture a good without infringing IP rights, the pool can work as a 'one-stop-shop' to access a technology's IP rights and thereby reduces transaction cost. Second, a patent pool reduces total royalties. If patent owners set their royalty independently of each other, the market is horizontally disintegrated and royalties are excessively high. By bundling and jointly licensing essential patents in a patent pool, the so called 'complements problem' can be reduced or even solved and the royalty can be efficiently low. The multiple interaction of patent owners and licensees in order to produce one product also leads to a double mark-up effect due to the disintegrated market from patent owners to producers to consumers.

Even though a patent pool reduces or even solves the complements problem and thereby increases profits for the patent owners as well as it decreases total royalties, patent owners may have an incentive not to join a patent pool. Participation in a patent pool is voluntary. I analyse the incentive compat-

1 Standards incorporate more and more inventions, each of them being subject to several patents. There are also extreme cases: The standard UMTS accounts for 11,000 and the standard 3GPP for 15,000 patent declarations (Baron and Pohlman, 2012). One of the standard setting organizations, the International Organization for Standardization, has published more than 19,500 international standards covering almost all aspects of technology and business since 1947.

2 Different definitions of essentiality exist: A patent is seen as legally essential to a standard if the standard cannot be implemented without infringing on this patent. If a patent is commercially essential the standard is refused by the consumers without this patent (Layne-Farrar and Lerner, 2011).

ibility of the membership in a patent pool and show how the incentives to free-ride on a patent pool depend on the fraction of patent owners included in a patent pool.

One of the first modern patent pools established around the widely adopted standard for digital video compression, the MPEG-2 standard. In the 1990s the standard faced a patent thicket and in 1997 the MPEG-2 patent pool was formed, including 880 essential patents in 57 countries owned by 25 patent owners. The prevalence of patent pools has significantly increased after the approval of the MPEG-2 and the following DVD patent pools by the U.S. Department of Justice in 1997 and 1999. Figure 2.1 gives a non-exhaustive overview of the development of patent pools by industries. Barnett (2014) finds 38 patent pools or similar joint patent agreements in the information and telecommunication industry from 1995 to 2013 and the data by Baron and Pohlman's (2012) on the declaration of essential patents from 1992-2010 to the main formal standard setting organizations includes 48 patent pools. Baron and Pohlman (2011) dataset includes 43 patent pools but also 11 failed attempts to form a patent pool.

Even though the number of patent pools is increasing, for many standards we observe no attempt to form a pool, the existence of incomplete pools or failed attempts to form a pool.[3]

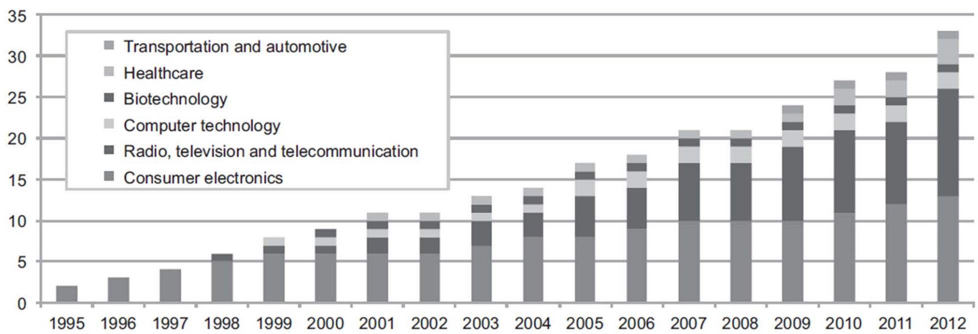

Figure 2.1: Number of patent pools established from 1995-2012 (Source: den Uijl et al., 2013, p.2)[4]

3 For example, in the case of the DVD standard or the Blu-ray Disc standards, several patent pools formed. No patent pool formed after discussions for IEEE802.3af and IEEE802.3at Power Over Ethernet standards and also for WiMAX technology. In another case, five compatibility standards for 3G mobile telecommunication tried to form a patent pool each, in the end only a pool on one standard formed.

4 This figure provides a non-exhaustive overview of data which is derived from multiple sources: Serafino (2007) and websites from various licence administrators such as MPEG LA, SISVEL, Via Licensing and SIPRO LAB.

I focus on these problems in establishing patent pools including (all) patents that are essential for a given standard. The incentive compatibility of the membership in a patent pool and therefore the stability of a patent pool is determined by the number of patent owners inside the pool and the number of patent owners who license their patent individually outside the patent pool. I apply a farsighted stability concept that has not been used in other models of patent pools to analyse stability. According to this concept, patent owners foresee not only changes in royalties and in profits but also changes in the size of the patent pool following a deviation. I provide a general algorithm to define the farsighted stable set of patent pool outcomes and apply the algorithm to a model of linear demand and price leadership of the patent pool.

I find that in equilibrium patent pools can be farsightedly stable including all or a fraction of all patents, depending on the number of patents. Assuming farsighted rather than myopic patent owners results in a set of stable outcomes rather than a unique stable outcome. In farsightedly stable outcomes, the fraction of patent owners who join the patent pool can be higher as in the unique myopically stable outcome if the number of patent owners is at least six. My analysis shows that a complete break-up of a patent pool is never a farsightedly stable outcome and a grand patent pool including all patents can be farsightedly stable even if the number of patent owners is high.

Much of the economic literature on patent pools focuses on the interaction with standards, the effect on innovation and the role in competition policy. I focus on the incentive compatibility of patent pools. Not many attempts have been made to examine the incentives to participate in a patent pool. Layne-Farrar and Lerner (2011) empirically investigate which factors influence patent pool participation rates. In their data, the participation rate ranges from 30-60%. They find that vertical integration and symmetry in patent quality have a positive effect on the participation rate, whereas a numeric proportional sharing rule of pool profits slightly decreases the participation rate.

Several models show how standard setting rules affect the formation of patent pools. In Lévêque and Ménière (2011), the formation of a stable patent pool fails if firms decide on their licensing strategy after the standard is set. A stable patent pool is possible if firms commit to join the patent pool before the standard is set.[5] Llanes and Poblete (2014) analyse the interaction of standard setting and patent pool formation if the standard has not yet

5 Lévêque and Ménière (2011) apply the myopic stability concept, which is discussed in detail in Section 2.3. They find that a grand pool is only stable if there are at most three firms which hold essential patents.

developed and show that an ex ante agreement on patent pool formation is welfare increasing compared to ex post negotiations.[6]

Brenner (2009) describes the patent pool formation as a coalition formation with sequential proposals and acceptance/rejection decisions and shows that compulsory individual licensing and exclusive pool membership stabilize welfare enhancing pools. Aoki and Nagaoka (2005) also analyse the formation process of a patent pool in a coalition formation model based on Maskin (2003). Patent owners sequentially decide on their participation by negotiating with the pool members. A grand coalition can only form if the number of agents is small, otherwise an outsider exists even though the remaining firms prefer a grand coalition. Aoki (2005) shows in a theoretical analysis that free-riding of outsiders on the patent pool and heterogeneous firms are two obstacles to the stability of a grand patent pool which bundles essential patents. By assuming that a patent pool exists in any case, Aoki (2005) shows that a single patent owner can always increase his profit by licensing his patent independently. Schmidt (2010) points out that in Aoki's (2005) model a patent pool must not always exist. By allowing more than one patent owner to licence his patent outside the pool, it might be that a grand patent pool exists because being one of several outsiders is not profitable or that the patent pool dissolves completely if a patent owner deviates from the grand pool.

The interaction of a group of firms, which sets prices and acts as a leader, and other firms that do not belong to the group and react to the group's behaviour does also exist in cartels. A cartel offers similar free-riding incentives as a patent pool. Contrary to essential patent owners in a patent pool, firms in a cartel produce substitutable goods and therefore cooperation decreases consumer welfare and increases prices. D'Aspremont et al. (1983) provide a theoretical model in which an industry is characterized by a price-leading cartel and fringe firms, which take the price of the cartel as given. They show that for a finite number of firms a stable cartel always exists, despite the free-riding of the firms which do not join the cartel. Several studies built on this model. Donsimoni et al. (1986) show the uniqueness of a stable cartel under particular cost parameters and find that the relative size of stable cartels is decreasing in the number of firms in the market. Prokop (1999) focuses on the process of cartel formation rather than the stability of cartels. The sequential move game supports the findings of D'Aspremont et al. (1983) but with simultaneous moves it can be impossible to form a stable cartel. Shaffer (1995) assumes that the cartel behaves as a Stackelberg leader and the com-

6 Llanes and Poblete (2014) define a patent pool as incentive compatible also applying the concept of myopic stability. If several pools are incentive compatible they assume that the largest pool forms.

petitive fringe firms react strategically to the cartel. In his model with linear demand and constant marginal costs, firms only form a grand coalition if the number of firms in the market is below five. If the number of firms is larger, a bare majority of firms join the cartel.[7]

Diamantoudi (2005) criticizes the cartel stability definition used by D'Aspremont et al. (1983) because it misses the farsightedness in the consequences of a firm's decision.[8] She points out that in the model by D'Aspremont et al. (1983), firms are able to anticipate changes in profits due to price changes of an entry/exit. But firms do not anticipate that the change in cartel and outsider profits due to their action can induce other firms to change their status as cartelist or fringe firm. Diamantoudi (2005) proposes a notion of farsighted stability and shows that there always exists a unique, non-empty farsightedly stable set.

Apart from Diamantoudi's (2005) short example to illustrate the concept of farsighted stability, the concept of farsighted stability has not been applied to models of cartel or patent pool stability. Also other strands of economic research that deal with coalition stability such as environmental agreements or network and team formation have rarely applied the farsighted stability concept. Because farsighted behaviour of patent owners has not been assumed so far in models of patent pool stability, the application of the concept of farsighted behaviour provides an interesting and new approach to analyse patent pool stability. I apply Diamantoudi's (2005) definition of farsighted stability to a model of patent pool stability and define an algorithm to derive the set of farsightedly stable patent pool outcomes.

The remainder of the chapter is organized as follows. In Section 2.2, I introduce a model of licensing of essential patents and compare royalties and profits in the cases of no integration, partial integration and full integration in a patent pool. I also analyse the effects that drive a deviation from the patent pool. Section 2.3 discusses the concepts of myopic and farsighted stability. I define an algorithm to solve for the set of farsightedly stable outcomes. In Section 2.4, I apply the algorithm to my model, assuming linear demand and price leadership of the patent pool. Section 2.5 concludes.

7 Konishi and Lin (1999) built on the model by Shaffer (1995) and proof the existence of a stable cartel under fairly general demand and cost condition. They also show that the size of the stable cartel is smaller with a price-taking fringe a la D'Aspremont et al. (1983) compared to the situation when fringe firms play a Cournot game, anticipating the price of the cartel. Zu et al. (2012) provide an analytical approach to determine the size of the stable cartel assuming a Cournot fringe with linear demand and quadratic cost functions.

8 The definition of myopic stability has already been criticized by Fisher (1898).

2.2 THE MODEL

In order to study the incentives of patent owners to become a member of a patent pool, I consider a model with two stages. At the first stage, patent owners decide individually whether or not they license their patent in a patent pool. I assume that only one patent pool is allowed. At the second stage, patent owners license their patents to producers, which pay a royalty in exchange for using the patented technology.

At the second stage, there are n firms in the upstream market, each of them having one patent that is essential to produce the same product on the downstream market. The patents are perfect complements, i.e. each of the n patents is needed to produce the product without infringing on some patent. Let r_i be the royalty charged by firm i for the licence to use its patent for the production of one product. I assume that the downstream market is perfectly competitive and each producer pays the same (cumulative) royalties. Producers are symmetric and have the same production cost. Producers charge a price for the product which is equal to their perceived marginal cost c plus their licensing costs: $p = c + \sum_{i=1}^{n} r_i$. The demand for the product is given by the function $Q(p)$ which is decreasing in the market price p.

At the first stage, firms decide how to license their patent. I differentiate between three ways of licensing. In the case of no integration (NI), each firm licenses its patent independently and non-cooperatively. Each firm chooses a royalty r_i^{NI} which maximizes its profit. Each producer has to pay royalties $n\, r_i^{NI}$ for the production of one product. In the case of full integration (FI) all firms license their patents in a single grand patent pool. The pool royalty r^{FI} for the whole portfolio of essential patents maximizes joint profits of all firms. I assume that the joint pool royalty is shared by a numeric proportional rule among the participating firms and each firm receives r^{FI}/n per licence bundle sold.[9] In the case of partial integration (PI) only k out of n firms license their patents in a bundle and $n-k$ firms license their patent outside the pool and choose their royalty non-cooperatively.[10] The pool royalty r^{PI} for the portfolio of patents included in the patent pool is shared by a numeric proportional rule among the participating firms and each firm

9 A numeric proportional sharing rule is often observed, e.g. in patent pools such as 1394, AVC, DVB-T, MPEG-2, MPEG-4 and WCDMA. See Layne-Farrar and Lerner (2011) for an overview of existing profit sharing rules and a discussion about the effects of the different sharing rules on patent pool participation.

10 I do not differentiate which k out of n firms will join the pool, because firms are assumed to be symmetric. It is also common in models on cartel stability not to differentiate between firms in case they are symmetric. Boyer and Moreaux (1987) and Gal-Or (1985) discuss the roles of leader and follower and their implications on the outcome.

receives r^{PI}/k per licence bundle sold. Each of the firms outside the pool requests a royalty of r_i^{PI}.

2.2.1 *The Complements Problem*

Shapiro (2001) identified the similarities between the classical complements problem analysed by Cournot (1838) and the situation when several firms hold essential patents. He concludes that the bundling of complementary patents reduces consumer prices as well as it increases patent owners' profits. Amongst others, the U.S. Department of Justice & the Federal Trade Commission (1995), the Japan Fair Trade Commission (2007) and the European Union (2014a) adopted in their guidelines on patent pools that patent pools consisting of complementary patents may provide pro-competitive benefits because these pools can be effective in reducing total royalties and decreasing consumer prices compared to independent licensing. In contrast, pools of substitute patents rather harm consumer welfare.[11]

Because the focus of this model is on the stability of patent pools and not on antitrust issues, I assume that all patents are clearly identified to be complements. The essentiality makes each patent owner a monopolist for the licence of his patent. Independent licensing results in higher cumulated royalties compared to the royalty of jointly licensing.

Lemma 2.1. *The cumulative royalty of all patents is lower if firms license their patents as a bundle compared to independent licensing:*
$r^{FI} < r^{PI} + \sum_{i=1}^{n-k} r_i^{PI} < \sum_{i=1}^{n} r_i^{NI}$.

Proof. See Appendix.

Each firm that prices its patent non-cooperatively increases the cumulative royalty and the price of the product. In the PI case, the firms in the pool set their royalty jointly and partly internalize the externality of their royalty on the profit of the other firms inside the pool. Firms outside the pool set their royalties non-cooperatively, therefore the cumulative royalty of the pool and of the outsider firms is in between the pool royalty r^{FI} and the cumulative

11 Legislative authorities as well as academic scholars are aware of the problems that come with the categorization of patents. Different tests for essentiality and complementarity are known and in practice. If the patent pool is built upon an existing standard, evaluation of essentiality is easier to conduct. Usually the standard setting organization (SSO) decides for one out of several substitute technologies to be included in the standard, therefore patents within the standard are supposed to be complements. After the standard is set, all patents included in the standard are essential to produce a good based on the specific standard. Because of the difficulties of categorization the U.S. Department of Justice announced that it will review the inclusion of patents in a patent pool according to the rule of reason.

royalty in the NI case. Because the royalty in the FI case is always lower than the royalty in the NI case, the product price is lower and the demand for the product and for the patent bundle increases. The internalization of the royalty interdependence leads to higher cumulative profits if patents are bundled:

Lemma 2.2. *Cumulative profits of all firms are higher with patent bundling than with independent licensing:* $\sum_{i=1}^{n} \pi_i^{FI} > \sum_{i=1}^{k} \pi_i^{PIp} + \sum_{i=1}^{n-k} \pi_i^{PIo} > \sum_{i=1}^{n} \pi_i^{NI}$.

Lemma 2.2 follows from Lemma 2.1 and from the assumptions on the demand and the downstream market. Lemma 2.1 and Lemma 2.2 show that not only consumers benefit from the bundling of patents in a pool through lower prices (due to a lower cumulative royalty). Also firms' profits increase through bundling. This raises the question why many patent pools fail to form even though they provide benefits for the patent owners. I will address this question in the following section.

2.2.2 *Firms' Licensing Strategies and Free-Riding*

The formation of a patent pool reduces the cumulative royalty that has to be paid by the producers in order to comply with the standard. With a competitive product market this decrease in costs leads to a decrease in product price and to an increase in the demand for the product. A patent pool creates a free-rider incentive because even though a firm does not join the patent pool, it benefits if other firms reduce the cumulative royalty by bundling. Each firm can decide not to join the pool and to free-ride on the pool's effect of increased demand through a lower cumulative royalty. Because producers have no other choice but to buy both the pool's licence and the outsider's(s') licence(s) in order to produce the product, each outsider firm can license its patent at a royalty that is higher than the per firm royalty in the pool.

When deciding whether to join the pool, firms compare their profit from licensing independently with the profit from licensing their patent in a patent pool. As shown in Lemma 2.1 and Lemma 2.2, an exit from the grand pool does not only increase the cumulative royalty but also reduces the cumulative profit of the firms. Two effects influence a firm's decision to join the patent pool. A firm can increase its profit by licensing independently rather than licensing in the pool. But since the cumulative royalty increases, the demand for all patents and the profit of all firms decrease.

In order to discuss the incentives for firms to join a pool or to remain as an outsider in more detail I introduce two assumptions. In the following these assumptions always hold unless mentioned otherwise. I assume the market demand function to be of linear form $Q(p) = A - bp$ with $A, b > 0$. This assumption simplifies the analysis and allows comparisons with related models of cartel stability. Furthermore, I assume that the pool behaves as a price leader compared to the outsiders when it sets its pool royalty. Each outsider firm maximizes its profit by licensing independently, taking the pool royalty as given. In the following I describe the equilibrium royalties and profits in the cases of NI, FI and PI.

No Integration

Each firm $i = 1, ..., n$ sets its royalty to maximize its profit:
$\max_{r_i} \pi_i = (A - b(c + \sum_{i=1}^{n} r_i))r_i$ yields the patent royalty

$$r_i^{NI} = \frac{A - bc}{b(n+1)} \tag{1}$$

and the firm profit

$$\pi_i^{NI} = \frac{(A - bc)^2}{b(n+1)^2} \ . \tag{2}$$

Full Integration

The patent pool sets its royalty to maximize its profit:
$\max_{r} \pi = (A - b(c + r))r$ yields the pool royalty

$$r^{FI} = \frac{A - bc}{2b} \ , \tag{3}$$

the pool profit

$$\pi^{FI} = \frac{(A - bc)^2}{4b} \tag{4}$$

and the per firm profit $\pi_i^{FI} = \frac{\pi^{FI}}{n}$, $i = 1, ..., n$.

Partial Integration

The pool as a Stackelberg leader sets its royalty to maximize profits:
$\max_{r^{PIp}} \pi^{PIp} = (A - b(c + r^{PIp} - (n-k)r_i^{PIo}))r^{PIp}$ with $i = 1, ..., n-k$ yields the pool royalty

$$r^{PIp} = \frac{A - bc}{2b} \ . \tag{5}$$

Each outsider firm $i = 1, ..., n-k$ maximizes its profits by taking the pool royalty as given:
$\max_{r_i^{PI}} \pi_i^{PIp} = (A - b(c + r_i^{PIo} + (n-k-1)r_j^{PIo} - r^{PIp}))r_i^{PI}$ with $j \neq i$
yields the outsider royalty

$$r_i^{PIo} = \frac{A - bc}{2b(n-k+1)} \,. \tag{6}$$

The profit of the pool is given by

$$\pi^{PIp} = \frac{(A-bc)^2}{4b(n-k+1)} \tag{7}$$

with a profit $\pi_i^{PIp} = \frac{\pi^{PIp}}{k}$ per firm $i = 1, ..., k$ in the pool.
The profit of each outsider firm $i = 1, ..., n-k$ is

$$\pi_i^{PIo} = \frac{(A-bc)^2}{4b(n-k+1)^2} \,. \tag{8}$$

As shown in Lemma 2.2, total profits of the firms are maximized by bundling all patents in one grand pool. But a single firm can increase its profit by not joining the pool:

Proposition 2.1. *A unilateral deviation from the grand pool increases profits for a single firm if more than four firms exist:* $\pi_i^{FI}(n) < \pi_i^{PIo}(n-1)$ *for* $n > 4$.

$\pi_i^l(n)$ denotes the profit of a firm i in case $l = \{FI, NI, PI\}$ with n firms in the patent pool. Proposition 2.1 shows that it is profitable for firm i to be the single outsider that licenses its patent independently if more than four firms exist. Because of the essentiality of each patent, the demand for the pool bundle and for each individually licensed patent is the same. The demand for all licences of the product is $Q(\sum_{i=1}^{n} r_i)$.[12] Because the producers have to buy all licences, $Q(\sum_{i=1}^{n} r_i)$ is the demand for the whole bundle and also the demand for any of the patents if they are sold independently. For example, if there is one pool and one outsider, the demand for each patent is $Q(r^{PI} + r^{PIo})$.

Because the patent pool sets its royalty first and the outsider follows, the profit of the patent pool is larger than the profit of the outsider firm. This means that although the pool and the outsider are faced with the same demand, they do not share total profits equally. But the outsider owns a larger share of total profits compared to one of the pool members.

12 Q is the demand for the product as well as for the bundle of essential patents because each product requires one bundle of all patents.

The effect on demand and the effect on the share of total profits determine whether a firm licenses its patent in a bundle or independently. These effects are described in more detail in the following.

Profit Share Effect

Independent licensing can increase a firm's share of the cumulative profit from the licence of all patents. Let $\Pi(k)$ denote the cumulative profit of all firms, k pool members and $(n-k)$ outsiders. The share of an outsider's profit on cumulative profits with k frims in the patent poiol is given by: $ps^o(k) = \frac{\pi_i^{PIo}(k)}{\Pi(k)}$. Similar, a pool member's share of profits on cumulative profits is given by $ps^p(k) = \frac{\pi_i^{PIp}(k)}{\Pi(k)}$. Inserting the profits derived in Section 2.2.2 we get the following result:

Proposition 2.2. *Independent licensing increases a firm's share on total profits compared to licensing in the pool, if* $k > \frac{n}{2} + 2$ *for* k *even and* $k > \frac{n}{2} + 2.5$ *for* k *odd. The difference in the profit shares decreases with the number of outsider firms.*

Proof. $ps^o(k-1) - ps^p(k) = \frac{\pi_i^o(k-1)}{\Pi(k-1)} - \frac{\pi_i^p(k)}{\Pi(k)} = \frac{1}{2n-2k+3} - \frac{n-k+1}{k(2n-2k-1)} > 0$ for $k > (3 + 3n - \sqrt{(n-3)(n+1)})/4$. Restricting k to the domain of natural numbers gives $k \geqslant \frac{n}{2} + 2$ for k even and $k \geqslant \frac{n}{2} + 2.5$ for k odd. The difference is decreasing in $(n-k)$ because $\frac{\partial(ps^o(k-1)-ps^p(k))}{\partial k} > 0$. □

The profit share of an outsider is higher than the profit share of a pool member if the number of outsiders is low enough/the number of firms in the pool is high enough. In the patent pool, each firm receives a share of $\frac{1}{k}$ of the pool's profits, which is a share of $\frac{n-k+1}{k(2n-2k-1)}$ of total profits. Each outsider earns a share of $\frac{1}{2n-2k-1}$ of total profits. The increase in the profit share due to an exit decreases with the number of firms licensing individually.

