# Three Essays on Competition Policy and Innovation Incentives

Inauguraldissertation

zur Erlangung des akademischen Grades
eines Doktors der Wirtschaftswissenschaften an der
wirtschaftswissenschaftlichen Fakultät
der Julius-Maximilians-Universität Würzburg

Vorgelegt von:
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Würzburg, im Oktober 2008

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Meiner Familie

# Danksagung

Die vorliegende Arbeit habe ich als wissenschaftlicher Mitarbeiter des Lehrstuhls für Industrieökonomik von Professor Norbert Schulz, Ph.D. sowie als Stipendiat des Bavarian Graduate Program in Economics "Incentives" angefertigt. Ich möchte mich an dieser Stelle bei allen Personen bedanken, die zum Gelingen dieser Arbeit beigetragen haben.

Norbert Schulz möchte ich besonders für das mir entgegengebrachte Vertrauen, die Motivation und die ständige Unterstützung danken. Er hat immer die richtige Mischung aus nötigem Druck und Freiräumen bei meiner Betreung gefunden. Die Arbeit an seinem Lehrstuhl hat mir sehr viel Spaß gemacht.

Peter Welzel war immer bereit, mich kurzfristig und unkompliziert mit wertvollen Ratschlägen und konstruktiver Kritik zu unterstützen. Auch hierfür möchte ich mich herzlich bedanken.

Weiterhin möchte ich mich bei allen Kollegen bedanken, die durch kritische Kommentare und Anregungen auf Konferenzen und Workshops erheblich zur Qualität der Arbeit beigetragen haben. Ausdrücklich erwähnen möchte ich hierbei Jay Pil Choi, der mich während meines Forschungssemesters an der Michigan State University betreut hat, sowie meinen Freund und Kollegen Alex Steinmetz, der in unserem gemeinsamen Büro mein Chaos ertragen musste.

Besonderer Dank gilt meine Eltern für ihre ständige Unterstützung in allen Bereichen des Lebens.

Zuletzt möchte ich meinem Bruder danken: Dafür, dass er so ist, wie er ist.

# Zusammenfassung

Diese Dissertation befasst sich mit dem Thema Innovationsökonomik. In einer allgemeinen Einführung werden wettbewerbspolitische Gesichtspunkte, die Innovationsanreize von Firmen beeinflussen, dargestellt. In drei einzelnen Arbeiten werden dann spezielle Fragestellungen intensiver analysiert.

Die erste Arbeit behandelt die Wechselwirkungen von Firmenzusammenschlüssen und Innovationen, zwei zentrale Elemente der Wettbewerbsstrategie von Unternehmen. Der Schwerpunkt der Arbeit liegt dabei auf dem Einfluss von Firmenzusammenschlüssen auf die Innovationsaktivitäten und den Wettbewerb im Produktmarkt. Dabei werden auch mögliche Ineffizienzen, die sich durch Probleme bei der Integration der Firmen nach dem Zusammenschluss ergeben, untersucht. Es wird gezeigt, dass die optimale Investitionsaktivität sehr stark von der sich ergebenden Marktstruktur abhängt und es signifikante Unterschiede zwischen Insider und Outsider des Firmenzusammenschlusses gibt. In dem Modell mit linearer Nachfragefunktion und konstanten Grenzkosten steigern Zusammenschlüsse die soziale Wohlfahrt.

Die zweite Arbeit betrachtet die unterschiedlichen Vorteile von kleinen und großen Firmen im Innovationswettbewerb. Während große Firmen typischerweise über einen besseren Zugang zu Produktmärkten verfügen, weisen kleine Firmen häufig eine bessere Forschungseffizienz auf. Diese verschiedenen Vorteile werfen unmittelbar die Frage nach Kooperationen auf. Im dargestellten Modell mit vier Unternehmen haben große Firmen die Möglichkeit kleine Firmen zu kaufen. Innovationen werden mittels Patentwettbewerb modelliert. Sequentielles Bieten ermöglicht es der ersten großen Firma strategisch zu handeln um eine Reaktion der zweiten großen Firma hervorzurufen. Ergeben sich hohe Effizienzen durch den Firmenzusammenschluss, so bevorzugen die großen Firmen eine unmittelbare Akquisition und es entsteht eine symmetrische Marktstruktur. Bei geringen Effizienzen

wartet die erste Firma dagegen ab und zwingt die zweite Firma dadurch zum Kauf. Somit entsteht trotz symmetrischer Ausgangssituation eine asymmetrische Marktstruktur. Weiterhin wird gezeigt, dass Akquisitionen die Chancen für eine erfolgreiche Innovation erhöhen.