Demand Effect

Lemma 2.1 shows that the cumulative royalty increases with the number of patents licensed independently. Because consumers' demand for the product decreases as the cumulative royalty for producers increases, each firm which licenses its patent as an outsider of the pool has a negative effect on the demand for the patents.[13]

Proposition 2.3. *Licensing as an outsider compared to licensing in the pool decreases the demand for all patents. This negative effect on the demand decreases with the number of firms who license their patents individually.*

13 The effect on demand is the same for all patents because all patents are requested equally by producers.

Proof. $\frac{\partial Q}{\partial \sum r} \frac{\partial \sum r}{\partial k} > 0$, $\frac{\partial Q}{\partial \sum r} \frac{\partial \sum r}{\partial k} \frac{\partial}{\partial k} > 0$ □

If the profit share of a firm ceteris paribus increases, its profit increases. If demand ceteris paribus decreases, an outsider's and a pool member's profit decrease. As shown in Proposition 2.1, a single deviation from a grand patent pool can be profitable. This means that the profit share effect might outweigh the demand effect. Because the profit share effect decreases with the number of outsiders and the demand effect always has a negative impact on profits, it is not profitable to license individually if too many firms license outside the pool. This leads us to the concept of stability.

2.3 STABILITY CONCEPTS AND STABLE PATENT POOLS

2.3.1 *Comparison of Myopic and Farsighted Stability*

Most models on the stability of cartels use the notion of internal and external stability. Internal and external stability can be defined in a farsighted or in a myopic concept. Myopic stability (as applied in D'Aspremont et al., 1983)) and farsighted stability differ in the way how agents compare profits at the status quo to profits after a deviation. Applying the myopic stability approach, agents compare their profit at the status quo outcome with their profit after their deviation, thereby taking into account the changes in prices, quantities and profits, but not taking into account any subsequent deviations by other agents.

Applying the myopic stability concept to my model of patent pools gives the following definition:

Definition 2.1. *An outcome is defined as* ***myopically stable*** *if it satisfies internal myopic stability (IMS) and external myopic stability (EMS). Internal myopic stability is satisfied if* $\pi_i^{PIp}(k) > \pi_i^{PIo}(k-1)$ *and external myopic stability is satisfied if* $\pi_i^{PIo}(k) > \pi_i^{PIp}(k+1)$.

A patent pool satisfies IMS if a firm's profit as one out of k members of the pool is higher than its royalty-adjusted profit as an outsider with $k-1$ members in the pool. Staying inside the pool is more profitable than leaving the pool. The pool fulfils EMS if a firm's profit as an outsider to the pool with k firms in the pool is higher than its royalty-adjusted profit as one out of $k+1$ pool members. A firm compares its status quo profit with the deviation profit, thereby taking into account the adjustments in royalties but not considering a change in the size of the coalition due to a subsequent deviation. Firms in this stability concept are myopic in the sense that they ignore reactions by other firms. As a consequence, the outcome they compare their status quo with may not be the final outcome that prevails after their deviation.

In the farsighted stability concept, each agent fully anticipates the reactions of all other agents. If an agent considers deviating, he compares his status quo profit to his profit in the stable outcome after his deviation. Diamantoudi's (2005) definition of a farsightedly stable outcome is based on the stable set defined by von Neumann and Morgenstern (1953). The stable set is a solution set, i.e. a collection of outcomes which are stable, while those excluded from the solution set are unstable. Agents are farsighted and compare their outcome only with outcomes included in the stable set when considering a deviation, because all other unstable outcomes will result in additional deviations until a new stable outcome is reached. Any stable outcome cannot be dominated by any other stable outcome. It can be dominated by an unstable outcome, but the deviation from a stable to a dominating unstable outcome is never credible. Any unstable outcome is dominated by a stable outcome.

To illustrate the definition of dominance, consider the following example. An outcome A is dominated by an outcome B, if profits in outcome B are higher, given that outcome B can actually be reached from outcome A. Indirect dominance is thereby sufficient, meaning that if an outcome B is preferred to an outcome A, but B cannot directly be reached from A but via outcome C, which is also dominated by B, than outcome B can be reached indirectly from outcome A. Hence B indirectly dominates A.[14] Figure 2.2 illustrates this concept of indirect dominance.

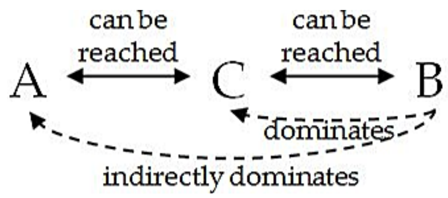

Figure 2.2: Dominance criterion of the farsightedly stable set

Assuming that each agent acts independently and only one coalition can be formed, Diamantoudi (2005) shows the existence of a unique stable set, containing one or several stable outcomes. This means that there is only one set of stable outcomes with one or more stable outcomes but no other set containing different stable outcomes. My definition of patent pool stability and

14 Harsanyi (1974) remarked on von Neumann and Morgenstern's (1953) stable set approach that for forward looking agents indirect dominance suffices to reach an outcome. Diamantoudi (2005) replaces the requirement of direct dominance used by von Neumann and Morgenstern (1953) with indirect dominance.

the farsightedly stable set follows from Diamantoudi's (2005) application of von Neumann and Morgenstern's (1953) stable set approach.

Definition 2.2. *An outcome is defined as* ***farsightedly stable*** *if it satisfies internal farsighted stability (IFS) and external farsighted stability (EFS). IFS is satisfied if no firm inside the pool wants to exit, comparing its status quo with the stable outcome that is reached after its deviation. EFS is satisfied if no firm outside the pool wants to enter the pool, comparing its status quo with the stable outcome that is reached after its deviation.*

Definition 2.3. *All stable patent pool outcomes included in the* ***farsightedly stable set*** *are farsightedly stable, whereas all outcomes excluded from the farsightedly stable set are unstable. Any outcome in the farsightedly stable set cannot be dominated by any other outcome in the farsightedly stable set (IFS). Any outcome excluded from the farsightedly stable set is dominated by an outcome in the farsightedly stable set (EFS). Dominance requires preference and feasibility, meaning that the dominance of outcome* a *over outcome* b *requires that* a *is preferred over* b *and that* a *can (at least indirectly) be induced from* b.

Diamantoudi (2005) also shows that the myopically stable outcome is always contained in the farsightedly stable set. The unique myopically stable outcome is always the outcome in the farsightedly stable set with the smallest coalition size. This outcome satisfies IFS and EFS. EFS is satisfied because if it is unprofitable for one agent to exit the coalition, it cannot be profitable for more than one agent to exit the coalition because the surplus from leaving the coalition decreases with every outsider (see Propositions 2.2 and 2.3). It satisfies IFS, because any exit will be followed by an entry that restores the outcome. The stable outcome to compare the status quo with when considering an entry or exit is the status quo itself.

As shown in Propositions 2.2 and 2.3, the more firms license their patent independently, the lower is the gain from independent licensing. Leaving the pool might be profitable for a firm if no or just some other firms subsequently exit the pool, but it becomes unprofitable if too many other firms follow the exit.

The following example applies the farsighted and the myopic stability concept to point out the difference in the concepts. Table 2.1 shows the profits of an firm outside the pool (π_i^{PIo}) and the profits of a firm inside the pool (π_i^{PIp}), depending on the number of firms (n) and the number of firms in the pool (k). The examples use $b, c = 1, A = 10$. In example A, $n = 5$, in example B, $n = 7$.

First, we derive the stable patent pool outcome applying the myopic stability concept (Definition 2.1). The grand pool does not satisfy IMS, because the profit of firm i is higher if it leaves the pool compared to the profit of

	Profits per patent owner			
	example A: $n = 5$		example B: $n = 7$	
k	π_i^{PIo}	π_i^{PIp}	π^{PIo}	π_i^{PIp}
n	–	4.05	–	2.89
n-1	5.06	2.53	5.06	1.69
n-2	2.25	2.25	2.25	1.35
n-3	1.26	2.53	1.27	1.27
n-4	0.81	4.05	0.81	1.35
n-5			0.56	1.69
n-6			0.41	2.89

Table 2.1: Example of myopic and farsighted stability

being one out of five pool members: $\pi_i^{PIo}(4) = 5.06 > \pi_i^{PIp}(5) = 4.05$. A pool with four members and one outsider satisfies IMS. No firm has an incentive to leave the pool because the profit of being a pool member is higher than the profit of being one out of two outsiders: $\pi_i^{PIp}(4) = 2.53 > 2.25 = \pi_i^{PIo}(3)$. This outcome also satisfies EMS, because the single outsider has higher profits outside the pool and therefore does not want to enter the pool. The outcome with one outsider satisfies EMS and IMS, therefore it is myopically stable. The profits of this outcome are double-underlined in Table 2.1.

In example B with $n = 7$, the grand patent pool does not satisfy IMS: $\pi_i^{PIp}(7) = 2.89 < 5.06 = \pi_i^{PIo}(6)$. A pool with six firms in the pool does also not satisfy IMS: $\pi_i^{PIp}(6) = 1.69 < 2.25 = \pi_i^{PIo}(5)$. The outcome with five firms in the patent pool satisfies IMS, because none of the firms inside the pool can gain higher profits by setting its royalty independently: $\pi_i^{PIp}(5) = 1.35 > 1.27 = \pi_i^{PIo}(4)$. It satisfies EMS because none of the outsiders can gain higher profits by joining the pool: $\pi_i^{PIp}(6) = 1.69 < 2.25 = \pi_i^{PIo}(5)$. The outcome with two outsiders is the unique myopically stable outcome.

In the following I apply the farsighted stability concept as defined in Definition 2.2 to example A and B. In example A, the outcome with four firms in the pool and one outsider is myopically stable. The myopically stable outcome is also farsightedly stable. There are no subsequent reactions to the deviation of one firm from the patent pool, because it is not profitable for any firm to react. The grand pool does not satisfy IFS because comparing a firm's profit inside the grand patent pool with the final outcome after a deviation from the grand pool shows that the outcome with one outsider and four firms in the pool yields higher profits: $\pi_i^{PIo}(4) = 5.06 > \pi_i^{PIp}(5) = 4.05$.

This is different in example B, in which subsequent reactions to a deviation are profitable. The unique myopically stable outcome is as always also farsightedly stable. The outcome satisfies IFS because no firm inside the pool has an incentive to deviate from the pool. The outcome also satisfies EFS because no outsider has an incentive to join the pool. Starting from a grand pool, a firm thinking of deviating has to compare its status quo profit with the outcome that is reached after its deviation. If one firms deviates, another firm will also leave the pool, therefore the outcome with one outsider and profits of $\pi_i^{PIo}(6) = 5.06$ is not farsightedly stable and does not serve as a comparison outcome to the status quo. Comparing the profit of in the grand patent pool with the farsightedly stable outcome with two outsiders shows that a deviation from the grand pool is not profitable: $\pi_i^{PIp}(7) = 2.89 > 2.25 = \pi_i^{PIo}(5)$. A grand pool satisfies IFS and therefore is farsightedly stable. The profits of the farsightedly stable outcomes which are not myopically stable are single-underlined in Table 2.1.

Both farsightedly stable outcomes are included in the farsightedly stable set, even though the outcome with the grand pool Pareto dominates the outcome with two outsiders. A single firm cannot induce the grand pool from the outcome with two outsiders. If one outsider enters the patent pool in order to form a grand pool, it is profitable for another firm to leave the pool. Only a combined action of two firms would make the grand pool possible, but firms are assumed to act non-cooperatively. Figure 2.A1 in the Appendix extends the example for $n = 4, ..., 15$ to further illustrate the circular approach of the definition of farsighted stability.

2.3.2 *The Farsightedly Stable Set of Patent Pool Outcomes*

In the following I define a general algorithm to derive the unique farsightedly stable set of patent pool outcomes. First, I describe the procedure in general and afterwards explain the intuition of each step. In Section 2.4, I apply the algorithm to my model, assuming price leadership of the patent pool and linear demand.

Let P^s denote the farsightedly stable set of patent pool outcomes. The farsightedly stable set consists of one or several farsightedly stable patent pool outcome(s). Each outcome included in the set is denoted by $k_j^s \in P^s$, with $j = 1, 2, ..., n/2$ for n even or $j = 1, 2, ..., n/2 + 1$ for n odd or until the algorithm stops.[15] For example, if $P^s = \{k_1^s, k_2^s\} = \{4, 6\}$, there are two outcomes in the farsightedly stable set, a patent pool with 4 firms in the pool

15 The maximal number of farsightedly stable outcomes is restricted to $n/2$ for n even and $n/2 + 1$ for n odd, because the number of coalition members in each farsightedly stable outcome has to differ at least by 2, otherwise the outcome does not satisfy IFS and EFS.

and one with 6 firms in the pool. The application of the algorithm defines the farsightedly stable set. Each step of the algorithm either ends with the definition of the farsightedly stable set or with the order to continue with the next step.

1. If $\pi_i^{FI} \geqslant \pi_i^{PIo}(n-1) \;\; \Rightarrow \;\; P^s = \left\{k_1^s\right\} = \{n\}$.
   If $\pi_i^{FI} < \pi_i^{PIo}(n-1)$, continue with next step.

2. Set $\pi_i^{PIp}(k_1) = \pi_i^{PIo}(k_1 - 1)$ and solve for $k_1 \in \mathbb{R}_+$. Define $k_1^s = \lfloor k_1 \rfloor$.

3. Following Step 2, for $j = 2, 3, ..., n/2$ if n even or $j = 2, 3, ..., n/2 + 1$ if n odd or until the algorithm stops, set $\pi_i^{PIp}(k_j) = \pi_i^{PIo}(k_{j-1}^s)$ and solve for $k_j > k_{j-1}$. Define $k_j^s = \lceil k_j \rceil$.
   If $k_j^s > n \;\; \Rightarrow \;\; P^s = \left\{k_1^s, ...k_{j-1}^s\right\}$.
   If $k_j^s = n \;\; \Rightarrow \;\; P^s = \left\{k_1^s, ..., k_{j-1}^s, k_j^s\right\}$.
   If $k_j^s < n$, repeat Step 3 with $j + 1$.

For example, applying Step 3 for $j = 2$ gives the following:

Set $\pi_i^{PIp}(k_2) = \pi_i^{PIo}(k_1^s)$ and solve for $k_2 > k_1^s$. Define $k_2^s = \lceil k_2 \rceil$.
If $k_2^s > n \;\; \Rightarrow \;\; P^s = \left\{k_1^s\right\}$.
If $k_2^s = n \;\; \Rightarrow \;\; P^s = \left\{k_1^s, k_2^s\right\}$.
If $k_2^s < n$, continue Step 3 with $j = 3$.

The farsightedly stable set of outcomes is fully defined by applying Steps 1,2,3. The intuition of the steps is as follows:

1. If $\pi_i^{FI} > \pi_i^{PIo}(n-1)$ holds, the grand pool is the only farsightedly stable outcome (and also the unique myopically stable outcome) and the analysis stops. The grand patent pool satisfies IFS, because a first outsider has the highest profits from exiting the pool and if it is not profitable for a single firm to leave the pool, it is also not profitable for an additional firm to leave the pool. If $\pi_i^{FI} < \pi_i^{PIo}(n-1)$, the grand pool is neither myopically nor farsightedly stable.

2. Solving $\pi_i^{PIp}(k_1) \geqslant \pi_i^{PIo}(k_1 - 1)$ for k_1 yields the unique myopically stable outcome, which is also the farsightedly stable outcome with the smallest coalition.[16] This farsightedly stable outcome with k_1^s firms in the pool is the farsightedly stable outcome with the lowest number of firms inside the pool. When comparing outcomes with higher number of firms in the pool, this outcome serves as a comparison to the status quo (as in example B of Table 2.1).

3. The procedure repeats after Step 2 (after the definition of the farsightedly stable outcome k_1^s with the lowest number of firms inside the pool) until the farsightedly stable set is fully defined. Setting $j = 2$, we test whether another farsightedly stable outcome exists with more firms in the patent pool than in the outcome k_1^s. We search for the number of firms in the patent pool, for which the profit of a pool member is as least as high as the profit of an outsider in the farsightedly stable outcome with k_1^s firms in the pool. k_2^s has to be a natural number larger than k_1^s and smaller or equal than n to be another farsightedly stable outcome.[17] If $k_2^s > n$, the farsightedly stable set is defined, including only k_1^s, because $k \leqslant n$ has to hold. If $k_2^s = n$, the grand pool is another stable outcome and the farsightedly stable set is defined. If $k_1^s < k_2^s < n$, k_2^s is another farsightedly stable outcome and additional stable outcomes might exist. The procedure continues with $j = 3$. We test whether another farsightedly stable outcome exists with more firms in the patent pool than in the outcome k_2^s. We search for the number of firms in the patent pool, for which the profit of a pool member is as least as high as the profit of an outsider in the farsightedly stable outcome with k_2^s firms in the pool. k_3^s has to be a natural number larger than k_2^s and smaller or equal than n to be another farsightedly stable outcome. If $k_3^s > n$, the farsightedly stable set is defined, with k_1^s and k_2^s included in the set. The outcome k_3^s is not included because $k \leqslant n$ has to hold. If $k_3^s = n$, the grand pool is a third stable outcome and the farsightedly stable set is defined. If $k_2^s < k_2^3 < n$, k_3^s is the third farsightedly stable outcome and additional stable outcomes might ex-

16 Because the number of firms (inside the pool k_1^s) is restricted to natural numbers, k_1 has to be brought down to the next natural number; the number that still solves the inequality.

17 Again, because of the restriction to natural numbers for k, $k_2^s = \lceil k_2 \rceil$, so that the inequality holds.

ist. The procedure continues with $j = 4$. By applying Step 1, 2 and 3, we define all farsightedly stable outcomes from k_1^s to maximal $k_{n/2}^s$ for n even or $k_{n/2+1}^s$ for n odd.

2.4 AN APPLICATION OF THE FARSIGHTED STABILITY CONCEPT TO LINEAR DEMAND AND PRICE LEADERSHIP OF THE PATENT POOL

Section 2.3.2 derives the algorithm to define the farsightedly stable set in general form. In this section, I apply the algorithm to the model of linear demand and price leadership of the patent pool introduced in Section 2.2.2. The definition of the farsightedly stable set of patent pool outcomes makes it possible to analyse the properties of the farsightedly stable set under linear demand and price leadership of the patent pool in more detail. For details on the derivation of k_1^s, k_2^s, k_3^s,... see Appendix.

1. $\pi_i^{FI} \geqslant \pi_i^{PIo}(n-1)$ for $n \leqslant 4 \quad \Rightarrow \quad k_1^s = n$ and $P^s = \{k_1^s\}$.
   If $n > 4$, then $\pi_i^{FI} < \pi_i^{PIo}(n-1)$ holds. Continue.

2. $k_1^s = \lfloor k_1 \rfloor = \left\lfloor \frac{1}{4}(5 + 3n - \sqrt{n^2 - 2n - 7}) \right\rfloor$, which can be simplified to $k_1^s = \frac{n}{2} + 1$ for n even and $k_1^s = \frac{n+1}{2} + 1$ for n odd.

3. For $j = 2, 3, ..., n/2$ if n even or $j = 2, 3, ..., n/2 + 1$ if n odd or until the algorithm stops:
   $k_j^s = \left\lceil \frac{1}{2}(1 + n + \sqrt{(1 + n - 2k_{j-1}^s)(2k_{j-1}^s - 3 - 3n)}) \right\rceil$
   If $k_j^s > n \Rightarrow P^s = \left\{k_1^s, ..., k_{j-1}^s\right\}$.
   If $k_j^s = n \Rightarrow P^s = \left\{k_1^s, ..., k_{j-1}^s, k_j^s\right\}$.
   If $k_j^s < n$, repeat Step 3 with $j + 1$.

Proposition 2.4. *For linear demand and price leadership of the patent pool*

(i) *the outcome k_1^s is a grand patent pool and the single outcome of the farsighted stable set if $n \leqslant 4$,*

(ii) *the fraction of firms included in a farsightedly stable patent pool is always larger than 50% ($\frac{n+2}{2n}$ for n even, $\frac{n+3}{2n}$ for n odd),*

(iii) *an outcome in which the patent pool dissolves completely is never a farsightedly stable outcome.*

(iv) *the farsightedly stable set contains a second outcome k_2^s with larger coalition size compared to k_1^s if $n \geqslant 6$.*

Proof. $\pi_i^{FI} \geqslant \pi_i^{PIo}(n-1)$ for $n \leqslant 4 \Rightarrow P^s = \{k_1^s\} = \{n\}$ if $n \leqslant 4$; $\frac{k_1^s}{n} = \frac{n/2+1}{n}$ for n even and $\frac{k_1^s}{n} = \frac{n+1/2+1}{n}$ for n odd; $\exists\, k_2^s \leqslant n$ if $n \geqslant 6$. □

Proposition 2.5. *For linear demand and price leadership of the patent pool, the smallest stable patent pool k_1^s is strictly increasing in n whereas $k_j^s \subseteq P^s$ with $j > 1$ weakly increases with n.*

Proof. $\frac{\partial k_1^s}{\partial n} > 0$, $\frac{\partial k_j^s}{\partial n} > 0$ for $j > 1$ if k_1^s is even, $\frac{\partial k_j^s}{\partial n} = 0$ for $j > 1$ if k_1^s is odd. □

Proposition 2.6. *For linear demand and price leadership of the patent pool, each outcome $k_j^s \subseteq P^s$ Pareto dominates all other outcomes $k_l^s \subseteq P^s$ with $j > l$. For $n \geqslant 6$, there is at least one outcome in the farsightedly stable set that Pareto dominates the outcome k_1^s.*

Proof. Follows from Proposition 2.4(iv) and $\frac{\partial \pi_i^{PIo}}{\partial k} > 0$, $\frac{\partial \sum_{i=1}^{k} \pi_i^{PIp}}{\partial k} > 0$. □

No outcome included in the farsightedly stable set dominates another outcome included in the set as defined in Definition 2.3. But each of the outcomes included in the set Pareto dominates each outcome with less firms inside the patent pool (lower index of the farsightedly stable outcome). The profit of an outsider as well as the profit of an insider ceteris paribus increase with the number of firms inside the pool.