Die dritte Arbeit befasst sich mit Forschungssubventionen. Dabei wird neben dem eigentlichen Ziel der Subvention – der Förderung sozial erwünschter Projekte, die nicht genügend private Anreize zur Durchführung bieten – die Signalwirkung einer Subvention betrachtet. Eine Staatsbehörde untersucht dabei die Projekte auf Risiken und Wohlfahrtswirkungen und entscheidet daraufhin über eine Förderung. Dies wird in einem einfachen Signalisierungsspiel mit zwei Risikoklassen von Forschungsprojekten modelliert. Die Staatsbehörde bevorzugt dabei riskante Projekte, die hohe erwartete soziale Gewinne versprechen, während Banken wenig riskante Projekte mit hohen privaten Gewinnen bevorzugen. Ermöglicht die Subvention lediglich die Unterscheidung von riskanten und weniger riskanten Projekten, so ist das Signal der Behörde wenig hilfreich für die Investitionsenscheidung der Banken. Bietet das Signal jedoch zusätzlich einen Hinweis auf die Qualität der Projekte, so können sich erhöhte, bzw. effizienter ausgewählte, private Investitionen ergeben.

Im letzten Kapitel werden die wichtigsten Aussagen zusammengefasst sowie in abschließenden Bemerkungen der Zusammenhang der Ergebnisse erläutert.

# Abstract

This thesis deals with the economics of innovation. In a general introduction we illustrate how several aspects of competition policy are linked to firms' innovation incentives. In three individual essays we analyze more specific issues.

The first essay deals with interdependencies of mergers and innovation incentives. This is particularly relevant as both topics are central elements of a firm's competitive strategy. The essay focuses on the impact of mergers on innovative activity and competition in the product market. Possible inefficiencies due to organizational problems of mergers are accounted for. We show that optimal investment strategies depend on the resulting market structure and differ significantly from insider to outsider. In our linear model mergers turn out to increase social surplus.

The second essay analyzes the different competitive advantages of large and small firms in innovation competition. While large firms typically have a better access to product markets, small firms often have a superior R&D efficiency. These distinct advantages immediately lead to the question of cooperations between firms. In our model we allow large firms to acquire small firms. In a pre-contest acquisition game large firms bid sequentially for small firms in order to combine respective advantages. Innovation competition is modeled as a patent contest. Sequential bidding allows the first large firms to bid strategically to induce a reaction of its competitor. For high efficiencies large firms prefer to acquire immediately, leading to a symmetric market structure. For low efficiencies strategic waiting of the first large firm leads to an asymmetric market structure even though the initial situation is symmetric. Furthermore, acquisitions increase the chances for successful innovation.

The third essay deals with government subsidies to innovation. Government subsidies for R&D are intended to promote projects with high returns to society but too little private returns to be beneficial for private investors. Apart from the direct funding of these projects, government grants may serve as a signal of good investments

for private investors. We use a simple signaling model to capture this phenomenon and allow for two types of risk classes. The agency has a preference for high risk projects as they promise high expected social returns, whereas banks prefer low risk projects with high private returns. In a setup where the subsidy can only be used to distinguish between high and low risk projects, government agency's signal is not very helpful for banks' investment decision. However, if the subsidy is accompanied by a quality signal, it may lead to increased or better selected private investments.

The last chapter summarizes the main findings and presents some concluding remarks on the results of the essays.

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"Innovation is not the product of logical thought, although the result is tied to logical structure."