Figure 2.3 shows the relationship between the number of firms in the market and the number of firms inside the patent pool for all farsightedly stable outcomes. To increase the readability, a line is added. All points on the line are farsightedly stable grand patent pools (100% participation rate). As shown in Proposition 2.4(i), if there are less than five firms in the market, the only farsightedly stable patent pool includes all firms. If the number of firms in the market increases, grand pools can still be farsightedly stable. As shown by Proposition 2.4(iv), if the number of firms in the market is larger

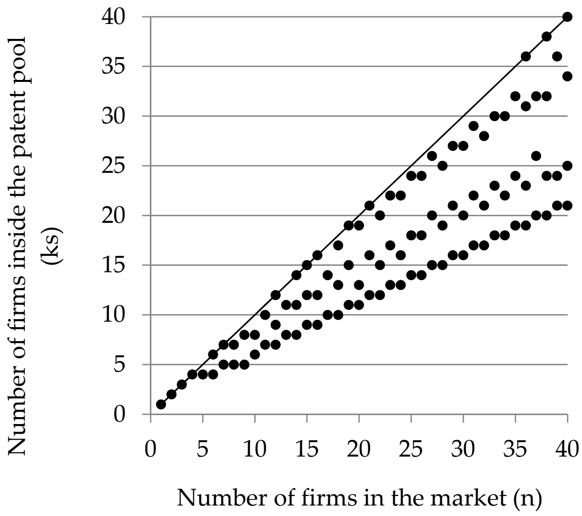

Figure 2.3: Farsightedly stable outcomes

than six, the farsightedly stable set contains at least two outcomes and the number of additional outcomes follows a non-monotonic upward trend.[18]

The application of the algorithm defines the farsightedly stable set for a given market size, which may contain several outcomes. This is different from the result of the application of the myopic stability concept. D'Aspremont et al. (1983) show that a unique myopically stable cartel always exists. In their model of price-leadership of the pool and price-taking fringe firms, they find that if the number of firms approaches infinity, the fraction of firms in the cartel approaches zero. Assuming myopic stability and fringe firms that react strategically to the cartel, Shaffer (1995) finds a unique stable outcome with a constant fraction of firms inside the coalition if n grows. In my model, the outcome included in the farsightedly stable set with the smallest coalition size (which is also the unique myopically stable outcome) has a constant fraction of firms in the patent pool ($\frac{n+2}{2n}$ for n even, $\frac{n+3}{2n}$ for n odd). In Aoki's (2005) model, the disincentive to join the patent pool increases with the number of firms in the market. Similarly, in Aoki and Nagaoka (2005), a grand patent pool only forms if the number of firms is small. I show that under the assumption of farsighted agents which anticipate adjustments in

18 The number of outcomes included in the farsightedly stable set does not monotonically increase because k is restricted to natural numbers.

prices and coalition size, higher participation rates in stable patent pools are possible than under the assumption of myopic agents.

The stable set approach by von Neumann and Morgenstern (1953) does not define each outcome individually but defines a collection of stable outcomes. The farsightedly stable set of my model builds upon von Neumann and Morgenstern's (1953) definition and also defines a collection of farsightedly stable outcomes. Even though outcomes in the set Pareto dominate each other, no outcome included in the set dominates another outcome in the set as defined in Definition 2.3, because a dominating outcome A must not only be preferred to the dominated outcome B, A must also be (at least indirectly) be reached by B.

Which of the stable patent pools included in the farsightedly stable set defined by my algorithm actually establishes, depends on the status quo before the kick-off of the patent pool. If no patent pool exists and firms then consider forming a patent pool, the farsightedly stable patent pool with the lowest number of participants forms, because firms cannot induce another, preferred farsightedly stable outcome with more firms in a pool by unilateral moves. On the other hand, if firms are for example forced by the government to form one patent pool and after some time are able to decide on their own whether or not they continue the cooperation, the farsightedly stable patent pool with the largest number of participants out of the farsightedly stable set forms, because no firm in this outcome has an incentive to enter or exit the pool.

2.5 CONCLUSION

Even though a grand patent pool is profitable for all patent owners as well as consumers, the formation of a patent pool can be difficult. Free-riding incentives exist, because outsiders to the patent pool profit from the pool's effect of reducing total royalties without joining the patent pool. The free-rider effect has been identified by previous work on stability issues of coalitions and especially of patent pools as the main problem of forming a stable agreement. I further analyse the free-rider incentive on the patent pool and show that the incentive depends on the increase in the share of total profits and the decrease in demand due to individual licensing.

So far, models on the stability of patent pools assumed that patent owners are myopic when deciding whether to become a member of a patent pool. Assuming that patent owners foresee reactions by other patent owners changes the results on stability. I derive a general algorithm that defines the farsightedly stable set of patent pool outcomes. Assuming farsighted patent owners can lead to stable outcomes that include at least as many patent owners in the patent pool than when assuming myopic patent owners. The application of the algorithm to linear demand and price-leadership of the patent pools identifies interesting characteristics of the farsightedly stable set. I show that a complete break-up of the patent pool is never profitable. The smallest farsightedly stable patent pool includes at least 50% of all patent owners. For more than six firms, outcomes with higher participation rates exist. Grand pools can be farsightedly stable, even for high number of patent owners. Free-riding might also exist with farsighted patent owners, but farsighted behaviour reduces the incentives to free-ride on the low patent pool royalty. This model contrasts the results on the stability by other models on the stability of patent pools such as Aoki (2005); Aoki and Nagaoka (2005); Lévêque and Ménière (2011); Llanes and Poblete (2014), which assume myopic behaviour.

These results are not restricted to the analysis of patent pools but can also be applied to other coalition formation problems such as cartels, patent pools, team formation or group agreements.

Previous successful and unsuccessful attempts to form a patent pool have shown that patent owners react and act very strategically when deciding whether to join a patent pool. The process of patent pool formation is tedious especially because no patent owner promises to definitely join the pool until the last minute of the negotiation. It happened that patent owners left the room at the moment of signing the contracts. These incidences and methods demonstrate that the model's assumption about foresight and strategic behaviour of the patent owners describes reality well.

Because the application of farsighted stability results in a set of possible outcomes, all being farsightedly stable, patent owners can be caught in an outcome with a low participation rate, unable to agree on a Pareto improving higher participation. Otherwise, if negotiations about the formation of a patent pool start at a point where all patent owners are already in one coalition and single patent owners then debate about leaving the coalition, a patent pool with high participation is possible. This raises the question if policies by the standard setting organizations concerning the formation of patent pools that build upon a given standard can improve the problem of the difficult and time-consuming process of patent pool formation.

Patent owners in my model are assumed to behave non-cooperatively, with unilateral moves. For future research it would be interesting to analyse patent pool stability if patent owners are able to coordinate their moves. Another interesting extension is to allow several patent pools to form. If in my model the outsider firms form a second patent pool, this would further reduce cumulative royalties. But the possibility of a second patent pool also affects the incentive to join a patent pool. The overall effect on cumulative royalties and patent owner profit depends on whether allowing for more than one patent pool leads to a dissolution of the single patent pool derived in this model or whether addition pool(s) form that include only the patent owners which did not join the pool in my model.

APPENDIX 2.A

Proof of Lemma 2.1

Similar to Shapiro (2001) it can be shown that the royalties in the integrated pool are lower than the royalties if firms license their patents independently. The demand for the product is $Q(p)$ and the price $p = c + \sum_{i=1}^{n} r_i$. The price elasticity of demand for the product is defined by $\epsilon = -\frac{Q'(p)p}{Q(p)}$. The profit of each firm $i = \{1, ..., n\}$ is given by

$$\pi_i = Q(p)r_i \; . \tag{9}$$

If each firm sets its royalty independently and non-cooperatively, the FOC for firm i is

$$\frac{\partial \pi_i}{\partial r_i} = Q(p) + Q'(p)r_i = 0 \; . \tag{10}$$

Adding up across all n firms gives

$$nQ(p) + Q'(p)\sum_{i=1}^{n} r_i = 0 \; , \tag{11}$$

which can be rewritten to

$$\frac{\sum\limits_{i=1}^{n} r_i}{p} = -\frac{Q(p)}{Q'(p)p} n \; . \tag{12}$$

Using the definition of elasticity, we have

$$\frac{\sum\limits_{i=1}^{n} r_i}{p} = -\frac{n}{\epsilon} \; . \tag{13}$$

If n firms set their royalty independently and non-cooperatively, the percentage of the sum of royalties relative to the product price is n times the inverse elasticity of demand for every price. In contrast, the percentage of the pool royalty relative to the product price if firms price and license their patents as a bundle is only the inverse elasticity of demand. To see this, define the profit of the pool when licensing jointly and selling the bundle of licences for a royalty of r^{FI} by

$$\pi = Q(p)r^{FI} \text{ with } p = r^{FI} + c \,. \tag{14}$$

The FOC for profit maximising of the pool is

$$\frac{\partial \pi}{\partial r^{FI}} = Q(p) + Q'(p)r^{FI} = 0 \,, \tag{15}$$

which can be rewritten to

$$\frac{r^{FI}}{p} = -\frac{Q(p)}{Q'(p)p} \,. \tag{16}$$

Using the definition of the elasticity, we have

$$\frac{r^{FI}}{p} = -\frac{1}{\epsilon} \,. \tag{17}$$

For the cumulative royalty in the NI case we have $\sum_{i=1}^{n} r_i = \frac{np}{\epsilon}$, whereas we have $r^{FI} = \frac{p}{\epsilon}$ in the FI case. $r^{FI} = \frac{p}{\epsilon} < \sum_{1}^{n} r_i = \frac{np}{\epsilon}$ $\forall n > 1$. The cumulative royalty in case of PI is in between the cumulative royalty of the NI case and the FI case because some firms bundle their patents and others set their royalty non-cooperatively. □

Derivation of k_1^s *and* k_2^s *(Section 2.4)*

Setting $\pi_i^p(k_1) = \pi_i^o(k_1 - 1)$ and solving for k_1 yields $k_1^{\pm} = \frac{1}{4}(5 + 3n \pm \sqrt{n^2 - 2n - 7})$. k_1^+ is not relevant because $k_1^+ > n$ but $k \leqslant n$ always has to hold. $k_1^s = \lfloor k_1^- \rfloor$ because we search for the number of firms k_1^s such that $\pi_i^p(k_1) \geqslant \pi_i^o(k_1 - 1)$, with k being a positive natural number.

Setting $\pi^p(k_2) = \pi^o(k_1^s)$ and solving for k_2 yields $k_2^{\pm} = \frac{1}{2}(1 + n + \pm\sqrt{-(1 + n - 2k_1^s)(3 + 3n - 2k_1^s)})$. k_2^- is not relevant because $k_2^- > n$. $k_2^s = \lceil k_2^+ \rceil$ because we search for the number of firms k_2^s such that $\pi_i^p(k_2) \geqslant \pi_i^o(k_1)$, with k being a positive natural number. The derivation of k_3^s, k_4^s etc. follows the same procedure as the derivation of k_2^s.

	profits per patent owner																							
n	4		5		6		7		8		9		10		11		12		13		14		15	
k	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}	π_i^{PIo}	π_i^{PIp}
n	–	5.1	–	4.1	–	3.4	–	2.9	–	2.5	–	2.3	–	2.0	–	1.8	–	1.7	–	1.6	–	1.5	–	1.4
n-1	5.1	3.4	5.1	2.5	5.1	2.0	5.1	1.7	5.1	1.5	5.1	1.3	5.1	1.1	5.1	1.0	5.1	0.9	5.1	0.8	5.1	0.8	5.1	0.7
n-2	2.3	3.4	2.3	2.3	2.3	1.7	2.3	1.4	2.3	1.1	2.3	1.0	2.3	0.8	2.3	0.8	2.3	0.7	2.3	0.6	2.3	0.6	2.3	0.5
n-3	1.3	5.1	1.3	2.5	1.3	1.7	1.3	1.3	1.3	1.0	1.3	0.8	1.3	0.7	1.3	0.6	1.3	0.6	1.3	0.5	1.3	0.5	1.3	0.4
n-4			0.8	4.1	0.8	2.0	0.8	1.4	0.8	1.0	0.8	0.8	0.8	0.7	0.8	0.6	0.8	0.5	0.8	0.5	0.8	0.4	0.8	0.4
n-5					0.6	3.4	0.6	1.7	0.6	1.1	0.6	0.8	0.6	0.7	0.6	0.6	0.6	0.5	0.6	0.4	0.6	0.4	0.6	0.3
n-6							0.4	2.9	0.4	1.5	0.4	1.0	0.4	0.7	0.4	0.6	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.3
n-7									0.3	2.5	0.3	1.3	0.3	0.8	0.3	0.63	0.3	0.5	0.3	0.4	0.3	0.4	0.3	0.3
n-8											0.3	2.3	0.3	1.1	0.3	0.8	0.3	0.6	0.3	0.5	0.3	0.4	0.3	0.3
n-9													0.2	2.0	0.2	1.0	0.2	0.7	0.2	0.5	0.2	0.4	0.2	0.3
n-10															0.2	1.8	0.2	0.9	0.2	0.6	0.2	0.5	0.2	0.4
n-11																	0.1	1.7	0.1	0.8	0.1	0.6	0.1	0.4
n-12																			0.1	1.6	0.1	0.8	0.1	0.5
n-13																					0.1	1.5	0.1	0.7
n-14																							0.1	1.4

Table 2.A1: Extended example of myopic and farsighted stability

3 THE INCENTIVE EFFECT OF COMPETITION

3.1 INTRODUCTION

It is often observed that individuals exert more effort when they are competing against each other. Also experiments on contests have shown that subjects' effort provision in contests is significantly higher than the risk-neutral equilibrium prediction (Dechenaux et al., forthcoming). This incentive effect of competition also seems to be prevalent in the management of firms. Bloom and Van Reenen (2007) show that poor management practices are more prevalent if product market competition is weak. Leibenstein's (1966) hypothesis of 'X-inefficiency' assumes that in the absence of strong competitive pressure, firms have a weakened incentive to reduce costs. If monopolistic firms exploit fewer profitable opportunities to reduce cost or to increase profit than competitive firms, this contradicts the neoclassical model. This model predicts that all profit-maximizing firms should have the same incentive to minimize costs and to pursue profitable innovations.

In this chapter, we want to answer whether competition affects the provision of effort independent of the monetary incentives provided in markets of differing degrees of competition. We therefore conduct a set of laboratory experiments designed to understand whether competition has an effect on investment decisions independent of monetary incentives.

There is by now a large body of theoretical and empirical literature on the effect of competition on innovation and vice versa. Despite its vastness, the literature has so far neglected the effect of competition on the incentives to invest which cannot be explained by differing monetary incentives.

The experimental method allows us to vary the degree of product market competition in a controlled manner as well as to observe the investments. We conduct three treatments with different degrees of competition but with the same Nash equilibrium (NE) investment to examine whether competition affects the investment choice. There are three main advantages of our set-up compared to empirical studies. First, we can draw clear-cut interpretations of causality, whereas with field data the causality of competition and innovation remains elusive. Second, we can control for the investment costs and the innovation technology which are diverse across firms and difficult to control for in an empirical analysis. Third, subjects are randomly assigned to one of the treatments that differ in the degree of competition, whereby we can circumvent self-selection of individuals in more or less competitive markets.

In our experiment, a subject decides how much to invest in a risky R&D project. The project's probability of success increases with the investment of the subject, but some uncertainty about the outcome of the project persists. The project either succeeds or fails and the probability of success depends only on the subject's investment. In the monopoly treatment, a subject's payment depends only on the outcome of its investment in the R&D project. In the treatments with a competitive market, a subject's payment depends on its own and on the competitors' project outcome. The experiment is designed in such a way that in equilibrium the monetary incentives to invest in the R&D project are independent of the degree of competition. This allows us to directly compare the investments under different degrees of competition.

We find that subjects in the competitive treatments invest significantly more than subjects in the monopoly treatment. We also observe that primarily subjects of the competitive treatments choose to invest their whole endowment in the risky project.

Why do subjects in the competitive treatments invest significantly more in the risky project than subjects in the monopoly treatment? What aspect of competition incentivizes the subjects to invest more? Subjects in the competitive treatments are confronted with a more complex investment decision. In the competitive treatments, subjects are exposed to the objectively assessable risk of failure, as well as to the risk that arises from the strategic interaction of the subject's project outcomes. Since subjects invest simultaneously, they do not know their competitor's(s') investment. One explanation for the difference in investments might be that subjects in the competitive treatments have beliefs about the investment of the other subject(s) which justify the observed investments. This explanation seems very implausible in our case as only very low investments by the other subject(s) can justify the observed investments.

We conduct a second experiment in which we still have a competitive and a monopoly treatment, but we control for some aspects of competition. Subjects invest sequentially, this eliminates the differences in complexity and uncertainty between the treatments. Subjects in the monopoly and the duopoly treatment are exposed to an exogenous uncertainty which is objectively assessable. Furthermore, we design the experiment in such a way that the monetary incentives to invest are always the same across treatments.

In this second experiment we find that there is no such clear effect of competition on investments as in the experiment with simultaneous investments. Our data show that subjects in the monopoly and duopoly treatments on average invest the same amount. This result suggests that a higher degree of complexity and the uncertainty about the competitor's decision are possible drivers of the higher investment in the competitive treatments which we observed in the first experiment. The experiment with sequential investment also shows that subjects in both treatments do not choose the optimal strategy. We find a significant difference in subjects' investment decisions when controlling for the exogenous uncertainty. Subjects in the duopoly treatment increase their investment if their expected payment decreases exogenously, subjects in the monopoly treatment decrease their investment if their expected payment decreases exogenously. This difference—motivating vs. discouraging investments—can only be explained by the incentive effect of competition, because the relationship between cost of investment and probability of success is in both treatments unaffected by the exogenous shock.

These results help to reconcile some of the seemingly conflicting and diverging findings in field evidence and provide controlled evidence that the degree of competition has an effect on individuals' investment incentives that cannot be explained by monetary differences.

Our research question is closely related to three strands of literature—the theoretical and empirical IO literature on competition and innovation, the experimental literature on competition and innovation and experiments on contests. The theoretical IO literature on competition, investments and innovation goes back to Schumpeter (1942) and Arrow (1962) and offers mixed results, depending on the underlying model (Bertrand or Cournot competition) and the characteristics of the market (the type of product differentiation, heterogeneity across firms, technological level of firms, etc.).[1] Other models investigate the effect of competition on managerial incentives (Martin, 1993; Schmidt, 1997; Raith, 2003). Managerial practices may provide an explanation for differences in productivity performances between firms and industries. Schmidt (1997) provides a theoretical explanation for the link between competitive pressure and managerial slack. In his model, competition incentivizes the manager either to work harder in order to avoid liquidation or to work less because the profit reduction renders his effort unprofitable. The model shows that the optimal incentive scheme for the manager depends on the competitive environment of the firm. Organizational slack and inefficient management due to the lack of competition was already mentioned by Leibenstein (1966). Collecting management practice data, Bloom and Van Reenen (2007) show that poor management practices are more prevalent when product market competition is weak. Although this study provides an interesting insight, it cannot answer if variations in management practices result from the differences in competition or vice versa.

The same problem exists in the empirical literature on competition and innovation. Using field data has the problem of mutual endogeneity when analysing the relationship between competition and innovation. Besides, it cannot be determined whether competition has an effect on innovation because of incentive or selection effects. Empirical studies find that either innovation increases linearly with competition (Geroski, 1994; Nickell, 1996; Blundell et al., 1999) or there is an inverted U-shaped relationship between competition and innovation (Scherer, 1967; Aghion et al., 2005).[2] Aghion et al. (2005) argue that the inverted U-shape emerges because the competitiveness of an industry is endogenous and varies with innovative activity. Depending on the innovation level, anti- or pro-competitive effects of an increase in the innovation level dominate.

There are several existing experiments on the relationship between competition and innovation. Isaac and Reynolds (1992) find a positive correlation between competition and cost-reducing R&D investments as well as Sacco and Schmutzler (2011), who consider an increase in competition by a switch from Cournot to Bertrand competition. Sacco and Schmutzler (2011) find

1 We refer to Vives (2008) and Schmutzler (2013) for an overview of the theoretical IO literature on competition, investments and innovation.
2 Gilbert (2006) gives an overview of the empirical literature on competition and innovation.

that an increase from two to four players in a Cournot setting leads to lower average investments. In Schmutzler et al. (2010) the degree of competition is varied by the degree of product differentiation. In a one-stage game, they find weak experimental evidence for a U-shaped relationship between competition and innovation. Aghion et al. (2014) test the effect of product market competition on innovation in a dynamic step-by-step innovation model. They find an encouraging effect of competition on innovation for neck-and-neck firms and a weak discouraging effect for laggard firms. The results of these experiments on competition and innovation are mixed because the rewards for innovation depend on the definition of the product market competition. Experiments on competition and innovation have so far focused on the monetary incentives to invest, which is not the case with our experiment. We do not explicitly model the market in which the subjects compete and we design the experiment in such a way that the monetary incentives are in equilibrium independent of the degree of competition.

Our experiments also reveal similarities to experiments on contest.[3] Experiments on Tullock (1980) contests (Millner and Pratt, 1989; Shogren and Baik, 1991), in which several agents exert effort to increase the probability of winning a prize, have shown that the dissipation rate[4] is significantly higher than predicted. We also find in our experiments that subjects overinvest. Similar to these studies, we also find a high variation in individual investments. In experiments on contests with negative spillovers from investments (Coughlan and Plott, 1997; Mancini and Dechenaux, 2008), the payoff decreases if the competitor is successful. This also holds in our experiment, but several features of our design are different from contests: In our model, the probability of success does not depend on the investments of the other subjects and there is more than one price. Unlike in experiments on innovation tournaments (Fullerton et al., 1999), subjects' participation in our experiment is exogenous.[5]

While our experimental study is conducted in an artificial environment, it offers several advantages over field studies. Among other problems, we can eliminate a selection bias that may appear in empirical studies. Monopolized

3 See Dechenaux et al. (forthcoming) for an extensive overview of experiments on contests and Baye and Hoppe (2003) for an overview of innovation tournaments and patent races.

4 total effort divided by total price

5 Even though the subjects in our experiment are allowed to invest zero points in the R&D project, they always compete with each other.

companies may attract different workers and managers than companies that are under strong competitive pressure. Frequently, monopolies are or were at some time related to state institutions, thus exhibiting different wage and pension systems than privately owned companies. These aspects may cause companies under less competitive pressure to have a different work force than other companies. In addition, these companies may offer different incentives to their employees by their payment system.

Furthermore, in our experiment we are able observe investments under different degrees of competition directly. By holding the degree of competition constant, we eliminate one of the biggest problems of empirical studies on competition and innovation. Because innovative activity influences the degree of competition and vice versa, causal relationships are hard to obtain. In our experiment, the incentives to invest depend on the bonuses which the subjects receive in case of success or failure of their investments, but the investments and the project outcomes do not affect the degree of competition. We can control for the monetary incentives and are thus able to separate the monetary effect from the incentive effect of competition.

The remainder of the chapter is organized as follows. Section 3.2 explains our experimental design of the experiment with simultaneous investments. Section 3.3 presents and discusses the results. We introduce the experiment with sequential investments in Section 3.4 and provide our conclusion in Section 3.5.

3.2 EXPERIMENTAL DESIGN AND HYPOTHESES

3.2.1 *Experimental Design*

Consider a manager who can decide how to divide his endowment between a project with safe return and a risky R&D project of his firm. The more he invests in the firm's R&D project, the higher is the probability of success of the project. A successful project increases the firm's profits and the manager is rewarded with a bonus payment.

Our experimental design captures the trade-off between investing in a risky project which might be successful and generate high profits and not investing. Only the manager's own investment in the R&D project has an effect on the success or failure of the R&D project. To investigate the effect of competition on the manager's investment, we conduct three treatments that differ in the degree of competition in the market of the manager's firm. Each treatment involves 20 periods.

In the MONOPOLY treatment, there is a single firm in the market and the subject's bonus payment in this treatment depends only on the outcome of his investment.[6] In the DUOPOLY treatment, two firms compete with each other. We therefore randomly matched two subjects in each of the 20 periods of the experiment. The bonus payment of each subject depends not only on the success of its own R&D project, but also on the other subject's success of the R&D project.[7] In the OLIGOPOLY treatment, four firms compete with each other. We therefore randomly matched four subjects in each of the 20 periods of the experiment. The bonus payment of each subject depends not only on the success of its own R&D project, but also on the outcome of the R&D project of the other three firms.

The timing of one period of the investment game is as follows. First, each subject decides how much of its endowment it wants to invest in the R&D project. The remainder is automatically invested in a risk-free project. Then a random draw for each subject independently decides on the outcome of the R&D projects. Each subject is informed about the outcome of its own R&D project and its bonus payment, and in the competitive treatments subjects are also informed about the outcome of R&D project of the other subject(s). In all three treatments, the relationship between investment and probability of success and the return on the risk-free project is the same.

3.2.2 *Experimental Procedure*

In all treatments, the investment game is repeated over 20 periods with rematching in the competitive treatments in each period. We conducted the experiment with a between-subject design in which each participant attended only one session. Prior to the investment game, subjects read the instruc-

6 The bonus payments are described in detail in Section 3.2.3.

7 The managers' bonus payments of the investment are motivated as follows: A successful innovation increases the profits of a firm. If the firm is the only firm with a successful innovation, it can improve its position in the market and earn even higher profits. The bonus the manager receives from the firm increases with the profit of the firm.

tions and answered control questions.[8] After the game, subjects answered questions regarding their risk, loss and ambiguity aversion, and filled in a standard form.

We conducted the experiments at MELESSA of the University of Munich in 2012/13. We conducted two sessions per treatment, with 20–24 subjects in each session, a total of 130 subjects participating in the experiments. In each DUOPOLY treatment session we had three matching groups with six subjects each and one with four subjects. In each OLIGOPOLY treatment session we had one matching group with 12 subjects and one with eight subjects. The experiment was computerized using the software z-Tree (Fischbacher, 2007) and ORSEE (Greiner, 2004). About 61% of all participants were female and the average age was 24.6 years. Sessions lasted about 75 minutes. Subjects were paid their earnings of all periods plus the outcome of a test in which we elicited subjects' risk, loss and ambiguity aversion.[9] On average, subjects earned about EUR 19.64, including a show-up fee of EUR 4. During the experiment, payments were expressed in points (500 points = 1 Euro).

3.2.3 *Theoretical Predictions and Hypotheses*

The central question of this experiment is whether competition has an effect on subjects' investments which cannot be explained by monetary incentives. The standard neoclassical approach assumes that people are fully rational and maximize their payments. If this is true, each subject in our experiment decides to invest the amount in the R&D project that maximizes its expected total payoff. Subjects in the DUOPOLY and in the OLIGOPOLY treatment take into account the investments of their competitor(s). In the following, we derive the payoff maximising investment for each treatment.

The initial endowment of each subject in each period is 100 points. The possible investments in the R&D project are $I_i = \{0, 10, 20, ..., 100\}$ points.

8 The instructions of the experiment are included in Appendix 3.A.3.

9 Following the investment game, we conducted tests to elicit the participants' risk, loss and ambiguity aversion in order to control for possible correlations between the investment and risk, loss and ambiguity aversion. The test we used for the elicitation of risk aversion is similar to the one used by Dohmen et al. (2010) and Holt and Laury (2002), the test on loss aversion is similar to Gaechter et al. (2010) and Fehr and Goette (2007) and the test on ambiguity aversion is a modified version of Ederer and Manso (2013). For each participant one of the lotteries was randomly chosen for payment at the end of the experiment. The tests can be found in Appendix 3.A.3.

Depending on the investment I_i, the probability of being successful p_i in this period is between 0% and 86% for subject i. The relationship between investment I_i and success probability p_i is given by

$$I_i(p_i) = \frac{p_i^2}{0.0075} \quad \forall\, i\,. \tag{1}$$

Table 3.1 shows the relationship between investments and the probability of success with rounded values. The information of the table was included in the participants' instructions (see Appendix 3.A.3).[10] The investment in the R&D project is subtracted from the initial endowment and the remainder is automatically invested in a risk-free project.

Investment in R&D project	0	10	20	30	40	50	60	70	80	90	100
Probability of success in %	0	27	39	47	55	61	67	73	78	83	86

Table 3.1: Relationship between investment and probability of success

Monopoly *Treatment*

Equation (2) shows the payoff function of a subject in the MONOPOLY treatment, which consists of the bonus and the return on the risk-free invested remainder of the endowment.

$$\pi^M = \begin{cases} 400 + 2(100 - I_i) & \text{if success} \\ 110 + 2(100 - I_i) & \text{if no success} \end{cases} \tag{2}$$

Equation (2) can be rewritten to

$$\pi^M(p_i, I_i) = p_i\, 400 + (1 - p_i)110 + 2(100 - I_i)\,. \tag{3}$$

Proposition 3.1. *The unique payoff-maximising investment in the* MONOPOLY *treatment is given by* $I^* = 40$.

Proof. See Appendix 3.A.1.

10 Note that the probability of a successful innovation increases with the investment, but the increase declines as the investment rises. A subject can increase its probability of a successful R&D project by investing more, but some probability of failure always remains (maximal probability of success is 86%).

DUOPOLY *Treatment*

Equation (4) shows the payoff function of subject $i = 1, 2$, with $i \neq j$ $j = 1, 2$ in the DUOPOLY treatment.

$$\pi_i^D = \begin{cases} 490 + 2(100 - I_i) & \text{if } i \text{ succeeds and } j \text{ fails} \\ 210 + 2(100 - I_i) & \text{if } i \text{ and } j \text{ succeed} \\ 90 + 2(100 - I_i) & \text{if } i \text{ and } j \text{ fail} \\ 10 + 2(100 - I_i) & \text{if } j \text{ succeeds and } i \text{ fails} \end{cases} \tag{4}$$

Equation (4) can be rewritten to

$$\begin{aligned} \pi_i^D(p_i, p_j, I_i) = & p_i(1 - p_j)\,490 + p_i\,p_j\,210 + (1 - p_i)(1 - p_j)\,90 \\ & + (1 - p_i)p_j\,10 + 2(100 - I_i), \quad i \neq j. \end{aligned} \tag{5}$$

The payoff function π_i^D depends on subject i's probability of success p_i, the other subject's probability of success p_j and i's investment I_i.

Proposition 3.2. *The investments of the two subjects are strategic substitutes. The unique Nash equilibrium in the* DUOPOLY *treatment is given by* $(I_1^*, I_2^*) = (40, 40)$.

Proof. See Appendix 3.A.1.

OLIGOPOLY *Treatment*

Equation (6) shows the payoff function of subject $i = 1, 2, 3, 4$ in the OLIGOPOLY treatment.

$$\pi_i^O = \begin{cases} 770 + 2(100 - I_i) & \text{if } i \text{ succeeds and all others fail} \\ 360 + 2(100 - I_i) & \text{if } i \text{ and one other succeed and the others fail} \\ 200 + 2(100 - I_i) & \text{if } i \text{ and two others succeed and one fails} \\ 100 + 2(100 - I_i) & \text{if all succeed} \\ 50 + 2(100 - I_i) & \text{if all fail} \\ 10 + 2(100 - I_i) & \text{if } i \text{ fails and all other succeed} \end{cases} \tag{6}$$

Equation (6) can be rewritten to

$$
\begin{aligned}
\pi_i^O(p_i, p_j, p_k, p_l, I_i) = & p_i(1-p_j)(1-p_k)(1-p_l)\ 770 \\
& + p_i\ p_j(1-p_k)(1-p_l)\ 360 \\
& + p_i\ p_k(1-p_j)(1-p_l)\ 360 \\
& + p_i\ p_l(1-p_j)(1-p_k)\ 360 \\
& + p_i\ p_j\ p_k(1-p_l)\ 200 \\
& + p_i\ p_l\ p_k(1-p_j)\ 200 + p_i\ p_j\ p_l)(1-p_k)\ 200 \\
& + p_i\ p_j\ p_k\ p_l\ 10 \\
& + (1-p_i)(1-p_j)(1-p_k)(1-p_l)\ 50 \\
& + (1-p_i) p_j\ p_k\ p_l 10 + 2(100 - I_i)\ , i \neq j \neq k \neq l\ . \qquad (7)
\end{aligned}
$$

The payoff function π_i^O depends on subject i's probability of success p_i, the other subjects' probabilities of success p_j, p_k, p_l and i's investment I_i.

Proposition 3.3. *The investments of the four subjects are strategic substitutes. The unique Nash equilibrium in the* OLIGOPOLY *treatment is given by* $(I_1^*, I_2^*, I_3^*, I_4^*) = (40, 40, 40, 40)$.

Proof. See Appendix 3.A.1.

Propositions 3.1,3.2 and 3.3 show that the optimal investment in the MONOPOLY treatment and the Nash equilibrium investment in the DUOPOLY and in the OLIGOPOLY treatment are identical. The monetary incentives to invest in the R&D project are in equilibrium independent of the degree of competition. The equality of the optimal investments across treatments allows us to directly compare the investments under different degrees of competition. We compare the average investment in the R&D project of the 20 periods across the MONOPOLY, DUOPOLY and OLIGOPOLY treatment. Hypothesis 3.1 follows from the theoretical predictions of Propositions 3.1, 3.2 and 3.3.

Hypothesis 3.1. *The investments in the R&D project are the same in the* MONOPOLY, DUOPOLY *and* OLIGOPOLY *treatment.*

3.3 RESULTS

Comparing the average investments over all periods across treatments shows significant differences in investments. The average investment in the R&D project in the MONOPOLY treatment is 50.4 points. In the DUOPOLY treatment, the average investment in the R&D project is 63.5 points and 59.5 points in the OLIGOPOLY treatment. Figure 3.1 shows the average investments per treatment with 95% confidence interval error bars. Average investments from period 5–20 are very similar to the average over all periods.

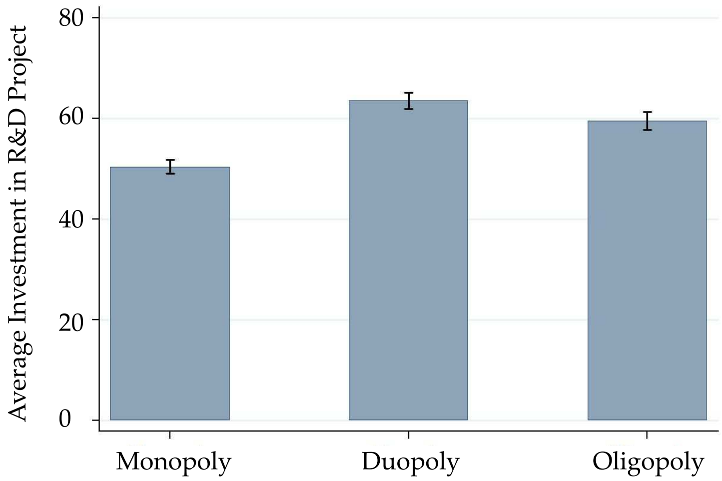

Figure 3.1: Average investments in the R&D project by treatment

Result 3.1. *In all treatments, subjects invest significantly more in the R&D project than predicted by the Nash equilibrium.*

In all three treatments, subjects overinvest in the R&D project compared to profit-maximising equilibrium investment (sign tests, p-values < 0.001). Overinvestments have been observed before in several experiments on investment decisions, for example in Sacco and Schmutzler (2011), and in most experiments on contests (for a discussion see Sheremeta, 2013).

A Wilcoxon rank-sum test on the equality of investments between treatments on subject averages yields a p-value< 0.001 for the DUOPOLY and a p-value of 0.0327 for the OLIGOPOLY treatment. We do not find a significant difference between investments in the DUOPOLY and the OLIGOPOLY treatment (Wilcoxon rank-sum test, $p = 0.1517$).

Result 3.2. *The average investment in the* DUOPOLY *treatment and the average investment in the* OLIGOPOLY *treatment are significantly higher than the average investment in the* MONOPOLY *treatment.*

The treatment difference between the MONOPOLY treatment and the competitive treatments is also significant in an OLS regression in which we compare investments across treatments. Table 3.2 reports the regression results. The results of regression (1) show that subjects in the DUOPOLY treatment invest on average 13.13 points more than in the MONOPOLY treatment ($p < 0.001$) and that subjects in the OLIGOPOLY treatment invest 9.12 points more than in the MONOPOLY treatment ($p = 0.017$).[11]

The treatment difference between the MONOPOLY treatment and the competitive treatments stays significant when we control for *gender, age, risk aversion, loss aversion* and *ambiguity aversion* in regression (2).[12] The only marginally significant control variable is *age*, which has a positive effect on the investment in the R&D project. None of the period dummies included in regression (2) is significant, i.e. there does not seem to be a time trend or end game effect. Figure 3.A1 in Appendix 3.A.1 shows average investments per treatment over periods and also does not indicate a time trend in any of the treatments. The main results also do not change if we consider only the investments in period 1, the average investment over periods or if we cluster the standard errors on matching groups instead of on subjects (see Table 3.A1 in Appendix 3.A.1).

Based on Result 3.2 we can reject Hypothesis 3.1. Investments differ significantly between the MONOPOLY treatment and the competitive treatments. To examine the differences in the average investments in more detail, Figure 3.2 displays the distribution of investments in the R&D project. We observe that investments are dispersed over the whole range in all treatments. Some subjects invests nothing of their endowment in the project, others invest their whole endowment of 100 points. High investments of 80 or more points are chosen in only 13.6% of all cases in the MONOPOLY treatment, but in 32.5% of all cases in the DUOPOLY and in 30.1% of all cases in the OLIGOPOLY treatment.

11 The difference between the DUOPOLY and the OLIGOPOLY treatment is also not significant in a *F*-test of the dummy coefficients in regression (1) of Table 3.2 ($p = 0.3205$).

12 See [9] for the description of the tests we used for the elicitation of risk, loss and ambiguity aversion (included in Appendix 3.A.3). Points range from 0 to 10 in the risk self-assessment and 0 to 7 in the tests. Higher values imply higher degree of aversion against risk, loss or ambiguity.

	Investment in R&D project	
	(1)	(2)
Duopoly	13.13***	13.27***
	(3.308)	(3.450)
Oligopoly	9.120**	9.319**
	(3.786)	(3.637)
Female		-4.662
		(3.166)
Age		0.544*
		(0.277)
Risk aversion		1.248
		(1.271)
Risk aversion quest.		-0.671
		(0.959)
Loss aversion		1.124
		(0.987)
Ambiguity aversion		-1.937
		(1.705)
Period dummies		yes
Period 1		-4.308*
		(2.313)
Constant	50.38***	40.85***
	(2.161)	(11.66)
Observations	2600	2600
Adjusted R^2	0.051	0.078

Notes: The table reports coefficients of OLS regressions. Robust standard errors are clustered by subject and reported in parentheses. In regression (2), only the dummy for period 1 is significant. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table 3.2: Determinants of the investment in the R&D project

The highest possible investment was chosen in less than 2% of all cases in the MONOPOLY treatment compared to 14.3% and 16.8% in the DUOPOLY and the OLIGOPOLY treatment.

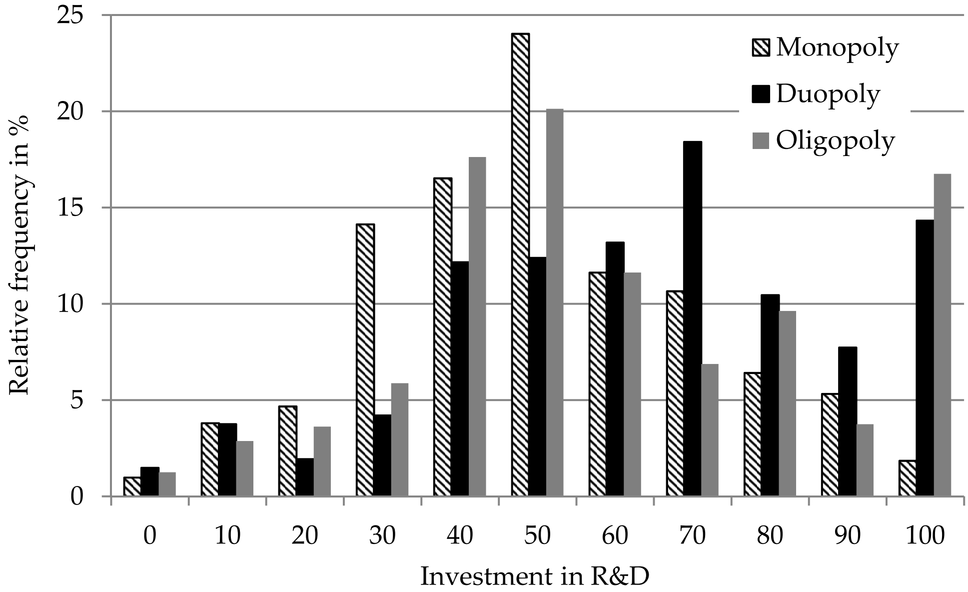

Figure 3.2: Frequencies of chosen investments in the R&D project by treatment

The observed difference in investments depending on the degree of competition raises the question which aspect of competition incentivizes the subjects in the competitive treatments to invest more than the subjects in the MONOPOLY treatment. Joy of winning is often observed in experiments. In our experiment, subjects in all treatment can experience joy of winning, but only subjects in the competitive treatments can experience joy of winning against another subject. But even though a high investment increases the probability of a successful R&D project, there is no direct link from high investments to being the only successful subject, i.e. winning against the other subject(s).

A competitive market is more complex and riskier for the market participants than a monopolistic market. In our experiment, the investment decision in the competitive treatments involves more complexity than the investment decision in MONOPOLY treatment. Whereas the payoff in the MONOPOLY treatment depends only on the outcome of the subjects own R&D project, the payoffs in the competitive treatments also depend on the outcome of the other subject's(s') R&D project. The investment in the MONOPOLY treatment involves the endogenous risk of failure of the investment and each subject knows its probability of success and thereby its probability of receiving the highest bonus. The investment in the competitive treatments involves the endogenous risk of failure of the own project and the exogenous risk of success of the competitor(s). Because subjects in the competitive treatments do not know their competitor's(s') investment, they can only form *subjective* probabilities about receiving the highest bonus.[13]

One explanation for the observed difference in average investments across treatments might be that subjects in the competitive treatments have beliefs about the investment(s) of the other subject(s) that justify the observed investments. In order for the DUOPOLY treatment's average investment of 63.5 points to be a best response, a subject's belief about the other subject's investment has to be extremely low. To see this, remember that the investments in the R&D project are strategic substitutes (Propositions 3.2 and 3.3), hence if one subject believes that its competitor(s) invest more than the optimal investment of 40 it should invest less and vice versa. This can be read from the Tables 3.A3 and 3.A4 in Appendix 3.A.1. These payoff-tables show that choosing an investment between 60 and 70 is only a best response if the other subject chooses an investment of 0 or 10.

The average investment of 59.9 observed in the OLIGOPOLY treatment is a best response if subjects believe that each of the three competitors invests either 20 or 30 in the R&D project. This can be read from Table 3.A5. Especially the belief in the DUOPOLY treatment seems unreasonable to us, therefore we do not think that the difference in investments between the MONOPOLY and the competitive treatments can be explained by beliefs.

3.4 EXPERIMENT WITH SEQUENTIAL INVESTMENTS

We conduct a second experiment in which we control for differences between a competitive market and a monopolistic market. The main design of the second experiment is similar to the first one, but subjects invest sequentially so that we can control for beliefs. Additionally, the sequential design makes

13 Even though subjects in the competitive treatments are informed about the outcome of their competitor's (competitors') R&D project when they realize their own outcome, they are not informed about the amount invested by their competitor(s).

the probability of success of subject 1 objectively assessable for subject 2. The design with sequential moves does not only expose the subjects to the same uncertainty, it also aligns the complexity of the investment decision. Furthermore, we adjust the bonus payments in such a way that the investment incentives are always (not only in equilibrium) identical, independent of the degree of competition.

The objective of the second experiment is to investigate subjects' investment behaviour under different degrees of competition, controlling for differences in complexity and uncertainty between competitive and non-competitive markets. In the first experiment we found that subjects in the DUOPOLY and OLIGOPOLY treatments invest significantly more than subjects in the MONOPOLY treatment. We are interested in whether this effect of competition on investment incentives is also prevalent in an experiment in which we further assimilate the investment decision in a monopoly and a duopoly market.

3.4.1 *Experimental Design*

The design of the experiment with sequential investments is similar to the experiment with simultaneous investments described in Section 3.2. Subjects invest in a risky R&D project and thereby determine their project's probability of success. A subject's project outcome depends only on the amount invested. The investment is costly but it increases the probability of a high bonus. We conducted two treatments. In the DUOPOLY-SEQ treatment two subjects invest sequentially. Subject 2 observes the probability of success chosen by subject 1 (p_1) and decides on its own probability of success (p_2). After two random draws decided independently from each other about the outcome of the projects, subjects learn both outcomes and their bonus. The bonus depends on a subject's own success and on the success of the other subject. The uncertainty about subject 1's project outcome imposes an exogenous risk with known probabilities on subject 2.

We introduce a nature's move in the MONOPOLY-SEQ treatment before the subject decides on its investment. This imposes an exogenous risk with objective probabilities on subject M in the MONOPOLY-SEQ treatment. This allows us to align the complexity and the uncertainty of the investment decision in both treatments. First, subject M in the MONOPOLY-SEQ treatment is informed about the probability of a bad market development (p_B), decided randomly by nature. Then it chooses the probability of success of its R&D project (p_M). The probability of a bad market development is mathematically equivalent to subject 1's probability of success. In both treatments subjects are exposed to the uncertainty of their own project's outcome and to an exogenous risk (competitor's project outcome/market development). They can influence the probability of success of their R&D project but they are not able to influence their competitor's success/the market development. In both treatments, subjects are informed about the probabilities of the exogenous uncertainty.

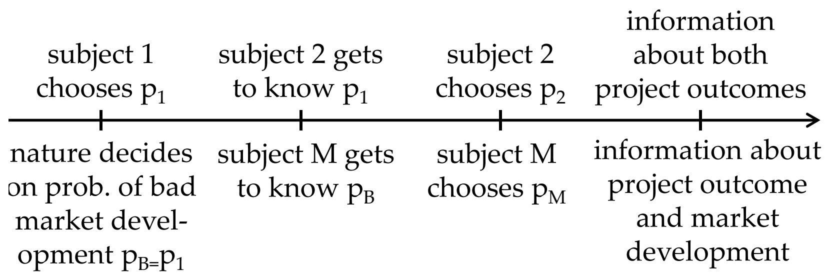

Figure 3.3: Sequence of actions in the monopoly-seq and the duopoly-seq treatment

The investment decision is repeated over 20 periods. Figure 3.3 shows the sequence of actions of one period in the monopoly-seq treatment (upper description) and the duopoly-seq treatment (lower description). In order to compare the investments of the monopoly-seq treatment and the duopoly-seq treatment, we use the probabilities chosen by subject 1 in the duopoly-seq treatment as probabilities of a bad market development in the monopoly-seq treatment. We take the complete history of probabilities p_1 over the 20 periods from one subject in the duopoly-seq treatment and use them as the sequence of probabilities p_B over the 20 periods for one subject in monopoly-seq treatment. We are only interested in the investments of subject 2 and subject M.

3.4.2 *Experimental Procedure*

We conducted the experiment with a between-subject design and each participant attended only one session. Prior to the experiment, subjects read the instructions and answered control questions.[14] After the experiment subjects answered questions regarding their risk, loss and ambiguity aversion and filled out a standard form.

The experiments took place at MELESSA of the University of Munich in 2013. We conducted nine sessions, three with the MONOPOLY-SEQ treatment and six with the DUOPOLY-SEQ treatment. Between 22 and 24 subjects participated in each session, a total of 210 subjects over all sessions. In the DUOPOLY-SEQ sessions we had either three matching groups with eight subjects or 2 groups with 8 subjects and 1 group with 6 subjects. Half of the participants in each DUOPOLY-SEQ treatment session were chosen to be first movers (subject 1), the other ones followers (subject 2). The experiment was computerized using the software z-Tree (Fischbacher, 2007) and ORSEE (Greiner, 2004).