– *Albert Einstein* –

# Chapter 1

# Introduction

Innovations are the source of development and growth for an economy. Whether you think of milestones, like the invention of letterpress printing, revolutionizing the media in the fifteenth century, the steam engine, pushing the industrial revolution in the eighteenth and nineteenth century, and the internet, facilitating communication all over the world at the end of the twentieth century or of smaller steps, like the aerodynamic design of a new car, improved contact lenses, and a new processing technology for raw materials: All these innovations lead to economic growth, making it so very crucial to understand what factors influence the innovative activity of a society. Joseph Schumpeter introduced the word ”innovation” in economic theory in the early twentieth century and started a systematic analysis of innovation and its dependency on the organization and the regulatory framework in economics. Since that time literature has been growing and there is an intense discussion about a large variety of issues. In addition to classical welfare analyses, the economics of innovation are a major topic in other strands of economic literature, like industrial management, economics of information, entrepreneurship, or international economics.

This thesis analyzes some important aspects of the economics of innovation with focus on competition policy. After a brief introduction on innovation and innovation measurement we give a short overview of measures of competition policy that might improve conditions for successful innovation and hence help to increase social welfare. Chapters two, three, and four assess firms' innovation incentives in specific contexts in more detail and analyze what interventions are likely to be beneficial to social welfare. The last chapter presents some concluding remarks.

## 1.1 Innovation – An Explanation of Terms

Formulating an undisputable definition of innovation is difficult. The Oslo manual on innovation data defines innovation as the "implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD (2005), p. 46). Schumpeter had a rather strict definition of innovation: "This historic and irreversible change in the way of doing things we call 'innovation' and we define: Innovations are changes in the production functions which cannot be decomposed into infinitesimal steps." (Schumpeter (1947), p.152). In the industrial management literature we find a rather provocative and very general formulation: "Innovation is new stuff that is useful" (McKeown (2008), p. 10). More precisely, the author refers to radical and incremental changes in thinking, in things, in processes, or in services.

The fact that there is no unique definition of innovation is partly caused by the existence of several innovation types. This in turn is immediately connected with problems of innovation measurement. We will deal with these issues in the following sections.

### 1.1.1 Classification of Innovation Types

In order to analyze innovation incentives more closely, it is useful to distinguish different types of R&D. Tirole (1989) categorizes R&D by its distance to market. *Basic research* aims at deriving fundamental knowledge. It is typically characterized by a high degree of uncertainty and unknown possible applications. *Applied research* is done in engineering sciences, usually already with a clear vision of the final product. *Development* is the final step of bringing products and processes to the market. Innovations in this step also include reduction of production costs or time.[1] Of course, there is no clear cut between the stages. Moreover, firms' behavior in each stage influences research activities in other stages. There is also a post research stage in which licensing, imitation of patented innovations, and adaptation of unpatented innovations occur and new ideas diffuse through industry.

[1] Iansiti (1993) argues that in high technology industries the complexity of systems calls for an approach that integrates all three stages of R&D. This approach is supposed to shorten time to market and reduce R&D costs.

Innovations can also be distinguished by their main objective. While *process innovations* aim at reducing costs by using a better manufacturing technology, processing information more efficiently, or other changes in the production process, *product innovations* aim at improving or changing an existing product or even developing a completely new product.[2]

The objective of product innovations is to differentiate against competitors' products and to increase market share by stimulating the demand for the improved product. Cefis, Rosenkranz, and Weitzel (2005) argue that the distinction between product and process innovations is crucial as the externalities of product and process innovations are different. Especially when interdependencies between market structure and R&D are analyzed, the externalities on competitors become important.

Porter (1980) claims firms should restrict themselves to one type of innovation. Due to the contradicting goals of cheaper versus improved and more differentiated products, firms otherwise risk to become stuck in the middle. However, there are several theoretical and empirical investigations supporting the opposite view, namely that a firm's competitive advantage is based on both types of innovations and that an optimal mix of these strategies exists (see for example Rosenkranz (2003) or Cefis et al. (2005)).