About 61% of all participants were female and average age was 24 years. Sessions lasted about 90 minutes. Subjects were paid their earnings of one period chosen randomly out of the 20 periods plus the outcome of one randomly chosen test in which we elicited subjects' risk, loss and ambiguity aversion.[15] On average, subjects earned about EUR 16.44, including a show-up fee of EUR 4. During the experiment, payments were expressed in points (25 points = 1 Euro).

3.4.3 *Theoretical Predictions and Hypotheses*

The central question of the experiment is whether competition has an effect on investments. In this experiment with sequential investments, the complexity of the investment decision and the monetary incentives to invest are independent of the degree of competition. We again test whether subjects in both treatments invest the amount in the R&D project that maximizes their expected total payoff. In the following, we derive the payoff maximising investment for both treatments.

The initial endowment of each subject in each period is 100 points. Subjects choose the success probability p_i of their R&D project. The possible success probabilities are $p_i = \{0, 0.1, 0.2, 0.3, ..., 0.9\}$. Depending on the success probability p_i, the investment costs are between 0 and 100 points. The

14 The instructions of the experiment are included in Appendix 3.A.3.

15 See [9] and [12] for a description of the tests. The tests are included in Appendix 3.A.3.

cost of the investment increases quadratically with the success probability p_i as follows:

$$I_i(p_i) = \frac{p_i^2}{0.008} \quad \forall i\,. \tag{8}$$

Table 3.3 shows the relationship between investment cost and probability of success with rounded values. The information of the table was included in the participants' instructions (see Appendix 3.A.3).[16] The investment in the R&D project is subtracted from the initial endowment and the remainder is automatically invested in a risk-free project.

Probability of success in %	0	10	20	30	40	50	60	70	80	90
Investment costs	0	1	5	11	20	31	45	61	80	100

Table 3.3: Relationship between investment costs and probability of success of the R&D project

DUOPOLY-SEQ *Treatment*

Equation (9) shows the payoff function π_i^D of subject $i = 1, 2$ with $i \neq j$ in the DUOPOLY-SEQ treatment which is the sum of the bonus and the return on the risk-free invested remainder of the endowment.

$$\pi_i^D = \begin{cases} 200 + (100 - I_i) & \text{if i succeeds and j fails} \\ 100 + (100 - I_i) & \text{if i and j succeed} \\ 100 + (100 - I_i) & \text{if i and j fail} \\ 0 + (100 - I_i) & \text{if j succeeds and i fails} \end{cases} \tag{9}$$

Equation (9) can be rewritten to

$$\begin{aligned} \pi_i^D(p_i, p_j) = {} & p_i(1-p_j)200 + p_i p_j\ 100 + (1-p_i)(1-p_j)100 \\ & + 100 - \frac{p_i^2}{0.008}\,. \end{aligned} \tag{10}$$

16 Note that even if a subject invests its whole endowment of 100 points, the success probability is only 90%. This means that a subject can increase its probability of success by investing more in the R&D project, but some probability of failure always remains.

Proposition 3.4. *The dominant strategy in the* DUOPOLY-SEQ *treatment is given by* $p_i = 0.4$ *for* $i = 1, 2$. *The unique Nash equilibrium is* $(p_1^*, p_2^*) = (0.4, 0.4)$.

Proof. See Appendix 3.A.2.

MONOPOLY-SEQ *Treatment*

Equation (11) shows the payoff function π^M of a subject in the MONOPOLY-SEQ treatment, which is the sum of the bonus and the return on the risk-free invested remainder of the endowment.

$$\pi^M = \begin{cases} 200 + (100 - I) & \text{if project successful and market development good} \\ 100 + (100 - I) & \text{if project successful and market development bad} \\ 100 + (100 - I) & \text{if project failed and market development good} \\ 0 + (100 - I) & \text{if project failed and market development bad} \end{cases} \tag{11}$$

Equation (11) can be rewritten to

$$\begin{aligned} \pi^M(p_M, p_B) = {} & p_M(1 - p_B)200 + p_M p_B\ 100 + (1 - p)(1 - p_B)100 \\ & + 100 - \frac{p_M^2}{0.008} \ . \end{aligned} \tag{12}$$

Proposition 3.5. *The dominant strategy in the* MONOPOLY-SEQ *treatment is given by* $p_M = 0.4$.

Proof. See Appendix 3.A.2.

The payoff functions of subject M in the MONOPOLY-SEQ treatment and of subject 2 in the DUOPOLY-SEQ treatment are mathematically the same because bonuses, cost and information are the same.[17] The probability of a bad market development p_B has the same effect on subject M's expected payoff as subject 1's probability of success p_1 has on subject 2's expected payoff. The dominant strategy in both treatments is to choose a probability of success of 40%, independent of p_1 and p_M.

17 See equations (9) and (11) and Figure 3.3.

Hypothesis 3.2. *The investment of subject 2 in the* DUOPOLY-SEQ *treatment and the investment of subject M in the* MONOPOLY-SEQ *treatment are the same.*

Hypothesis 3.3. *Subject 2 and subject M both choose the dominant strategy of* $p = 0.4$. *Subject 2's investment does not depend on subject 1's probability of success. Subject M's investment does not depend on the probability of a bad market development.*

3.4.4 *Results*

The average chosen probability of success is 53.6% for subject 2 in the DUOPOLY-SEQ treatment and 52.6% for the subject in the MONOPOLY-SEQ treatment. As in the experiment with simultaneous investments, we observe that subjects invest more than the equilibrium prediction in both treatments (sign tests, p-values< 0.001). The dominant strategy of $p = 0.4$ was chosen in only 12.5% of all investment decisions in the MONOPOLY-SEQ treatment and in 9.5% of all investment decisions in the DUOPOLY-SEQ treatment.

Result 3.3. *In both treatments, subjects on average invest significantly more than predicted by the dominant strategy.*

A Wilcoxon rank-sum test on equality of the chosen probability of success in the MONOPOLY-SEQ treatment and the DUOPOLY-SEQ treatment cannot be rejected (average over periods and subjects in a treatment, $p = 0.47$). A Chi-test on independence of the distributions of the probabilities of success p_M and p_2 between the treatments rejects the hypothesis on equal investment distributions across treatments ($p < 0.001$). The treatment difference in the probabilities of success between the treatments is not significant in an OLS regression in which we compare the probability of success of subject M in the MONOPOLY-SEQ and the probability of success of subject 2 in the DUOPOLY-SEQ treatment (see Table 3.4, regression (1)).

The treatment difference becomes significant if we control for the probability of success of subject 1/the probability of a bad market development.[18]

18 These probabilities are mathematically equivalent across treatments and we used the probabilities p_1 generated by subject 1 in the DUOPOLY-SEQ treatment as probabilities of a bad market development p_B which were shown to subjects M in the MONOPOLY-SEQ treatment in our experiment.

	Probability of success of the R&D project in % (subject M and 2)		
	(1)	(2)	(3)
Monopoly	-1.029	15.05***	15.35***
	(2.647)	(4.754)	(4.722)
Prob. of subject 1/ Prob. of bad market development		0.0940*	0.0983*
		(0.0545)	(0.0527)
Monopoly × Prob. of subject 1/ Prob. of bad market development		-0.305***	-0.309***
		(0.0809)	(0.0801)
Female			5.792**
			(2.615)
Age			0.284
			(0.241)
Risk aversion			-1.735
			(1.149)
Risk aversion quest.			0.0954
			(0.861)
Loss aversion			-1.198
			(0.793)
Ambiguity aversion			-1.605
			(1.617)
Period dummies			yes
Period 1			-4.071*
			(2.211)
Period 2			-4.984**
			(2.144)
Period 13			-4.357**
			(2.197)
Constant	53.64***	48.68***	55.53***
	(1.933)	(3.418)	(10.10)
Observations	2800	2800	2800
Adjusted R^2	0.000	0.022	0.058

Notes: The table reports coefficients of OLS regressions. Robust standard errors are clustered by subject and reported in parentheses. All probabilities are expressed in percent. In regression (3), of the 20 period dummies only the listed ones are significant. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table 3.4: Determinants of the investment in the R&D project in the SEQ-experiment

Regrssion (2) in Table 3.4 shows that the treatment variable *monopoly* has a highly significant and positive effect on the chosen probability.

Regression (3) shows that the difference in the investment behaviour with and without competition is significant and large even if we control for other characteristics. Only the control variable *female* has a marginally significant and positive effect on the chosen probability. The other characteristics *age*, *risk aversion*, *risk aversion questionnaire*, *loss aversion* and *ambiguity aversion* do not have a significant effect on subjects' investment decision.[19] Controlling for period effects does not affect the results and there does not seem to be an end-game effect. Figure 3.A2 in Appendix 3.A.2 shows average investments per treatment over periods. The main results of the regressions do not change if we consider only the investments in period 1 or if we cluster the standard errors on matching groups (see Table 3.A6 in Appendix 3.A.2).

Result 3.4. *Subjects in both treatments do not choose the dominant investment strategy. The probability of success of subject 2 depends positively on the probability of success of subject 1 in the* DUOPOLY-SEQ *treatment. The probability of success of subject M depends negatively on the probability of a bad market development in the* MONOPOLY-SEQ *treatment.*

In the experiment with simultaneous investments we found that subjects in the competitive treatments invest on average significantly more than subjects in the MONOPOLY treatment (see Result 3.2). By controlling for the differences in the complexity of the investment decision and the exposure to risk we find that subjects in the DUOPOLY-SEQ treatment do not invest on average significantly more than in the MONOPOLY-SEQ treatment. We find that subject 2 and subject M both do not choose the dominant strategy which is independent of the probability of success of subject 1 and the probability of a bad market development, respectively. Instead we find that subjects react differently to the exogenous uncertainty. Regression (2) of Table 3.4 predicts the following reaction functions $p_2(p_1)$ of subject 2 and $p_M(p_B)$ of subject M, which are visualized in Figure 3.4:

$$p_2(p_1) = 0.4868 + 0.00094\, p_1 \tag{13}$$

$$p_M(p_B) = 0.6373 - 0.00211\, p_B \tag{14}$$

19 For a description of the aversion tests see Section 3.3.

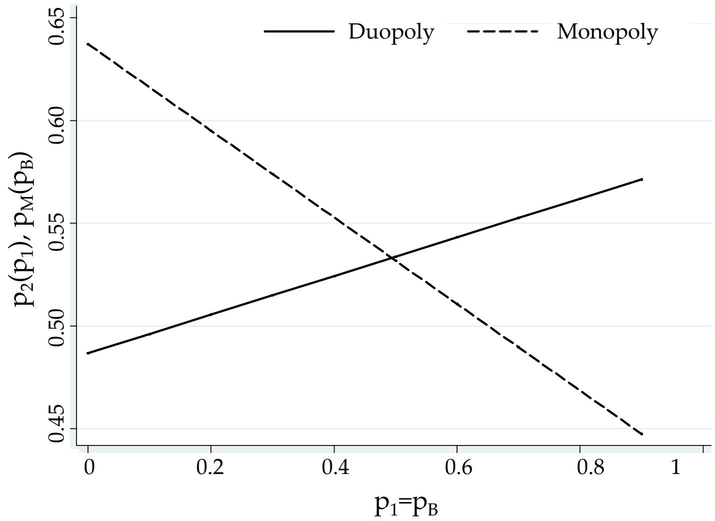

Figure 3.4: Reaction functions $p_2(p_1)$ and $p_M(p_B)$

In the DUOPOLY-SEQ treatment, a high investment of the competitor reduces the subject's expected profit. The marginal effect of the investment remains unaffected but the higher probability of success of the competitor has a negative wealth effect on the subject's profit. The same holds true for the subjects in the MONOPOLY-SEQ treatment: An increase in the probability of a bad market development imposes a negative wealth effect on a subject's profit, keeping the marginal effect of the investment unaffected. However, subjects in the DUOPOLY-SEQ and in the MONOPOLY-SEQ treatment react differently. In the DUOPOLY-SEQ treatment, the exogenous decrease in the expected profit motivates subject 2 to increase his investment. This effect is reversed in the MONOPOLY-SEQ treatment, in which subject M is discouraged by a low expected profit and therefore invests less.

Our findings reveal, that in our experiment with sequential investments, the difference in the average investment disappears. But we find that subjects in the DUOPOLY-SEQ and the MONOPOLY-SEQ treatment have a significantly different investment strategy. Even though the experiment with sequential moves controls for several factors that are prevalent in competitive markets such as exogenous uncertainty, strategic interaction, beliefs and complex decision-making, subjects' incentives to invest still differ with and without competitive pressure.

3.5 CONCLUSION

In simple laboratory experiments we addressed the question whether competition affects the incentives to invest in independent of the monetary incentives. We conduct an investment decision in treatments with competition and without and keep the degree of competition constant. Additionally, we design the experiment in such a way that the monetary incentives (in equilibrium) are independent on the degree of competition. Our main result of the experiment with simultaneous investments in the competitive treatments is that competition significantly increases the incentives to invest. The results of the experiment contradict the theoretical prediction that the investments are independent of the degree of competition. This shows that the competition between subjects has an effect on the incentives to invest. This effect cannot be explained by differing monetary incentives.

We examine this incentive effect of competition in a second experiment, in which we control for several differences between competitive and monopolistic markets. Sequential moves by the players align the complexity and the uncertainty involved in the decision. Besides, payoffs and monetary incentives are always identical, independent of the degree of competition. We find that the average investment is the same under competition and monopoly. But our results also show that the degree of competition affects subject's investment strategy significantly. Even though the marginal effect of investing is unchanged, subjects in competition increase their investment if their expected payoff decreases exogenously, whereas subjects in the monopoly treatment decrease their investment. Competition seems to motivate subjects to invest more effort if expected profits decrease exogenously, whereas subjects in a monopolistic market are discouraged from investing.

Our results contribute to the understanding of the interaction of competition and innovation. They support models which find a positive relationship between competition and innovation. Our experiment adds to the existing literature by showing that the positive correlation may not only be driven by differing monetary investment incentives, but also by an effect which cannot be explained by differences in monetary incentives. The experiment with simultaneous investments demonstrates that the mere fact that individuals interact in a competitive environment lets them increase their investments compared to a situation in which they do not interact. The results of our experiment with sequential investments in which we aligned the uncertainty and complexity between competition and monopoly suggests that the higher degree of complexity and uncertainty in competitive markets compared to monopolistic markets can explain a higher level of investments with competition. But higher complexity and uncertainty in competitive markets compared to monopolistic markets can not explain the incentive effect of competition completely. Even if we equalize complexity and uncertainty, subjects in the duopoly treatment still have a different investment strategy than subjects in the monopoly treatment.

An exogenous decrease in expected payments from a project seems to motivate effort in competitive markets, whereas it discourages effort in monopolistic markets. This difference can only be explained by the incentive effect of competition, because the relationship between cost of investment and probability of success is unaffected by the exogenous shock. This observation of the investment behaviour has important implications for the understanding of the interaction of competition and innovation. It predicts that firms may increase their investments in R&D if their competitors do so, even though it is not profitable. On the other hand, it predicts that firms in monopolistic markets tend to decrease their investments if a low payoff becomes more likely.

These results help to reconcile some of the seemingly conflicting findings in field evidence. Our results are complementary and provide controlled evidence that investment decisions are affected by the degree of competition independent of differences in monetary incentives. It would be interesting to identify what aspect of the competitive environment affects the investment strategy. Especially social preferences and peer effects might play a role.

APPENDIX 3.A

3.A.1 *Experiment with Simultaneous Investments*

Supplementary Tables and Figures

Figure 3.A1 shows the average over subjects' investment per period and treatment. In all treatments and periods, the investments are above the Nash equilibrium prediction of 40 (solid grey line). The investments of the DUOPOLY and OLIGOPOLY treatment are in each period above the investments of the MONOPOLY treatment. There does not seem to be a time trend of endgame effect.

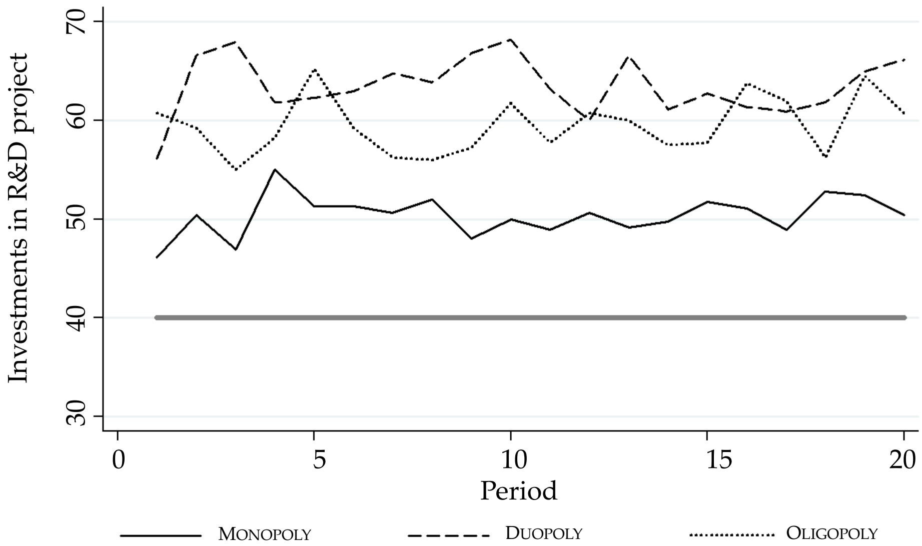

Figure 3.A1: Per period investments by treatment in the experiment with simultaneous investments

Table 3.A1 reports regressions on the determinants of the investment in the R&D project additional to Table 3.2. Regression (1) shows that subjects invest significantly more in the DUOPOLY and the OLIGOPOLY treatments compared to the MONOPOLY treatment if we restrict the data to the first period. Regression (2) and (3) show that repeating regressions (1) and (2) of Table 3.2, but clustering the standard errors on matching group level instead of subject level slightly decreases the standard errors. It does not affect the

significance of the results. The effect of the *oligopoly* treatment dummy is significant at the 1% level instead of the 5% level. In regression (4) we use the mean of the investments over all periods (which reduces the observations to 130). Again, all results stay significant and the *oligopoly* treatment dummy is even significant at the 1% level.

	Investment in R&D project			
	(1)	(2)	(3)	(4)
Duopoly	10.05*	13.13***	13.27***	13.27***
	(4.602)	(2.924)	(3.284)	(3.373)
Oligopoly	14.66***	9.120***	9.319***	9.319***
	(3.173)	(2.559)	(2.274)	(2.336)
Female			-4.662	-4.662
			(3.133)	(3.218)
Age			0.544*	0.544*
			(0.304)	(0.312)
Risk aversion			1.248	1.248
			(1.077)	(1.106)
Risk aversion quest.			-0.671	-0.671
			(1.069)	(1.098)
Loss aversion			1.124	1.124
			(0.988)	(1.015)
Ambiguity aversion			-1.937	-1.937
			(1.769)	(1.817)
Restrict to period 1	yes			
Period dummies			yes	
Period 1			-4.308*	
			(2.249)	
Constant	46.09***	50.38***	41.85***	41.18***
	(1.225)	(2.171)	(10.93)	(11.86)
Observations	130	2600	2600	130
Adjusted R^2	0.055	0.051	0.078	0.105

Notes: The table reports coefficients of OLS regressions with robust standard errors in parentheses. Regression (1) is restricted to period 1 and standard errors are clustered by session. In regression (2) and (3) standard errors are clustered by matching groups instead of subjects. In regression (3), none of the 20 period dummies is significant, i.e. there is no time trend or end game effect. Regression (4) regresses the subject mean over periods of the investment in the R&D project, standard errors are clustered by matching groups. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table 3.A1: Experiment with simultaneous investments: Additional results on the determinants of the investment in the R&D project

Proof of Proposition 3.1

Table 3.A2 shows the rounded total payoffs from the investment game (hereafter payoffs) of the subject in the MONOPOLY treatment depending on its investment I. An investment of 40 in the R&D project maximizes the subject's payoff. □

I	
0	310.00
10	368.30
20	383.10
30	386.30
40	<u>389.50</u>
50	386.90
60	384.30
70	381.70
80	376.20
90	367.80
100	359.40

Table 3.A2: Payoffs in the MONOPOLY treatment

Proof of Proposition 3.2

Table 3.A3 shows the rounded payoffs of subject i depending on its own investment and the investment of the other player j in the DUOPOLY treatment. Similarly, Table 3.A4 shows the rounded payoffs of subject j depending on its own investment and the investment of the other player i in the DUOPOLY treatment. From the tables can be read that the investments of the two subjects are strategic substitutes: If subject j increases its investment, it is optimal for subject i to decrease its investment and vice versa. The payoffs resulting from investments which are best responses for each investment of the other player are in underlined. Comparing the best responses of player i and player j in Tables 3.A3 and 3.A4 shows that $(I_i, I_j) = (40, 40)$ is the single Nash equilibrium in the DUOPOLY treatment. The payoff of the Nash equilibrium is double-underlined. □

Proof of Proposition 3.3

Table 3.A5 shows the rounded payoffs of subject i in the OLIGOPOLY treatment depending on the investments of the three other players $-i$ (assuming that players $-i$ choose the same investment). The payoffs from investments which are best responses of player i for each investment of the other players $-i$ are underlined. From the table can be read that the investments of the three subjects are strategic substitutes: If the subjects $-i$ increase their investment, it is optimal for subject i to decrease its investment. This holds true for all subjects. Comparing the best responses of all players shows that only the investment of 40 is a best response for all subjects. Therefore, $(I_i, I_j, I_k, I_l) = (40, 40, 40, 40)$ is the single Nash equilibrium in the OLIGOPOLY treatment. $\square$

I_i/I_j	0	10	20	30	40	50	60	70	80	90	100
0	290.00	268.40	258.80	252.40	246.00	241.20	236.40	231.60	227.60	224.40	221.20
10	378.00	341.82	325.74	315.02	304.30	296.26	288.22	280.18	273.48	268.12	262.76
20	406.00	363.34	344.38	331.74	319.10	309.62	300.14	290.66	<u>282.76</u>	<u>276.44</u>	<u>270.12</u>
30	418.00	371.02	350.14	336.22	322.30	311.86	301.42	290.98	282.28	275.32	268.36
40	430.00	378.70	<u>355.90</u>	<u>340.70</u>	<u>325.50</u>	<u>314.10</u>	<u>302.70</u>	<u>291.30</u>	281.80	274.20	266.60
50	434.00	379.46	355.22	339.06	322.90	310.78	298.66	286.54	276.44	268.36	260.28
60	438.00	380.22	354.54	337.42	320.30	307.46	294.62	281.78	271.08	262.52	253.96
70	<u>442.00</u>	<u>380.98</u>	353.86	335.78	317.70	304.14	290.58	277.02	265.72	256.68	247.64
80	<u>442.00</u>	378.28	349.96	331.08	312.20	298.04	283.88	269.72	257.92	248.48	239.04
90	438.00	372.12	342.84	323.32	303.80	289.16	274.52	259.88	247.68	237.92	228.16
100	434.00	365.96	335.72	315.56	295.40	280.28	265.16	250.04	237.44	227.36	217.28

Table 3.A3: Payoffs of player i in the DUOPOLY treatment

I_i/I_j	0	10	20	30	40	50	60	70	80	90	100
0	290.00	378.00	406.00	418.00	430.00	434.00	438.00	442.00	442.00	438.00	434.00
10	268.40	341.82	363.34	371.02	378.70	379.46	380.22	380.98	378.28	372.12	365.96
20	258.80	325.74	344.38	350.14	355.90	355.22	354.54	353.86	349.96	342.84	335.72
30	252.40	315.02	331.74	336.22	340.70	339.06	337.42	335.78	331.08	323.32	315.56
40	246.00	304.30	319.10	322.30	325.50	322.90	320.30	317.70	312.20	303.80	295.40
50	241.20	296.26	309.62	311.86	314.10	310.78	307.46	304.14	298.04	289.16	280.28
60	236.40	288.22	300.14	301.42	302.70	298.66	294.62	290.58	283.88	274.52	265.16
70	231.60	280.18	290.66	290.98	291.30	286.54	281.78	277.02	269.72	259.88	250.04
80	227.60	273.48	282.76	282.28	281.80	276.44	271.08	265.72	257.92	247.68	237.44
90	224.40	268.12	276.44	275.32	274.20	268.36	262.52	256.68	248.48	237.92	227.36
100	221.20	262.76	270.12	268.36	266.60	260.28	253.96	247.64	239.04	228.16	217.28

Table 3.A4: Payoffs of player j in the Duopoly treatment

I_i/I_{-i}	0	10	20	30	40	50	60	70	80	90	100
0	250.00	225.56	219.08	215.96	213.65	212.37	211.44	210.79	210.43	210.23	210.11
10	424.96	331.20	300.63	283.43	268.49	258.62	249.78	241.86	235.89	231.48	227.37
20	490.24	365.68	324.39	300.93	280.38	266.69	254.33	243.19	234.73	228.45	222.57
30	529.49	384.39	335.96	308.34	284.04	267.81	253.11	239.81	229.68	222.16	215.09
40	565.33	399.70	344.13	312.33	284.29	265.51	248.47	233.01	221.23	212.46	204.21
50	589.97	408.93	348.01	313.08	282.24	261.54	242.75	225.68	212.65	202.94	193.81
60	612.69	416.25	349.97	311.92	278.27	255.66	235.11	216.42	202.15	191.50	181.48
70	633.49	421.64	350.01	308.83	272.38	247.86	225.55	205.25	189.72	178.14	167.24
80	649.36	424.67	348.58	304.79	266.00	239.89	216.11	194.47	177.91	165.54	153.90
90	661.09	426.14	346.47	300.60	259.94	232.55	207.60	184.88	167.49	154.51	142.27
100	671.97	426.75	343.51	295.56	253.02	224.36	198.24	174.44	156.23	142.61	129.79

Table 3.A5: Payoffs of subject i in the OLIGOPOLY treatment

3.A.2 *Experiment with Sequential Investments*

Supplementary Tables and Figures

Figure 3.A2 shows the average over subjects' investment per period and treatment. Subject M in the MONOPOLY-SEQ treatment and subject 1 and 2 in the DUOPOLY-SEQ treatments choose a probability of success above the Nash equilibrium prediction of 40 (solid grey line). There does not seem to be a time trend of endgame effect.

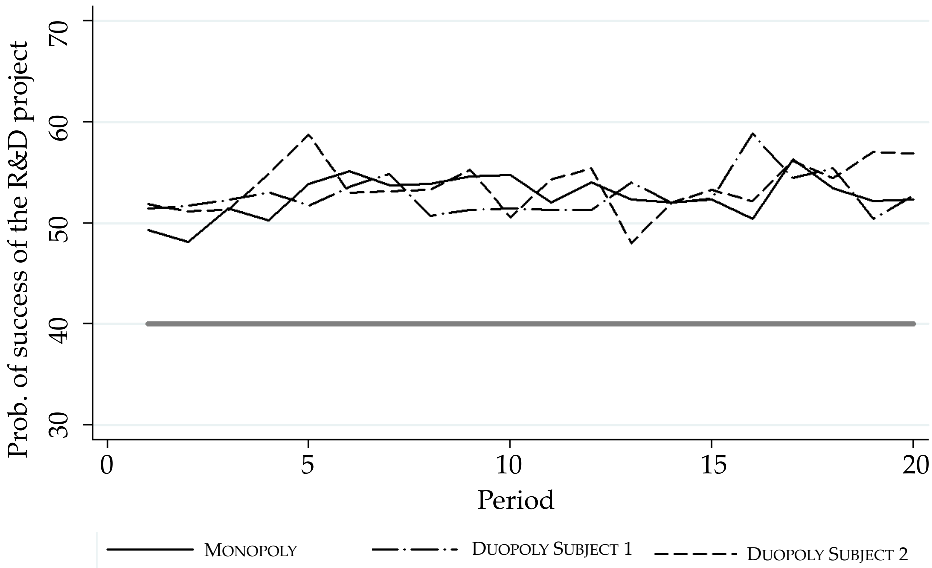

Figure 3.A2: Per period investments by treatment in the experiment with sequential investments

Table 3.A6 reports regressions on the determinants of chosen probability of success of the R&D project additional to Table 3.4. Regression (1) restricts the analysis to the investments of period 1. It shows that subjects across treatments react very different to the probability of subject 1/the probability of bad market development and the difference is even more pronounced than predicted by regression (2) in Table 3.4. Regression (1) of Table 3.A6 predicts the following reaction functions: $p_2(p_1) = 0.3572 + 0.00314\, p_1$ and $p_M(p_B) = 0.6406 - 0.000287\, p_B$.

From regression (2) can be read that repeating regressions (2) of Table 3.2 but clustering the standard errors on matching groups instead of on subjects slightly decreases the standard errors. It does not affect the significance of the results. Regression (3) repeats regressions (3) of Table 3.2 but standard errors are clustered by matching groups instead of subjects. This results in some minor changes in the standard errors and on the significance levels, but it does not chnage the significance of the effect of competition on the investment decision.

	Probability of success of the R&D project in % (subject M and 2)		
	(1)	(2)	(3)
Monopoly	28.34**	15.05***	15.35***
	(9.811)	(4.367)	(4.164)
Probability of Subject 1/ Probability of bad market development	0.314***	0.0940**	0.0989**
	(0.0884)	(0.0439)	(0.0381)
Monopoly × Probability of subject 1/ Probability of bad market development	-0.601***	-0.305***	-0.309***
	(0.174)	(0.0742)	(0.0720)
Female			5.792*
			(3.119)
Age			0.284
			(0.258)
Risk aversion			-1.735
			(1.106)
Risk aversion quest.			0.0954
			(0.903)
Loss aversion			-1.198
			(0.837)
Ambiguity aversion			-1.605
			(1.656)
Restrict to period 1	yes		
Period dummies			yes
Period 1			-4.071*
			(2.152)
Period 2			-4.984**
			(1.947)
Period 1			-4.357*
			(2.326)
Constant	35.72***	48.68***	55.53***
	(6.861)	(2.848)	(9.903)
Observations	140	2800	2800
Adjusted R^2	0.058	0.022	0.058

Notes: The table reports coefficients of OLS regressions with robust standard errors in parentheses. Regression (1) is restricted to period 1 and standard errors are clustered by session. In regression (2) and (3) standard errors are clustered by matching groups instead of subjects. In regression (3), of the 20 period dummies only the listed ones are significant. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table 3.A6: Experiment with sequential investments: Additional results on the determinants of the investment in the R&D project

Proof of Proposition 3.4

Table 3.A7 shows the payoffs of subject 1 in the DUOPOLY-SEQ treatment depending on its own probability of success p_1 and the probability of success of subject 2, p_2. Table 3.A8 shows the payoffs of subject 2 in the DUOPOLY-SEQ treatment depending on its own probability of success p_2 and the probability of success of subject 1, p_1. The payoffs resulting from investments which are best responses for each investment of the other subject are underlined. Choosing the probability of success of 0.4 is a dominant strategy for both subjects because it is the payoff-maximising strategy for each probability of success of the other subject. □

p_2/p_1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.0	200.0	211.0	218.0	223.0	225.0	224.0	221.0	214.0	205.0
0.1	190.0	200.8	207.6	212.4	214.2	213.0	209.8	202.6	193.4
0.2	180.0	190.6	197.2	201.8	203.4	202.0	198.6	191.2	181.8
0.3	170.0	180.4	186.8	191.2	192.6	191.0	187.4	179.8	170.2
0.4	160.0	170.2	176.4	180.6	181.8	180.0	176.2	168.4	158.6
0.5	150.0	160.0	166.0	170.0	171.0	169.0	165.0	157.0	147.0
0.6	140.0	149.8	155.6	159.4	160.2	158.0	153.8	145.6	135.4
0.7	130.0	139.6	145.2	148.8	149.4	147.0	142.6	134.2	123.8
0.8	120.0	129.4	134.8	138.2	138.6	136.0	131.4	122.8	112.2

Table 3.A7: Payoffs of subject 1 in the DUOPOLY-SEQ treatment

p_2/p_1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.0	200.0	190.0	180.0	170.0	160.0	150.0	140.0	130.0	120.0
0.1	211.0	200.8	190.6	180.4	170.2	160.0	149.8	139.6	129.4
0.2	218.0	207.6	197.2	186.8	176.4	166.0	155.6	145.2	134.8
0.3	223.0	212.4	201.8	191.2	180.6	170.0	159.4	148.8	138.2
0.4	225.0	214.2	203.4	192.6	181.8	171.0	160.2	149.4	138.6
0.5	224.0	213.0	202.0	191.0	180.0	169.0	158.0	147.0	136.0
0.6	221.0	209.8	198.6	187.4	176.2	165.0	153.8	142.6	131.4
0.7	214.0	202.6	191.2	179.8	168.4	157.0	145.6	134.2	122.8
0.8	205.0	193.4	181.8	170.2	158.6	147.0	135.4	123.8	112.2

Table 3.A8: Payoffs of subject 2 in the DUOPOLY-SEQ treatment

Proof of Proposition 3.5

Table 3.A9 shows the payoffs of the subject in the MONOPOLY-SEQ treatment depending on its own probability of success p_M and the probability of a bad market development p_B. The payoffs from investments which are best responses of the subject for each probability p_B are underlined. Choosing the probability $p_M = 0.4$ is a dominant strategy for the subject because it is the payoff-maximising strategy for each probability p_B. □

p_M/p_B	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.0	200.0	190.0	180.0	170.0	160.0	150.0	140.0	130.0	120.0
0.1	211.0	200.8	190.6	180.4	170.2	160.0	149.8	139.6	129.4
0.2	218.0	207.6	197.2	186.8	176.4	166.0	155.6	145.2	134.8
0.3	223.0	212.4	201.8	191.2	180.6	170.0	159.4	148.8	138.2
0.4	<u>225.0</u>	<u>214.2</u>	<u>203.4</u>	<u>192.6</u>	<u>181.8</u>	<u>171.0</u>	<u>160.2</u>	<u>149.4</u>	<u>138.6</u>
0.5	224.0	213.0	202.0	191.0	180.0	169.0	158.0	147.0	136.0
0.6	221.0	209.8	198.6	187.4	176.2	165.0	153.8	142.6	131.4
0.7	214.0	202.6	191.2	179.8	168.4	157.0	145.6	134.2	122.8
0.8	205.0	193.4	181.8	170.2	158.6	147.0	135.4	123.8	112.2

Table 3.A9: Payoffs of the subject in the MONOPOLY-SEQ treatment

3.A.3 *Instructions*

All experimental instructions are translated from German.

Experiment with simultaneous choices: monopoly treatment

Welcome to the experiment and thank you for participating!
From now on please do not speak with the other participants any more.

General Information

This experiment will investigate economic decision making. Thereby you can earn money. You will receive the income you earned during the experiment in cash at the end of the experiment.
During the experiment you and the other participants are asked to make decisions. Your own decisions as well as the other participants' decisions determine your income according to the rules that are explained below. The whole experiment lasts about 1.5 hours. At first you will receive detailed instructions. If you have any questions after reading the instructions or during the experiment, please raise your hand. One of the experiment conductors will come to your place and answer your questions privately.
We refer to all persons in the masculine form in order to make the text more readable. We ask for your understanding.

Payments
All the points you earn during the experiment will be converted to Euro at the end of the experiment. The following exchange rate applies:

500 points = 1.00 Euro

Furthermore, you will receive a show-up fee of **2000 points (4 Euro)** at the beginning of the experiment. This show-up fee also serves the purpose to compensate for possible losses that may occur during the experiment. Furthermore, you receive remuneration for answering a questionnaire at the end of the experiment.

Anonymity
The other participants will neither during nor after the experiment receive any information about your decisions and about how much you earned. We analyse the data as an aggregate and never match names with data of the experiments. At the end of the experiment you will have to sign a receipt that you received your money. This receipt is only needed for accounting reasons of our sponsor, which will not receive any additional data of this experiment.

Auxiliary Means
There is a pen at your desk. Please leave it there at the end of the experiment.

The Experiment

Experiment procedere During the experiment you assume the role of a manager, who invests in research and development of his company. Your company holds a monopoly position in a market, this means it is the only supplier and it does not compete against other companies. The experiment lasts for 20 rounds.

Making a decision in a round
You are a manager of a company which is a monopolist on a market. In every round you have an investment budget of 100 points. You have to spend all 100 points. You can invest these points either in a risk-free project or in research and development (R&D).

- Every point that you invest in the risk-free project will increase your payment by two points, which will be given to you at the end of the experiment.
- Every point that you invest in research and development increases the probability that your innovation will be successful. This innovation will improve the market position of your firm. The first points of your investment in R&D lead to a relatively high increase of the probability of success. The more points you invest the less strong is the positive effect on the probability of success. Please have a look at the enclosed table for the detailed relationship between invested points and probability of success. The managers you are competing with face the same decision like you.

The success/failure of your R&D investment determines the gains of your company. Your payments depend on your company's profits:

- If you are successful your company realizes a high profit. In this case you receive a bonus of **400 points**.
- If you are not successful your company realizes a low profit. In this case you receive a bonus of 110 points.

The detailed process in each round

- At the beginning of a round you receive a budget of 100 points that you have to split on two investment projects.
  - Every point that you invest in the risk-free project will increase your payment by two points, which will be given to you at the end of the experiment.
  - Every point that you invest in research and development increases the probability that your innovation will be successful. This innovation will improve the market position of your firm. The effect on the probability of success decreases with the number of points invested in R&D. Please have a look at the enclosed table for the detailed relationship between invested points and probability of success. When increasing your investment from 10 to 20 points, your probability of success goes up from 27% to 39%, an increase of 12 percentage points. But if you increase your investment from 80 to 90 points, your probability of success rises only from 78% to 82%, an increase of 4 percentage points.
- After you decided how to split the 100 points on the two investment projects there will be a decision about success or failure of your company's R&D investment. This outcome is generated by a random process only depending on the chosen success probability:
  - Imagine a rotating wheel of fortune with a red and a black field. If the wheel stops at the red field your investment is successful. If the wheel stops at the black field your investment is not successful.

  - The more points you invest the larger is the red field on the wheel of fortune and with it the probability that your investment is successful.

- After your wheel of fortune was turned and success or failure of your investment is determined, your company will realize either a high or a low profit. This market outcome has an influence on your payment:
  - If you are successful you get a bonus of **400 points**.
  - If you are not successful you get a bonus of **110 points**.

- Herewith the round ends. The next round is independent of the previous round.

- Please notice: Even if you decide to invest 0 points in R&D your payment nevertheless depend on the market outcome of your company in this round.

Your total income of this experiment is the sum of your payments over the 20 rounds plus your show-up fee.

Do you have any questions?

Investment in R&D in points	Probability of success in %	Increase of probability due to the last 10 points invested in R&D in %
0	0	–
10	27	27
20	39	12
30	47	8
40	55	8
50	61	6
60	67	6
70	73	6
80	78	5
90	82	4
100	86	4

Control Questions

We ask you to compute the following examples before beginning the experiment. **Wrong answers have no consequences for you.** The experiment will not be started until all the participants have answered the questions correctly. If you have questions, please raise your hand. The conductor of the experiment will pass all seats and answer your questions privately.

1. You decided to invest 60 points in the risk-free investment project and to invest 40 points in the R&D project. Hence, your probability of success is 55%. Your investment is successful.
   - What is your income of the investment in the risk-free project?
   - What is your income and the income from the R&D project in this round?
2. You decided to invest 30 points in the risk-free investment project and to invest 70 points in the R&D project. Hence, your probability of success is 73%. Your investment is not successful.
   - What is your income of the investment in the risk-free project?
   - What is your income and the income from the R&D project in this round?
3. You decided to invest 80 points in the risk-free investment project and to invest 20 points in the R&D project. Hence, your probability of success is 39%. Your investment is successful.
   - What is your income of the investment in the risk-free project?
   - What is your income and the income from the R&D project in this round?
4. You decided to invest 100 points in the risk-free investment project and to invest 0 points in the R&D project. Hence, your probability of success is 0%. Your investment is not successful.
   - What is your income of the investment in the risk-free project?
   - What is your income and the income from the R&D project in this round?

EXPERIMENT WITH SIMULTANEOUS CHOICES: DUOPOLY TREATMENT

Welcome to the experiment and thank you for participating!

From now on please do not speak with the other participants any more.

General Information

This experiment will investigate economic decision making. Thereby you can earn money. You will receive the income you earned during the experiment in cash at the end of the experiment.
During the experiment you and the other participants are asked to make decisions. Your own decisions as well as the other participants' decisions determine your income according to the rules that are explained below. The whole experiment lasts about 1.5 hours. At first you will receive detailed instructions. If you have any questions after reading the instructions or during the experiment, please raise your hand. One of the experiment conductors will come to your place and answer your questions privately.
We refer to all persons in the masculine form in order to make the text more readable. We ask for your understanding.

Payments
All the points you earn during the experiment will be converted to Euro at the end of the experiment. The following exchange rate applies:

500 points = 1.00 Euro

Furthermore, you will receive a show-up fee of **2000 points (4 Euro)** at the beginning of the experiment. This show-up fee also serves the purpose to compensate for possible losses that may occur during the experiment. Furthermore, you receive remuneration for answering a questionnaire at the end of the experiment.

Anonymity
Neither during nor after the experiment you will get to know with whom you were matched with in each round. The other participants will also not receive any information with whom they were matched and about how much

you earned. We analyze the data as an aggregate and never match names with data of the experiments. At the end of the experiment you will have to sign a receipt that you received your money. This receipt is only needed for accounting reasons of our sponsor, which will not receive any additional data of this experiment.

Auxiliary Means
There is a pen at your desk. Please leave it there at the end of the experiment.

The Experiment

Experiment procedere
During the experiment you assume the role of a manager, who invests in research and development of his company. The experiment lasts for **20 rounds**. In every round your company competes with one other company, which manager also invest in research and development. You are randomly matched with one other participant of the experiment. In every round you are matched with **one other, new manager**. Neither during nor after the experiment you receive any information about the identity of the other persons you were matched with. They will not receive any information about your identity too. This guarantees full anonymity of decisions in every round.

Making a decision in a round
You are a manager of a company which competes with another company. In every round you have an investment budget of 100 points. You have to spend all 100 points. You can invest these points either in a risk-free project or in research and development (R&D).

- Every point that you invest in the risk-free project will increase your payment by two points, which will be given to you at the end of the experiment.
- Every point that you invest in research and development increases the probability that your innovation will be successful. This innovation will improve the market position of your firm. The first points of your investment in R&D lead to a relatively high increase of the probability

of success. The more points you invest the less strong is the positive effect on the probability of success. Please have a look at the enclosed table for the detailed relationship between invested points and probability of success. The manager you are competing with faces the same decision like you.

Please note: The probability that your investment is successful or not is independent on the success of the other manager.

The success/failure of the R&D investments of both companies determines the gains/losses of the two companies in the market. Your payment depends on this market outcome:

- If **only you** are successful and **the other manager** is not successful, your company dominates the market. In this case you receive a bonus of **490 points**, the other manager only receives a bonus of **10 points**.
- If **both managers** are successful, both companies are on a par. In this case both managers get a bonus of **210 points**.
- If no manager is successful, both companies are also on a par, but are less profitable. In this case both managers get **90 points**.
- If **only the other manager is successful**, than the other company dominates the market. In this case the other manager gets a bonus of **490 points** and you receive **10 points**.

The detailed process in each round

- At the beginning of a round you receive a budget of 100 points that you have to split on two investment projects.
  - Every point that you invest in the risk-free project will increase your payment by two points, which will be given to you at the end of the experiment.
  - Every point that you invest in research and development increases the probability that your innovation will be successful. This innovation will improve the market position of your firm. The effect on the probability of success decreases with the number of points invested in R&D. Please have a look at the enclosed table for the

detailed relationship between invested points and probability of success. When increasing your investment from 10 to 20 points, your probability of success goes up from 27% to 39%, an increase of 12 percentage points. But if you increase your investment from 80 to 90 points, your probability of success rises only from 78% to 82%, an increase of 4 percentage points.

- After both managers decided how to split the 100 points on the two investment projects there will be two separate outcomes about success or failure of each company's R&D investment. These outcomes are generated by a random process only depending on the chosen success probability:
  - Imagine a rotating wheel of fortune with a red and a black field. If the wheel stops at the red field your investment is successful. If the wheel stops at the black field your investment is not successful.
  - The more points you invest the larger is the red field on the wheel of fortune and with it the probability that your investment is successful. The manager of the other company your company is competing against can influence the red field of his own wheel of fortune with his investments.
- After your wheel of fortune and the wheel of the other manager were turned and success or failure of both companies is determined, one of the following four market outcomes prevails. The market outcome has an influence on your payment as well as on the other manager's payment:
  - If you are successful but the other manager is not successful, you company dominates the market. You get a bonus of 490 points and the other manager gets **10 points**.
  - If both managers are successful, both get a bonus of **210 points** each.
  - If both managers are not successful, both get **90 points** each.
  - If the other manager is successful but you are not successful, then the other company holds a better market position than your com-

pany. In this case the manager of the other company receives a bonus of **490 points**. You get **10 points**.

- Herewith the round ends.
- In the next round every manager is matched with another new randomly chosen manager. This new round is independent of the previous round.
- Please notice: Even if you decide to invest 0 points in R&D your payment nevertheless depend on the market outcome of your company in this round.

Your total income of this experiment is the sum of your payments over the 20 rounds plus your show-up fee.

Do you have any questions?

Investment in R&D in points	Probability of success in %	Increase of probability due to the last 10 points invested in R&D in %
0	0	–
10	27	27
20	39	12
30	47	8
40	55	8
50	61	6
60	67	6
70	73	6
80	78	5
90	82	4
100	86	4

Control Questions

We ask you to compute the following examples before beginning the experiment. **Wrong answers have no consequences for you.** The experiment will not be started until all the participants have answered the questions correctly. If you have questions, please raise your hand. The conductor of the experiment will pass all seats and answer your questions privately.

1. You decided to invest 60 points in the risk-free investment project and to invest 40 points in the R&D project. Hence, your probability of success is 55%. The other manager decided to invest 50 points in the risk-free project and 50 points in the R&D project. Hence, his probability of success is 61%.Your investment is successful. The investment of the other manager is not successful.
   What is your income of the investment in the risk-free project?
   - Your income:
   - Income of the other manager:

   What is your income and the income of the other manager from the market interaction in this round?
   - Your income:
   - Income of the other manager:

2. You decided to invest 100 points in the risk-free investment project and to invest 0 points in the R&D project. Hence, your probability of success is 0%. The other manager decided to invest 70 points in the risk-free project and 30 points in the R&D project. Hence, his probability of success is 73%. The investment of the other manager is successful. Your investment is not successful.
   What is your income of the investment in the risk-free project?
   - Your income:
   - Income of the other manager:

   What is your income and the income of the other manager from the market interaction in this round?
   - Your income:
   - Income of the other manager:

3. You decided to invest 20 points in the risk-free investment project and to invest 80 points in the R&D project. Hence, your probability of success is 78%. The other manager decided to invest 60 points in the risk-

free project and 40 points in the R&D project. Hence, his probability of success is 55%. Both investments are successful.
What is your income of the investment in the risk-free project?