Theoretical literature distinguishes two ways of modeling product innovations. Dasgupta and Stiglitz (1980) model product innovations as *vertical* product differentiation, leading to increased willingness to pay. The external effect on competitors is negative as their products' relative quality is reduced. In contrast, Rosenkranz (2003) models product innovations as a *horizontal* product differentiation, and assumes the externalities caused by product and process innovation to be different. Process innovations cause negative externalities: Lower prices force other companies to invest in cost reductions as well or to accept a decreased market share. Therefore competitors face reduced profits due to a process innovation. Horizontal product differentiation, however, reduces the substitutability of competitors' products and thus increases the overall market. The externality is positive, competition becomes less direct, and ceteris paribus competitors' profits rise.

[2]Again, classification is not always unambiguous. Tirole (1989) argues that it is theoretically possible to consider any product innovation as a process innovation. The new product already existed before the innovation and the innovation simply reduced its production costs to a feasible level.

In addition to product and process innovations, OECD (2005) explicitly mentions marketing innovations which involve significant changes in product design, packaging, product placement, promotion, or pricing and organizational innovations which implement a new organizational method in the firm's business practices, workplace organization, or external relations.[3] This distinction is closely related to Schumpeter's (1934) list of 5 types of innovations:

- Introduction of new products,
- introduction of new methods of production,
- opening of new markets,
- development of new sources of supply for raw materials or other inputs,
- creation of new market structures in an industry.

Firms typically use an individual mix of these types of innovations, adapted to their competitive strategy.

When incentives to innovate are analyzed in a game theoretical framework, two important ways of modeling can be distinguished (see Dasgupta (1986)).

In *tournament* models firms invest in R&D in order to win a certain prize. Reward schedules of these models usually distinguish sharply between winners and losers. Typical examples for this type of model are patent races (see for example Reinganum (1989) for an excellent overview) or patent contests (see for example Dixit (1987)).

The most apparent difference of *non-tournament* frameworks is that these models (implicitly) assume that there is an infinite number of research strategies: A continuum of possible patents is to be won by participating firms, thus making firm's payoff functions continuous. Non-tournament frameworks are typically used to model process innovations. A higher investment in R&D leads to lower costs of production. All firms participating in R&D may invest and benefit from reduced marginal costs after innovation. Dasgupta and Stiglitz (1980) extensively discuss the existence and qualities of equilibria of this type of model.

[3] Marketing innovations are aimed at better addressing customer needs and opening of new markets and can therefore usually be seen as product innovations. Organizational innovations can be interpreted as product or process innovations, depending on the aim of the change in firm's structure.

An important factor influencing incentives to innovate is that the knowledge derived from R&D might also be beneficial to competitors. Marshall (1920) was the first to formally discuss these spillovers. He argues that the secrecy of business is disappearing and improvements in method seldom remain secret for long after discovery. Griliches (1992) provides an overview of empirical studies, giving the overall impression that R&D spillovers are present and important to innovation. Spillovers do also represent a major source of endogenous growth in New Growth Theory models (see for example Grossman and Helpman (1991)).

### 1.1.2 Innovation Indicators

This section deals with problems of innovation measurement. When analyzing innovation incentives – especially in empirical work – finding the right measure for innovation is a crucial step.

First, one has to specify whether the determinants of innovative input, output, or efficiency are the subject of the analysis. A merger, for example, might lead to a reduction of total money spent on R&D. However, improved organization and complementary skills of the merged firms might lead to a more efficient use of resources and finally to an increased output. Of course, the opposite effect is also possible, for example if there are inefficiencies induced by the merger.

Second, the way in which innovative input, output, and efficiency are measured influences the analysis significantly.

Standard measures for innovative input are R&D spending and R&D employees, typically adjusted for firm size (see for example Hitt, Hoskisson, Ireland, and Harrison (1991) or Dessyllas and Hughes (2005)). While these measures seem very convincing at first glance, there are several problems, especially when the innovative effort of small firms has to be analyzed. These small firms often do not have a specific R&D department. More generally, Kleinknecht, van Montfort, and Brouwer (2002) emphasize the importance of non-R&D departments – like product design, training of employees, software development, or market analysis – for the production of innovative output.