- Your income:
- Income of the other manager:

What is your income and the income of the other manager from the market interaction in this round?

- Your income:
- Income of the other manager:

4. You decided to invest 60 points in the risk-free investment project and to invest 40 points in the R&D project. Hence, your probability of success is 55%. The other manager decided to invest 50 points in the risk-free project and 50 points in the R&D project. Hence, his probability of success is 61%.No investment is successful.
What is your income of the investment in the risk-free project?

    - Your income:
    - Income of the other manager:

    What is your income and the income of the other manager from the market interaction in this round?

    - Your income:
    - Income of the other manager:

Experiment with simultaneous choices: oligopoly treatment

Welcome to the experiment and thank you for participating!

From now on please do not speak with the other participants any more.

General Information

This experiment will investigate economic decision making. Thereby you can earn money. You will receive the income you earned during the experiment in cash at the end of the experiment.
During the experiment you and the other participants are asked to make decisions. Your own decisions as well as the other participants' decisions determine your income according to the rules that are explained below. The whole experiment lasts about 1.5 hours. At first you will receive detailed instructions. If you have any questions after reading the instructions or during the experiment, please raise your hand. One of the experiment conductors will come to your place and answer your questions privately.
We refer to all persons in the masculine form in order to make the text more readable. We ask for your understanding.

Payments
All the points you earn during the experiment will be converted to Euro at the end of the experiment. The following exchange rate applies:

500 points = 1.00 Euro

Furthermore, you will receive a show-up fee of **2000 points (4 Euro)** at the beginning of the experiment. This show-up fee also serves the purpose to compensate for possible losses that may occur during the experiment. Furthermore, you receive remuneration for answering a questionnaire at the end of the experiment.

Anonymity
Neither during nor after the experiment you will get to know with whom you were matched with in each round. The other participants will also not receive any information with whom they were matched and about how much

you earned. We analyse the data as an aggregate and never match names with data of the experiments. At the end of the experiment you will have to sign a receipt that you received your money. This receipt is only needed for accounting reasons of our sponsor, which will not receive any additional data of this experiment.

Auxiliary Means
There is a pen at your desk. Please leave it there at the end of the experiment.

The Experiment

Experiment procedere
During the experiment you assume the role of a manager, who invests in research and development of his company. The experiment lasts for **20 rounds**. In every round your company competes with **three other companies**, which managers also invest in research and development. You are randomly matched with three other participants of the experiment. In every round you are matched with **three other, new managers**. Neither during nor after the experiment you receive any information about the identity of the other persons you were matched with. They will not receive any information about your identity too. This guarantees full anonymity of decisions in every round.

Making a decision in a round
You are a manager of a company which competes with three other companies. In every round you have an investment budget of 100 points. You have to spend all 100 points. You can invest these points either in a risk-free project or in research and development (R&D).

- Every point that you invest in the risk-free project will increase your payment by two points, which will be given to you at the end of the experiment.
- Every point that you invest in research and development increases the probability that your innovation will be successful. This innovation will

improve the market position of your firm. The first points of your investment in R&D lead to a relatively high increase of the probability of success. The more points you invest the less strong is the positive effect on the probability of success. Please have a look at the enclosed table for the detailed relationship between invested points and probability of success. The managers you are competing with face the same decision like you.

Please note: The probability that your investment is successful or not is independent on the success of the other managers.

The success/failure of the R&D investments of the four companies determine the gains/losses of the four companies in the market. Your payments (and the payments of the other managers) depend on this market outcome:

- If **only you** are successful and **no other manager** is successful, your company dominates the market. In this case you receive a bonus of **770 points**, the other managers only receive a bonus of **10 points** each.
- If **you and one other manager** are successful, both companies dominate the market. In this case you (and the manager of the other successful company) get a bonus of **360 points**, the other managers only receive a bonus of **10 points** each.
- If **you and two other managers** are successful, you (and the other two successful managers) get a bonus of **200 points**, the other managers only receive a bonus of **10 points** each.
- If **you and all other three managers** are successful, you will share the market with these other four companies and you and the other three managers get a bonus of **100 points**.
- **If you are not successful and all other managers are also not successful**, all companies are on the same level, but are less profitable. In this case you and all other managers get **50 points**.
- If **you are not successful** but **at least one other manager is successful**, than the other company/companies dominate the market and you get **10 points**.

The detailed process in each round

- At the beginning of a round you receive a budget of 100 points that you have to split on two investment projects.
  - Every point that you invest in the risk-free project will increase your payment by two points, which will be given to you at the end of the experiment.
  - Every point that you invest in research and development increases the probability that your innovation will be successful. This innovation will improve the market position of your firm. The effect on the probability of success decreases with the number of points invested in R&D. Please have a look at the enclosed table for the detailed relationship between invested points and probability of success. When increasing your investment from 10 to 20 points, your probability of success goes up from 27% to 39%, an increase of 12 percentage points. But if you increase your investment from 80 to 90 points, your probability of success rises only from 78% to 82%, an increase of 4 percentage points.
- After all four managers decided how to split the 100 points on the two investment projects there will be four separate outcomes about success or failure of each company's R&D investment. These outcomes are generated by a random process only depending on the chosen success probability:
  - Imagine a rotating wheel of fortune with a red and a black field. If the wheel stops at the red field your investment is successful. If the wheel stops at the black field your investment is not successful.
  - The more points you invest the larger is the red field on the wheel of fortune and with it the probability that your investment is successful. The three managers of the other companies which your company is competing against can influence the red fields of their own wheels of fortune with their investments.
- After your wheel of fortune and the wheels of the other managers were turned and success or failure of all four companies is determined, one

of the following five market outcomes prevails. The market outcome has an influence on your payment as well as on the other managers' payments:

- One manager is successful, the other three are not successful. The company of the successful manager dominated the market and the manager gets a bonus of **770 points**. The other managers get **10 points**.
- Two managers are successful and their companies dominate the market. The other two managers are not successful. The two successful managers get a bonus of **360 points** each. The other two managers who are not successful get **10 points**.
- Three managers are successful and one manager is not successful. The three successful managers get a bonus of **200 points** each. The manager who is not successful gets **10 points**.
- All four managers are successful and the four companies share the market. Each manager gets a bonus of **100 points**.
- No manager is successful and the four companies share the market but realize lower profits. In this case all managers get **50 points**.

• Herewith the round ends.

• In the next round every manager is matched with three new randomly chosen managers. This new round is independent of the previous round.

• Please notice: Even if you decide to invest 0 points in R&D your payment nevertheless depend on the market outcome of your company in this round.

Your total income of this experiment is the sum of your payments over the 20 rounds plus your show-up fee.
Do you have any questions?

Control Questions

We ask you to compute the following examples before beginning the experiment. **Wrong answers have no consequences for you.** The experiment will

Investment in R&D in points	Probability of success in %	Increase of probability due to the last 10 points invested in R&D in %
0	0	–
10	27	27
20	39	12
30	47	8
40	55	8
50	61	6
60	67	6
70	73	6
80	78	5
90	82	4
100	86	4

not be started until all the participants have answered the questions correctly. If you have questions, please raise your hand. The conductor of the experiment will pass all seats and answer your questions privately.

1. You decided to invest 60 points in the risk-free investment project and to invest 40 points in the R&D project. Hence, your probability of success is 55%. Your investment is successful. The investments of the other managers are not successful.
   What is your income of the investment in the risk-free project?
   - Your income:

   What is your income and the income of each other manager from the market interaction in this round?
   - Your income:
   - Income of the other managers:
2. You decided to invest 100 points in the risk-free investment project and to invest 0 points in the R&D project. Hence, your probability of success is 0%. Your investment is not successful. The investment of the second manager is successful, the investments of the third and fourth

managers are not successful.
What is your income of the investment in the risk-free project?

- Your income:

What is your income and the income of each other manager from the market interaction in this round?

- Your income:
- Income of the second manager:
- Income of the third manager:
- Income of the fourth manager:

3. You decided to invest 20 points in the risk-free investment project and to invest 80 points in the R&D project. Hence, your probability of success is 78%. Your investment is successful. The investments of the other three managers are also successful.
What is your income of the investment in the risk-free project?

   - Your income:

   What is your income and the income of each other manager from the market interaction in this round?

   - Your income:
   - Income of the other managers:

4. You decided to invest 60 points in the risk-free investment project and to invest 40 points in the R&D project. Hence, your probability of success is 55%. Your investment is not successful. The investments of the other three managers are also not successful.
What is your income of the investment in the risk-free project?

   - Your income:

   What is your income and the income of each other manager from the market interaction in this round?

   - Your income:
   - Income of the other managers:

Experiment with sequential choices: monopoly treatment

Welcome to the experiment and thank you for participating!

From now on please do not speak with the other participants any more.

General Information

This experiment will investigate economic decision making. Thereby you can earn money. You will receive the income you earned during the experiment in cash at the end of the experiment.
During the experiment you and the other participants are asked to make decisions. Your own decisions determine your income according to the rules that are explained below.
The whole experiment lasts about 1.5 hours. At first you will receive detailed instructions. If you have any questions after reading the instructions or during the experiment, please raise your hand. One of the experiment conductors will come to your place and answer your questions privately.
We refer to all persons in the masculine form in order to make the text more readable. We ask for your understanding.

Payments
All the points you earn during the experiment will be converted to Euro at the end of the experiment. The following exchange rate applies:

25 points = 1.00 Euro

Furthermore, you will receive a show-up fee of 175 points (7 Euro) at the beginning of the experiment. This show-up fee also serves the purpose to compensate for possible losses that may occur during the experiment. Furthermore, you receive remuneration for answering a questionnaire at the end of the experiment.

Anonymity
The other participants will neither during nor after the experiment receive any information about your decisions and about how much you earned. We

analyse the data as an aggregate and never match names with data of the experiments. At the end of the experiment you will have to sign a receipt that you received your money. This receipt is only needed for accounting reasons of our sponsor, which will not receive any additional data of this experiment.

Auxiliary Means
There is a pen at your desk. Please leave it there at the end of the experiment.

The Experiment

Experiment procedure
During the experiment you assume the role of a manager, who invests in research and development (R&D) of his company. The experiment last for **20 rounds. Only one of these 20 rounds will be randomly selected at the end of the experiment and you will be paid out your earnings of this round.** The selected payout-round is the same for every participant. You will not be paid for any other round.
Your company holds a monopoly position in a market, this means it is the only supplier and it does not compete against other companies. The more you invest in research and development, the higher is the probability that your innovation is successful, that your company's profit increases on these grounds and that you receive a bonus. Independent from this bonus you receive a fixed payment of **100 points** in every round.

Making a decision in a round
You are a manager of a company which is a monopolist on a market. The more you invest in research and development, the higher is the probability that your innovation is be successful which increases your company's chances of higher profits. In every round you have a fixed payment of **100 points**. Points which you do not spend on your investment will be saved and paid out at the end of the experiment.
The relationship between investment cost and probability of success is shown in the following table:
Keep in mind:

Probability of success in %	0	10	20	30	40	50	60	70	80	90
Investment cost	0	1	5	11	20	31	45	61	80	100

1. If you choose a certain probability of success (for example 40%), you have to pay the investment cost which are shown in the second row (for example 20 points
2. The costs increase more than proportionate with the probability of success: An increase of the probability of success from 10% to 20% increases the investment cost by 4 points. An increase of the probability of success from 60% to 70% increases the investment cost by 16 points.
3. The maximal achievable probability of success is 90%.

The profit of your company depends on the success or failure of your R&D investment and on the general development of the market. The general development of the market can either be good or bad. You cannot influence whether the development of the market is good or bad, this will be decided by chance. The exact probability of a bad or good market development varies from round to round. You receive information about it at the beginning of every round.

The bonus payment which you receive additionally to the fixed payment of **100 points** is determined as follows:

- If you are successful and the general market development is good, then your company makes high profits and you receive a bonus of **200 points**.
- If you are successful and the general market development is bad, then your company makes medium profits and you receive a bonus of **100 points**.
- If you are successful and the general market development is bad, then your company makes low profits and you receive a bonus of**0 points**.

Additionally you have to pay the investment cost. Your total payment in one round therefor is:

Payment = 100 + performance-related bonus payment - investment cost

Please consider that you receive a fixed payment of **100 points** in every round so that your payment will never be negative even if you invest the maximum amount of **100 points** and your bonus payment is**0 points**. Every point that you do not invest belongs to you.

The detailed process in each round

- At the beginning of a round you are informed about the probability of a bad market development in this round.
- Then you decide on your probability of success of your R&D investment. Depending on the chosen probability of success you have to pay the investment cost which are listed in the table.
- After this a random mechanism decides whether you are successful or not. Your probability of success only depends on the amount you have invested. It is independent of the general development of the market.
  - Imagine a rotating wheel of fortune with a red and a black field. If the wheel stops at the red field your investment is successful. If the wheel stops at the black field your investment is not successful.
  - The more points you invest the larger is the red field on the wheel of fortune and with it the probability that your investment is successful.
- At the same time another random mechanism decides on the outcome of the market development. Imagine a second rotating wheel of fortune. The red field represent the probability of a bad market development. If the wheel stops at the red field the market development is bad.
- After both wheels of fortune were turned and success or failure and market development are determined, one of the following outcomes emerges. This market outcome has an influence on your payment:
  - If you are successful and the general market development is good, you receive a bonus of **200 points**.

  - If you are successful and the general market development is bad or if you are not successful and the general market development is good, you receive a bonus of **100 points**.
  - If you are not successful and the general market development is bad, you receive**0 points**.
  - Herewith the round ends.

- In the next round a new investment decision has to be made and a new general market development will be determined. The next round is totally independent of the previous round.

Please note: Even though you play this experiment over 20 rounds only one round will be paid. This round will be selected randomly at the end of the experiment and is the same for all participants. All other rounds are irrelevant for your payments.

Do you have any questions?

Control Questions

Please answer the follwing control questions. **Wrong answers have no consequences for you.** The experiment will not be started until all the participants have answered the questions correctly. If you have questions, please raise your hand. The conductor of the experiment will pass all seats and answer your questions privately.

1. You decided on a probability of success of 60%. The probability of a bad market development is 50%. Your investment is successful. The actual market development is good.

   - What is your bonus from the R&D project in this round?
   - What is your total payment is this round?

2. You decided on a probability of success of 0%. The probability of a bad market development is 30%. Your investment is not successful. The actual market development is bad.
   - What is your bonus from the R&D project in this round?

- What is your total payment is this round?

3. You decided on a probability of success of 80%. The probability of a bad market development is 40%. Your investment is successful. The actual market development is bad.
    - What is your bonus from the R&D project in this round?
    - What is your total payment is this round?

4. You decided on a probability of success of 50%. The probability of a bad market development is 60%. Your investment is not successful. The actual market development is good.
    - What is your bonus from the R&D project in this round?
    - What is your total payment is this round?

Experiment with sequential choices: monopoly treatment

Welcome to the experiment and thank you for participating!
From now on please do not speak with the other participants any more.

General Information

This experiment will investigate economic decision making. Thereby you can earn money. You will receive the income you earned during the experiment in cash at the end of the experiment.
During the experiment you and the other participants are asked to make decisions. Your own decisions and that of the other participants determine your income according to the rules that are explained below.
The whole experiment lasts about 1.5 hours. At first you will receive detailed instructions. If you have any questions after reading the instructions or during the experiment, please raise your hand. One of the experiment conductors will come to your place and answer your questions privately.
We refer to all persons in the masculine form in order to make the text more readable. We ask for your understanding.

Payments
All the points you earn during the experiment will be converted to Euro at the end of the experiment. The following exchange rate applies:

25 points = 1.00 Euro

Furthermore, you will receive a show-up fee of 175 points (7 Euro) at the beginning of the experiment. This show-up fee also serves the purpose to compensate for possible losses that may occur during the experiment. Furthermore, you receive remuneration for answering a questionnaire at the end of the experiment.

Anonymity
You are neither during nor after experiment informed with whom you are/were matched in each single round. The other participants will neither during nor after the experiment receive information about the matching or about your

income, too. We analyse the data as an aggregate and never match names with data of the experiments. At the end of the experiment you will have to sign a receipt that you received your money. This receipt is only needed for accounting reasons of our sponsor, which will not receive any additional data of this experiment.

Auxiliary Means
There is a pen at your desk. Please leave it there at the end of the experiment.

The Experiment

Experiment procedure
During the experiment you assume the role of a manager, who invests in research and development (R&D) of his company. The experiment last for **20 rounds. Only one of these 20 rounds will be randomly selected at the end of the experiment and you will be paid out your earnings of this round**. The selected payout-round is the same for every participant. You will not be paid for any other round.
Your company competes in each round with another company, whose manager also invests in R&D. The more a manager invests in R&D, the higher is the probability that his innovation is successful, that his company's profit increases on these grounds and that he receive a bonus. Independent from this bonus each manager receives a fixed payment of **100 points** in every round.
The managers of both companies decide one after the other how much they invest in R&D. First manager 1 decides on his investment without knowing how much manager 2 will invest. Manager 2 observes the investment choice of manager 1, but he does not know whether the investment of manager 1is successful or not. Only after manager 2 has made his investment, a random drawing decides about success or failure of both investments and about the payments of both managers.
Half of all participants is manager 1 in all 20 rounds and the other half of the participants is manager 2 in all 20 rounds. Before the first round begins you will be informed about your role. **In each round you are matched with another manager of the other role**.
You are not informed about the identity of the persons you are matched with, neither during nor after the experiment. This ensures full anonymity

of the decisions in all rounds.

Making a decision in a round

You are a manager of a company which competes with another company. The more you invest in research and development, the higher is the probability that your innovation is be successful which increases your company's chances of higher profits. In every round you have a fixed payment of **100 points**. Points which you do not spend on your investment will be saved and paid out at the end of the experiment.

The relationship between investment cost and probability of success is shown in the following table:

Probability of success in %	0	10	20	30	40	50	60	70	80	90
Investment cost	0	1	5	11	20	31	45	61	80	100

Keep in mind:

1. If you choose a certain probability of success (for example 40%), you have to pay the investment cost which are shown in the second row (for example 20 points

2. The costs increase more than proportionate with the probability of success: An increase of the probability of success from 10% to 20% increases the investment cost by 4 points. An increase of the probability of success from 60% to 70% increases the investment cost by 16 points.

3. The maximal achievable probability of success is 90%.

4. The probability of success of your R&D investment is independent of the success of the investment of the other manager.

Whether the companies succeed or fail with their investments in R&D determines the profits or losses of both companies in the market. Your bonus payment, which you receive additionally to your fixed payment of **100 points**, depends on this market outcome:

- If only you are successful, but the other manager is not successful, your company dominates the market. In this case you receive a bonus of **200 points**, the other manager only receives**0 points**.

- If both managers are successful or if no manager is successful, both companies are on a par. In this case both managers get a bonus of **100 points**.
- If, both companies are also on a par, but are less profitable. In this case both managers get 90 points.
- If only the other manager is successful, than the other company dominates the market. In this case the other manager gets a bonus of **200 points** and you receive **0 points**.

Additionally you have to pay the investment cost. Your total payment in one round therefore is:

Payment = **100** + **performance-related bonus payment - investment cost**

Please consider that you receive a fixed payment of **100 points** in every round so that your payment will never be negative even if you invest the maximum amount of **100 points** and your bonus payment is **0 points**. Every point that you do not invest belongs to you.

The detailed process in each round

- First manager 1 decides on his probability of success. Depending on the chosen probability of success he has to pay the investment cost which are listed in the table.
- Then manager 2 is informed about the probability of success which manager 1 has chosen. Manager 2 does not know whether the investment of manager 1 was successful or not. Now manager 2 has to choose on his probability of success. He also has to pay the investment cost which are listed in the table.
- After both managers have decided on their probability of success, a random drawing decides whether manager 1 and whether manager 2 are successful. The probability of success depends only on the amount he has invested. It is independent of the investment of the other manager:

  - Imagine for each manager a rotating wheel of fortune with a red and a black field. If your wheel stops at the red field your investment is successful. If the wheel stops at the black field your investment is not successful.
  - The more points you invest the larger is the red field on the wheel of fortune and with it the probability that your investment is successful. The manager of the other company your company is competing against can influence the red field of his own wheel of fortune with his investments.

- After your wheel of fortune and the wheel of the other manager were turned and success or failure of both companies is determined, one of the following three market outcomes prevails. The market outcome has an influence on your payment as well as on the other manager's payment:
  - If you are successful but the other manager is not successful, you company dominates the market. You get a bonus of **200 points** and the other manager gets **0 points**.
  - If both managers are successful or if both managers are not successful, both get a bonus of **100 points** each.
  - If the other manager is successful but you are not successful, then the other company holds a better market position than your company. In this case the manager of the other company receives a bonus of **200 points**. You get **0 points**.
- Herewith the round ends.
- In the next round every manager is matched with another new randomly chosen manager. This new round is independent of the previous round.

Please note: Even though you play this experiment over 20 rounds only one round will be paid. This round will be selected randomly at the end of the experiment and is the same for all participants. All other rounds are irrelevant for your payments.

Do you have any questions?

Control Questions

Please answer the follwing control questions. **Wrong answers have no consequences for you**. The experiment will not be started until all the participants have answered the questions correctly. If you have questions, please raise your hand. The conductor of the experiment will pass all seats and answer your questions privately.

1. You decided on a probability of success of 60%. The other manager decided on a probability of success of 50%. Your investment is successful. The investment of the other manager is not successful.
   What is your bonus and the bonus of the other managers because of your investment in the R&D in this round?
   - Your bonus:
   - Bonus of the other manager :

   What is your total payment and the total payment of the other manager is this round?
   - Your payment:
   - Payment of the other manager:
2. You decided on a probability of success of 0%. The other manager decided on a probability of success of 30%. The investment of the other manager is not successful. Your investment is not successful.
   What is your bonus and the bonus of the other managers because of your investment in the R&D in this round?
   - Your bonus:
   - Bonus of the other manager :

   What is your total payment and the total payment of the other manager is this round?
   - Your payment:
   - Payment of the other manager:
3. You decided on a probability of success of 80%. The other manager decided on a probability of success of 40%. Both investments are successful.

What is your bonus and the bonus of the other managers because of your investment in the R&D in this round?

- Your bonus:
- Bonus of the other manager :

What is your total payment and the total payment of the other manager is this round?

- Your payment:
- Payment of the other manager:

4. You decided on a probability of success of 50%. The other manager decided on a probability of success of 60%. Both investments are not successful.
   What is your bonus and the bonus of the other managers because of your investment in the R&D in this round?

   - Your bonus:
   - Bonus of the other manager :

   What is your total payment and the total payment of the other manager is this round?

   - Your payment:
   - Payment of the other manager:

INSTRUCTIONS FOR TESTS ON RISK, LOSS AND AMBIGUITY AVERSION

Additional Decisions

Now three short parts follow. Each of the three parts consists of seven decisions (seven rows), in which you have to decide for one out of of two possibilities. All together you have to make 31 decisions. **One** of these 21 decisions is **randomly chosen for your payment**.

In **Part 1** you have to choose in each of the seven rows between a lottery and a secure payment. At the lottery you get in each row with 50% probability 7 Euros and with 50% probability 1 Euro. The secure payment varies in each row.

In **part 2** you have to choose in each of the seven rows whether you want to participate in a lottery or not. At the lottery, you receive one out of two payments, each payment being equally likely. The payments vary from row to row. If you do not participate in the lottery you receive zero Euro in each row.