A different problem associated with these measures is the bias towards the manufacturing industries (see Brouwer and Kleinknecht (1997)). This is particularly relevant as several empirical studies show different effects of market structure on innovation for different industries (see for example Scherer (1967)). Levin, Cohen, and Mowery (1985) attribute these variations to differences across industries concerning technological opportunities and appropriability conditions.

Comparable problems occur when studies on innovative output are conducted. Innovation output measures should cover the benefits of a company achieved via innovation.[4] A very apparent approach is to take the number of patents awarded to a company. However, this approach has the deficiency that not all patents are useful for a company and some patents are more, others less important (see Kamien and Schwartz (1975)). Depending on the specific intellectual property rights, some important inventions are even not patented at all. Despite these shortcomings, various authors refer to the number of patents awarded as the most appropriate indicator to describe technological performance (see for example Griliches (1990)). As with innovation input the factor usually gets scaled to account for firms' size.

A variation of this measure is to weigh patents by their forward citations. Griliches (1990) argues that more frequently cited patents are more likely to be highly valued by companies. The OECD Factbook uses "triadic patent families which are designed to capture all important inventions only and to be internationally comparable." A patent family is a set of patents in various countries that protect the same invention. Triadic refers to the three major patent offices - the European Patent Office (EPO), the Japan Patent Office (JPO), and the United States Patent and Trademark Office (USPTO). Not surprisingly, the countries where these offices are located account for the majority of shares in the triadic patent family (see OECD (2008)).

Other studies (for example Dessyllas and Hughes (2005)) use the stock of accumulated knowledge, measured via the patent stock of a company to assess the past innovative output of a company. This stock is often used as a proxy for absorptive capacity, i.e., the capacity to identify and use new innovative possibilities.

Efficiency in innovative performance is usually measured as the quotient of inputs to outputs, choosing related measures of the two previous paragraphs. This aggregated value, of course, combines the defects of the two measures used and should therefore be interpreted with care.

[4] Depending on the focus of the analysis, the measure should also include benefits to society.

A different possibility is to measure performance directly, for example using the development time of a new product. This measure is, however, difficult to handle as it is often impossible to attribute R&D to a specific product or process.[5]

This description of different indicators and their respective advantages and shortcomings shows the first of several possible sources of different outcomes in different empirical studies on the determinants of innovative activity and output. While this description focuses on the problems associated with the choice of an innovation indicator for empirical studies, these problems are, of course, still present in theoretical models: The author has to take into consideration what type of innovation is to be modeled and what kind of innovation measure the model is supposed to address.

## 1.2 Importance of Innovation

Investment in innovation is crucial for an economy. Solow (1957) shows that only a small fraction of per-capita growth can be attributed to the capital to labor ratio. Thus, technological progress is needed for an economy to grow significantly. Therefore, it is not surprising that OECD countries spend a considerable percentage of their GDP on R&D. Figure 1.1 shows expenditures on R&D in percentage of GDP for OECD countries in 2006. This indicator includes R&D investments by all resident companies, research institutes, universities, and government laboratories. It excludes R&D expenditures financed by domestic firms but performed abroad.[6] This figure is a key indicator of government and private sector efforts to obtain a competitive advantage in science and technology. In emerging economies R&D expenditure is often growing even faster than GDP. In China this resulted in a rapidly increasing R&D intensity, growing from 0.9% in 2000 to 1.4% in 2006.

Moreover, in terms of employment, R&D is a crucial factor. R&D and the resulting innovations secure employment for the future. Additionally, R&D departments constitute an important job market themselves. Approximately 3.9 million people

[5]For a more comprehensive overview of collection, measurement, and interpretation of innovation data see OECD (2005).

[6]See OECD (2008) for a more detailed discussion on problems of comparability and different measurement methods in OECD countries.

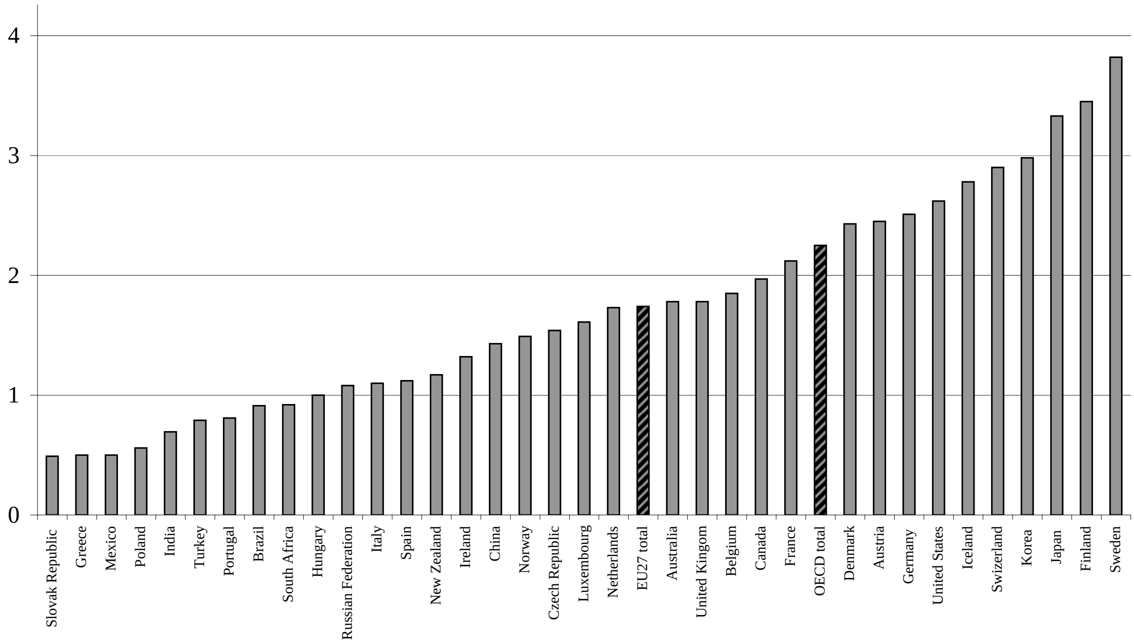


Figure 1.1: R&D expenditure in percentage of GDP for OECD countries, adapted from OECD (2008).

in the OECD area were employed in research and development in 2005; approximately two-thirds of these were engaged in the business sector. Table 1.1 shows the employees working as researchers, defined as "professionals engaged in the conception and creation of new knowledge, products, processes, methods, and systems as well as those who are directly involved in the management of projects" (OECD (2008)), per thousand employees for G8 countries from 1995 to 2005. We see a steady increase in the number of researchers for G8 states, with the exception of Italy and Russia. This fact emphasizes the still growing importance of research in industrialized countries.

Of course, innovative activities are not only important for the economy but also for individual companies. Innovations help to gain or to secure a competitive advantage. Especially in a fast changing environment it is important to innovate. Otherwise, the company is at risk of falling behind its competitors, eventually leading to a loss in market share and profits, or as Steven Jobs, the co-founder of Apple Inc., once said: "Innovation distinguishes between a leader and a follower."

| | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada | 6.4 | 6.6 | 6.7 | 6.7 | 6.7 | 7.2 | 7.6 | 7.5 | 7.5 | 7.8 | – |
| France | 6.7 | 6.8 | 6.8 | 6.7 | 6.8 | 7.1 | 7.2 | 7.5 | 7.7 | 8 | 8.2 |
| Germany | 6.2 | 6.1 | 6.3 | 6.3 | 6.6 | 6.6 | 6.7 | 6.8 | 6.9 | 7 | 7.2 |
| Italy | 3.5 | 3.5 | 3 | 2.9 | 2.9 | 2.9 | 2.9 | 3 | 2.9 | 3 | 3.4 |
| Japan | 8.3 | 9.2 | 9.3 | 9.8 | 10 | 9.9 | 10.4 | 10.1 | 10.6 | 10.6 | 11 |
| Russia | 9.2 | 8.5 | 8.2 | 7.7 | 7.8 | 7.8 | 7.9 | 7.5 | 7.4 | 7.1 | 6.8 |
| United Kingdom | 5.2 | 5.1 | 5.1 | 5.5 | 5.6 | 5.4 | 5.6 | 5.8 | 5.9 | 5.7 | 5.8 |
| United States | 8.1 | – | 8.8 | – | 9.3 | 9.3 | 9.5 | 9.7 | 9.9 | 10 | 9.7 |
| **EU 27 total** | **4.8** | **4.7** | **4.9** | **4.9** | **5.1** | **5.1** | **5.3** | **5.5** | **5.6** | **5.7** | **6** |
| **OECD total** | **5.9** | **6.1** | **6.2** | **6.4** | **6.5** | **6.6** | **6.8** | **6.9** | **7.2** | **7.2** | **7.4** |