In part 3 you decide in each of the seven rows for lottery A or lottery B. In both lotteries you can either get 7 Euros or 1 Euro. In lottery A, the probabilities of receiving 7 Euros or 1 Euro are randomly chosen by the computer. In lottery B the probabilities are given and vary from row to row.

Payments:
After you have made all 21 decisions, the computer randomly selects one out of the 21 decisions. If you have chosen a lottery in this decision, a random process decides with the respective probabilities about the outcome of the lottery and your payment. If you have chosen a secure payment at the selected decision, you receive this payment.

Part 1

Please decide in every row whether you want to participate in the lottery or whether you want the safe payment.

1. Lottery: With 50% probability you win 7 Euro, with 50% probability you win 1 Euro. Safe payment: 4.5 Euros. ○

2. Lottery: With 50% probability you win 7 Euro, with 50% probability you win 1 Euro. ○ Safe payment: 4 Euros. ○

3. Lottery: With 50% probability you win 7 Euro, with 50% probability you win 1 Euro. ○ Safe payment: 3.5 Euros. ○

4. Lottery: With 50% probability you win 7 Euro, with 50% probability you win 1 Euro. ○ Safe payment: 3 Euros. ○

5. Lottery: With 50% probability you win 7 Euro, with 50% probability you win 1 Euro. ○ Safe payment: 2.5 Euros. ○

6. Lottery: With 50% probability you win 7 Euro, with 50% probability you win 1 Euro. ○ Safe payment: 2 Euros. ○

7. Lottery: With 50% probability you win 7 Euro, with 50% probability you win 1 Euro. ○ Safe payment: 1.5 Euros. ○

Part 2

Please decide for each lottery whether you want to participate or not. If you do not participate in the lottery, you receive 0 Euro. In case any of these rows will be chosen for payment, you have to pay a possible loss from your earnings or your participation fee.

1. Lottery A: With 50% probability you lose 1 Euro, with 50% probability you win 6 Euros. Participate ○ Not participate ○

2. Lottery A: With 50% probability you lose 2 Euro, with 50% probability you win 6 Euros. Participate ○ Not participate ○

3. Lottery A: With 50% probability you lose 3 Euro, with 50% probability you win 6 Euros. Participate ○ Not participate ○

4. Lottery A: With 50% probability you lose 4 Euro, with 50% probability you win 6 Euros. Participate ○ Not participate ○

5. Lottery A: With 50% probability you lose 5 Euro, with 50% probability you win 6 Euros. Participate ○ Not participate ○

6. Lottery A: With 50% probability you lose 6 Euro, with 50% probability you win 6 Euros. Participate ○ Not participate ○

7. Lottery A: With 50% probability you lose 7 Euro, with 50% probability you win 6 Euros. Participate ○ Not participate ○

Part 3

Please decide in every row whether you want to participate in lottery A or lottery B. In lottery A the probabilities of winning 7 or 1 Euro are unknown.

1. Lottery A: You either win 7 Euros or 1 Euro. Lottery B: With 80% probability you win 7 Euro, with 20% probability you win 1 Euro. Lottery A ○ Lottery B ○
2. Lottery A: You either win 7 Euros or 1 Euro. Lottery B: With 70% probability you win 7 Euro, with 30% probability you win 1 Euro. Lottery A ○ Lottery B ○
3. Lottery A: You either win 7 Euros or 1 Euro. Lottery B: With 60% probability you win 7 Euro, with 40% probability you win 1 Euro. Lottery A ○ Lottery B ○
4. Lottery A: You either win 7 Euros or 1 Euro. Lottery B: With 50% probability you win 7 Euro, with 50% probability you win 1 Euro. Lottery A ○ Lottery B ○
5. Lottery A: You either win 7 Euros or 1 Euro. Lottery B: With 40% probability you win 7 Euro, with 60% probability you win 1 Euro. Lottery A ○ Lottery B ○
6. Lottery A: You either win 7 Euros or 1 Euro. Lottery B: With 30% probability you win 7 Euro, with 70% probability you win 1 Euro. Lottery A ○ Lottery B ○
7. Lottery A: You either win 7 Euros or 1 Euro. Lottery B: With 20% probability you win 7 Euro, with 80% probability you win 1 Euro. Lottery A ○ Lottery B ○

BIBLIOGRAPHY

Aghion, P., Bechtold, S., Cassar, L. and Herz, H. (2014). The causal effects of competition on innovation: Experimental evidence, *NBER Working Paper Series* **19987**.

Aghion, P., Bloom, N., Blundell, R., Griffith, R. and Howitt, P. (2005). Competition and innovation: an inverted-U relationship, *The Quarterly Journal of Economics* **120**(2): 701–728.

Aoki, R. (2005). Intellectual property and consortium standard patent pools, *Journal of Intellectual Property Rights* **10**: 206–213.

Aoki, R. and Nagaoka, S. (2005). Coalition formation for a consortium standard through a standard body and a patent pool–theory and evidence from MPEG2, DVD and 3G, *Hitotsubashi University IIR Working Paper* **05-01**.

Arrow, K. (1962). Economic welfare and the allocation of resources for invention, *The Rate and Direction of Inventive Activity: Economic and Social Factors*, National Bureau of Economic Research, pp. 609–626.

Atlee, L., Botteman, Y. and Patsa, A. (2013). A step closer to effective actions for damages for breach of EU competition rules, `http://www.steptoe.com/publications-8873.html`. acessed: 07.03.2014.

Aubert, C., Rey, P. and Kovacic, W. E. (2006). The impact of leniency and whistle-blowing programs on cartels, *International Journal of Industrial Organization* **24**(6): 1241–1266.

Barnett, J. M. (2014). From patent thickets to patent networks: The legal infrastructure of the digital economy, *Jurimetrics, forthcoming* .

Baron, J. and Pohlman, T. (2011). Patent pools and patent inflation, conference proceedings: 4th zew conference on economics of innovation and patenting & finale conference cost network strike, `http://ftp.zew.de/pub/zew-docs/veranstaltungen/innovationpatenting2011/papers/`. accessed: 25.11.2014.

Baron, J. and Pohlman, T. (2012). Patent pools and patent inflation, `http://www.oecd.org/site/stipatents/3-1-Baron-Pohlmann.pdf`. accessed: 25.11.2014.

Basedow, J. (ed.) (2007). *Private enforcement of EC competition law*, Kluwer Law Internat., Alphen aan den Rijn.

Basedow, J., Terhechte, J. P. and Tichý, L. (eds) (2011). *Private enforcement of competition law*, Nomos, Baden-Baden.

Baye, M. R. and Hoppe, H. C. (2003). The strategic equivalence of rent-seeking, innovation, and patent-race games, *Games and Economic Behavior* **44**(2): 217–226.

Bloom, N. and Van Reenen, J. (2007). Measuring and explaining management practices across firms and countries, *The Quarterly Journal of Economics* **122**(4): 1351–1408.

Blundell, R., Griffith, R. and Van Reenen, J. (1999). Market share, market value and innovation in a panel of british manufacturing firms, *Review of Economic Studies* **66**(3): 529–554.

Borenstein, S. and Farell, J. (2000). Is cost cutting evidence of x-inefficiency?, *American Economic Review Papers and Proceedings* **90**(2): 224–227.

Boyer, M. and Moreaux, M. (1987). Being a leader or a follower: Reflections on the distribution of roles in duopoly, *International Journal of Industrial Organization* **5**(2): 175–192.

Brenner, S. (2009). Optimal formation rules for patent pools, *Economic Theory* **40**(3): 373–388.

Buccirossi, P. and Spagnolo, G. (2006). Leniency policies and illegal transactions, *Journal of Public Economics* **90**(6-7): 1281–1297.

Calcagno, C. (2012). Stand-alone private antitrust damages: (how) should competition authorities react?, *European Journal of Law and Economics* **34**(2): 365–389.

Chen, Z. and Rey, P. (2013). On the design of leniency programs, *Journal of Law and Economics* **56**(4): 917–957.

Coughlan, P. J. and Plott, C. R. (1997). An experimental analysis of the structure of legal fees: American rule vs. english rule, *California Institute of Technology, Social Science working paper* **1025**.

Cournot, A.-A. (1838). *Researches into the mathematical principles of the theory of wealth*, Macmillan, New York.

D'Aspremont, C., Jacquemin, A., Gabszewicz, J. J. and Weymark, J. A. (1983). On the stability of collusive price leadership, *The Canadian Journal of Economics–Revue canadienne d'Economique* **16**(1): 17–25.

Dechenaux, E., Kovenock, D. and Sheremeta, R. M. (forthcoming). A survey of experimental research on contests, all-pay auctions and tournaments, *Experimental Economics* .

Diamantoudi, E. (2005). Stable cartels revisited, *Economic Theory* **26**: 907–921.

Dohmen, T., Falk, A., Huffman, D. and Sunde, U. (2010). Are risk aversion and impatience related to cognitive ability?, *American Economic Review* **100**(3): 1238–60.

Donsimoni, M. P., Economides, N. S. and Polemarchakis, H. M. (1986). Stable cartels, *International Economic Review* **27**(2): 317–327.

Ederer, F. and Manso, G. (2013). Is pay-for-performance detrimental to innovation?, *Management Science* **59**(7): 1496–1513.

European Commission (2005). Green paper on damages actions for breach of the EC antitrust rules, COM(2005) 672 final.

European Commission (2008). White paper on damages actions for breach of the EC antitrust rules, COM(2008) 165 final.

European Commission (2013a). Antitrust: Commission proposes legislation to facilitate damage claims by victims of antitrust violations, IP/13/525. Press Report of June 11th.

European Commission (2013b). Commission recommends Member States to have collective redress mechanisms in place to ensure effective access to justice, IP/13/524. Press Report of June 11th.

European Commission (2013c). Commission Staff Working Document: Impact Asssessment Report: Damages actions for breach of the EU antitrust rules, COM(2013) 203 final.

European Commission (2013d). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: "Towards a European Horizontal Framework for Collective Redress", COM(2013) 401 final.

European Commission (2013e). Proposal for a Directive of the European Parliament and of the Council on certain rules governing actions for damages under national law for infringements of the competition law provisions of the Member States and of the European Union, COM(2013) 404 final.

European Commission (2014). Antitrust: Commission welcomes Council adoption of Directive on antitrust damages actions, IP/14/1580. Press Report of November 10th.

European Parliament (2014). Corrigendum of the Directive of the European Parliament and of the Council on certain rules governing actions for damages under national law for infringements of the competition law provisions of the Member States and of the European Union, P7_TA-PROV(2014)0451.

European Union (2006). Commission Notice on Immunity from fines and reduction of fines in cartel cases, *Official Journal of the European Union* **C 298**: 17–22.

European Union (2008). Commission Notice on the conduct of settlement procedures in view of the adoption of Decisions pursuant to Article 7 and Article 23 of Council Regulation (EC) No 1/2003 in cartel cases, *Official Journal of the European Union* **C 167**: 1–6.

European Union (2014a). Commission Regulation (EU) No 316/2014 of 21 March 2014 on the application of Article 101(3) of the Treaty on the Functioning of the European Union to categories of technology transfer agreements, *Official Journal of the European Union* **L93**: 17–23.

European Union (2014b). Directive of the European Parliament and of the Council on certain rules governing actions for damages under national law for infringements of the competition law provisions of the Member States and of the European Union, PE-CONS 80/14.

Fehr, E. and Goette, L. (2007). Do workers work more if wages are high? Evidence from a randomized field experiment, *The American Economic Review* **97**(1): 298–317.

Field, A. J. (2003). The most technologically progressive decade of the century, *The American Economic Review* **93**(4): 1399–1413.

Fischbacher, U. (2007). z-tree: Zurich toolbox for ready-made economic experiments, *Experimental Economics* **10**(2): 171–178.

Fisher, I. (1898). Cournot and mathematical economics, *The Quarterly Journal of Economics* **12**(2): 119–138.

Friedman, J. W. (1971). A non-cooperative equilibrium for supergames, *The Review of Economic Studies* **38**(113): 1–12.

Fullerton, R., Linster, B. G., McKee, M. and Slate, S. (1999). An experimental investigation of research tournaments, *Economic Inquiry* **37**(4): 624–636.

Gaechter, S., Johnson, E. J. and Herrmann, A. (2010). Individual-level loss aversion in riskless and risky choices, *Centre for Decision Research and Experimental Economics (CeDEx) Working Paper Series* **2010-20**.

Gal-Or, E. (1985). First mover and second mover advantages, *International Economic Review* **26**(3): 649–653.

Geroski, P. (1994). *Market structure, corporate performance, and innovative activity*, Oxford University Press.

Gilbert, R. (2006). Looking for Mr. Schumpeter: Where are we in the competition-innovation debate?, *Innovation policy and the economy*, Vol. 6, MIT Press, Cambridge, book section 6, pp. 159–215.

Greiner, B. (2004). An online recruitment system for economic experiments, *in* K. Kremer and V. Macho (eds), *Forschung und wissenschaftliches Rechnen*, Vol. 63 of *GWDG Bericht*, Ges. für Wiss. Datenverarbeitung, Göttingen, pp. 79–93.

Harrington, J. E. (2008). Optimal corporate leniency programs, *The Journal of Industrial Economics* **56**(2): 215–246.

Harsanyi, J. C. (1974). An equilibrium-point interpretation of stable sets and a proposed alternative definition, *Management Science* **20**(11): 1472–1495.

Holt, C. A. and Laury, S. K. (2002). Risk aversion and incentive effects, *The American Economic Review* **92**(5): 1644–1655.

Isaac, R. M. and Reynolds, S. S. (1992). Schumpeterian competition in experimental markets, *Journal of Economic Behavior & Organization* **17**(1): 59–100.

Japan Fair Trade Commission (2007). Guidelines for the Use of Intellectual Property under the Antimonopoly Act, `http://www.jftc.go.jp/en/legislation_gls/imonopoly_guidelines.html`. accessed: 02.12.2014.

Komninos, A. P. (2008). *EC private antitrust enforcement: Decentralised application of EC competition law by National Courts*, Hart, Oxford.

Konishi, H. and Lin, P. (1999). Stable cartels with a Cournot fringe in a symmetric oligopoly, *Keio Economic Studies* **36**(2): 1–10.

Lampe, R. and Moser, P. (2010). Do patent pools encourage innovation? evidence from the nineteenth-century sewing machine industry, *The Journal of Economic History* **70**: 898–920.

Layne-Farrar, A. and Lerner, J. (2011). To join or not to join: Examining patent pool participation and rent sharing rules, *International Journal of Industrial Organization* **29**(2): 294–303.

Leibenstein, H. (1966). Allocative efficiency vs. "X-efficiency", *The American Economic Review* **56**(3): 392–415.

Lévêque, F. and Ménière, Y. (2011). Patent pool formation: Timing matters, *Information Economics and Policy* **23**(3-4): 243–2510.

Llanes, G. and Poblete, J. (2014). Ex ante agreements in standard setting and patent-pool formation, *Journal of Economics & Management Strategy* **23**(1): 50–67.

Mancini, M. and Dechenaux, E. (2008). Auction-theoretic approach to modeling legal systems: An experimental analysis, *Applied Economics Research Bulletin* **2**(Special Issue I): 142–177.

Marra, A. and Sarra, A. (2010). Incomplete antitrust laws and private actions for damages, *European Journal of Law and Economics* **30**(2): 111–135.

Martin, S. (1993). Endogenous firm efficiency in a Cournot principal-agent model, *Journal of Economic Theory* **59**(2): 445–450.

Maskin, E. (2003). Bargaining, coalitions and externalities, `http://www.feem-web.it/ctn/papers/05_Maskin.pdf`. accessed: 25.11.2014.

McAfee, R. P., Mialon, H. M. and Mialon, S. H. (2008). Private v. public antitrust enforcement: A strategic analysis, *Journal of Public Economics* **92**(10-11): 1863–1875.

Miller, N. H. (2009). Strategic leniency and cartel enforcement, *The American Economic Review* **99**(3): 750–768.

Millner, E. L. and Pratt, M. D. (1989). An experimental investigation of efficient rent-seeking, *Public Choice* **62**(2): 139–151.

Motchenkova, E. and Leliefeld, D. (2010). Adverse effects of corporate leniency programs in view of industry asymmetry, *Journal of Applied Economic Sciences* **5**(2(12)): 115–129.

Motta, M. and Polo, M. (2003). Leniency programs and cartel prosecution, *International Journal of Industrial Organization* **21**(3): 347–379.

Nickell, S. J. (1996). Competition and corporate performance, *Journal of Political Economy* **104**(4): 724–746.

Peyer, S. (2012). Private antitrust litigation in Germany from 2005 to 2007: Empirical evidence, *Journal of Competition Law & Economics* **8**(2): 331–359.

Peyer, S. and Hüschelrath, K. (2013). Public and private enforcement of competition law: A differentiated approach, *World Competition Law and Economic Review* **36**(4): 585–613.

Prokop, J. (1999). Process of dominant-cartel formation, *International Journal of Industrial Organization* **17**(2): 241–257.

Raith, M. (2003). Competition, risk, and managerial incentives, *The American Economic Review* **93**(4): 1425–1436.

Renda, A., Peysner, J., Riley, A. J., Rodger, B. J., Van Den Berg, R. J., Keske, S., Pardolesi, R., Camilli, E. L. and Caprile, P. (2007). Making antitrust damages actions more effective in the EU: welfare impact and potential scenarios (Report for the European Commission), `http://ec.europa.eu/competition/antitrust/actionsdamages/files_white_paper/impact_study.pdf`. accessed: 07.03.2014.

Rodger, B. (2006a). Competition law litigation in the UK courts: a study of all cases to 2004: Part I, *European Competition Law Review* **241**.

Rodger, B. (2006b). Competition law litigation in the UK courts: a study of all cases to 2004: Part II, *European Competition Law Review* **341**.

Rodger, B. (2009a). Competition law litigation in the UK courts: a study of all cases 2005-2008: Part I, *Global Competition Litigation Review* pp. 93–114.

Rodger, B. (2009b). Competition law litigation in the UK courts: a study of all cases 2005-2008: Part II, *Global Competition Litigation Review* **3**: 136–147.

Rodger, B. (2013). Competition law litigation in the UK courts : a study of all cases 2009-2012, *Global Competition Litigation Review* **6**(2): 55–67.

Sacco, D. and Schmutzler, A. (2011). Is there a U-shaped relation between competition and investment?, *International Journal of Industrial Organization* **29**(1): 65–73.

Scherer, F. M. (1967). Market structure and the employment of scientists and engineers, *The American Economic Review* **57**(3): 524–531.

Schmidt, K. M. (1997). Managerial incentives and product market competition, *The Review of Economic Studies* **64**(2): 191–213.

Schmidt, K. M. (2010). Standards, innovation incentives, and the formation of patent pools, *SFB Discussion Paper* **342**.

Schmitz Jr, J. (2005). What determines productivity? lessons from the dramatic recovery of the u.s. and canadian iron ore industries following their early 1980s crisis, *Journal of Political Economy* **113**(3): 582–625.

Schmutzler, A. (2013). Competition and investment–A unified approach, *International Journal of Industrial Organization* **31**(5): 477–487.

Schmutzler, A., Darai, D. and Sacco, D. (2010). Competition and innovation: An experimental investigation, *Experimental Economics* **13**(4): 439–460.

Schumpeter, J. (1942). *Capitalism, socialism, and democracy*, Harper, New York.

Segal, I. R. and Whinston, M. D. (2007). Public vs. private enforcement of antitrust law: A survey, *European Competition Law Review* pp. 323–332.

Serafino, D. (2007). Survey of patent pools demonstrates variety of purposes and management structures, *KEI Research Note* **2007:6**.

Shaffer, S. (1995). Stable cartels with a Cournot fringe, *Southern Economic Journal* **61**(3): 744–754.

Shapiro, C. (2001). Navigating the patent thicket: Cross licenses, patent pools, and standard setting, *in* J. L. Adam B. Jaffe and S. Stern (eds), *Innovation Policy and the Economy*, Vol. 1, MIT Press, pp. 119–150.

Sheremeta, R. M. (2013). Overbidding and heterogeneous behavior in contest experiments, *Journal of Economic Surveys* **27**: 491–514.

Shogren, J. F. and Baik, K. H. (1991). Reexamining efficient rent-seeking in laboratory markets, *Public Choice* **69**(1): 69–79.

Spagnolo, G. (2004). Divide et impera: Optimal leniency programs, *CEPR Discussion Paper* **4840**.

Spagnolo, G. (2008). Leniency and whistleblowers in antitrust, *in* P. Buccirossi (ed.), *Handbook of antitrust economics*, MIT Press, Cambridge, Mass., book section 7, pp. 259–303.

Tullock, G. (1980). Efficient rent seeking, *in* J. M. Buchanan, R. D. Tollison and G. Tullock (eds), *Toward a theory of the rent-seeking society*, College Station, TX: Texas A&M University Press, pp. 97–112.

U.S. Department of Justice & the Federal Trade Commission (1995). Antitrust Guidelines for the Licensing of Intellectual Property, `http://www.justice.gov/atr/public/guidelines/0558.htm`. accessed: 02.12.2014.

Vives, X. (2008). Innovation and competitive pressure, *The Journal of Industrial Economics* **56**(3): 419–469.

von Neumann, J. and Morgenstern, O. (1953). *Theory of Games and Economic Behavior*, third edn, Princeton University Press.

Waelbroeck, D., Slater, D. and Even-Shoshan, G. A. (2004). Study on the conditions of claims for damages in case of infringement of EC competition rules, `http://ec.europa.eu/competition/antitrust/actionsdamages/study.html`. accessed: 01.12.2014.

Wils, W. P. (2009). The relationship between public antitrust enforcement and private actions for damages, *World Competition* **32**(1).

Zu, L., Zhang, J. and Wang, S. (2012). The size of stable cartels: An analytical approach, *International Journal of Industrial Organization* **30**(2): 217–222.

LIST OF CASES

Case C-453/99, *Courage Ltd. v. Crehan* [2001] ECR I-6297; judgment of 20 September 2001.

Joined Cases C-295/04 to C-298/04, *Vincenzo Manfredi and Others v. Lloyd Adriatico Assicurazioni SpA and Others* [2006] ECR I-6619; judgment of 13 July 2006.

Case COMP/F/38.899, *Gas Insulated Switchgear* C(2006) 6762 final; judgment of 24 January 2007.

Case B11-18/08 Decision on the Fine in the Proceedings against several Coffee Roasters [2010]; judgment of 6 August 2010.

Case C-360/09, *Pfleiderer AG v. Bundeskartellamt* [2011] ECR I-5161; judgment of 14 June 2011.

Case C-199/11, *Europese Gemeenschap v. Otis NV and Others* [2012]; judgment of 6 November 2012.

Case T-437/08, *CDC Hydrogene Peroxide Cartel Damage Claims v European Commission* [2011] ECR II-08251; judgment of 15 December 2011.

National Grid Electricity Transmission Plc v. ABB Ltd & Ors [2012] EWHC 869 (Ch); judgment of 4 April 2012.

Case T-344/08, *EnBW Energie Baden-Württemberg AG v. European Commission* [2012]; judgment of 22 May 2012.

OLG Düsseldorf, BB 2012, 2459-2462; judgment of 22 August 2012.

Case C-536/11, *Bundeswettbewerbsbehörde v. Donau Chemie AG and Others* [2013]; judgment of 6 June 2013.

Case T-380/08, *Kingdom of the Netherlands v. European Commission* [2013]; judgment of 13 September 2013.

Case C-365/12 P, *European Commission v. EnBW Energie Baden-Württemberg AG* [2014]; judgment of 27 February 2014.

Case C-557/12 , *Kone AG and Others v. ÖBB-Infrastruktur AG* [2014]; judgment of 5 June 2014.