Table 1.1: Researchers per 1000 employees, adapted from OECD (2008).

Innovation helps to stay competitive in two ways. First, process innovations enable firms to bring established products cheaper and faster to the market, imposing pressure on competitors. Second, new and improved products can facilitate access to new markets and gain new customers. The percentage of turnover generated with sales of new or significantly improved products for the EU 27 countries in 2004 is varying between 5% (Cyprus) and 25% (Bulgaria), Germany is in the mid-range with 9% (see Eurostat (2008), p. 478).

## 1.3 Competition Policy and Innovation

The three essays in this thesis analyze interdependencies of innovation, market structure, and competition policy. When technological progress no longer falls "like manna from heaven" as in Solow's (1956) seminal work on economic growth, there is a need to analyze which market structure and regulatory framework is most beneficial to innovation incentives. Generally, there are three policy instruments that can be used to increase innovation incentives. The first is general competition policy. If innovation incentives can be increased through co-operations, competition policy should take this effect into account when assessing the competitive effects of mergers, acquisitions, or R&D joint ventures. The second is to increase innovation investments by granting subsidies for firms' R&D or even directly perform government R&D. The third instrument is intellectual property protection, especially the process of granting patents and patent duration.

In this thesis we focus on the first two instruments. Firms' incentives to invest depending on the respective market structure are analyzed in the first two essays. The third essay assesses the impact of R&D subsidies. In the following section we will first analyze general interdependencies between market structure and innovation before focusing on the specific structures analyzed in the essays.

### 1.3.1 Market Structure and Innovation

An intensively discussed topic in economics is the most promotional market structure for innovation incentives. The discussion started in the early twentieth century with the Schumpeterian defense of monopoly power and bigness (Schumpeter (1976)). Perfect competition does not efficiently allocate resources for technical innovation as firms cannot exploit benefits from successful innovation. The question is then, what degree of rivalry or concentration is most beneficial for innovation. Schumpeter argues that the possibility of becoming a monopolist in a certain sector as well as the fear of losing a dominant position creates high incentives to innovate. The temporary monopolist is always in danger of losing its position due to a competitor's innovation. This market structure of switching temporary monopolists reduces price competition but creates innovative competition among firms.

The opposite view is that monopolists are not expected to innovate enough as they cannibalize profits they could make with the old technology. This is a more static view, often attributed to Arrow (1962), considering monopolies as stable.

Scherer (1967) shows a positive relationship between patenting activity and firm size with a diminishing impact at larger sizes when allowing for nonlinearities. He concludes that there is an inverted-U relationship between competition and innovation and found strong support by a recent analysis of Aghion, Bloom, Blundell, Griffith, and Howitt (2005).

The only generally agreed statement in today's economics literature is that it is difficult to find the optimal level of competition for innovation since the incentives depend heavily on the considered industry, the exclusivity of intellectual property rights, and various other factors (see for example Dasgupta and Stiglitz (1980) or Gilbert (2006)).

Spence (1984) emphasizes that several market failures lead to performance problems when firms conduct R&D to reduce costs. Figure 1.2 summarizes the R&D market structure relationships and their associated impact on market performance. A higher market concentration leads to increased profits and margins for firms. This

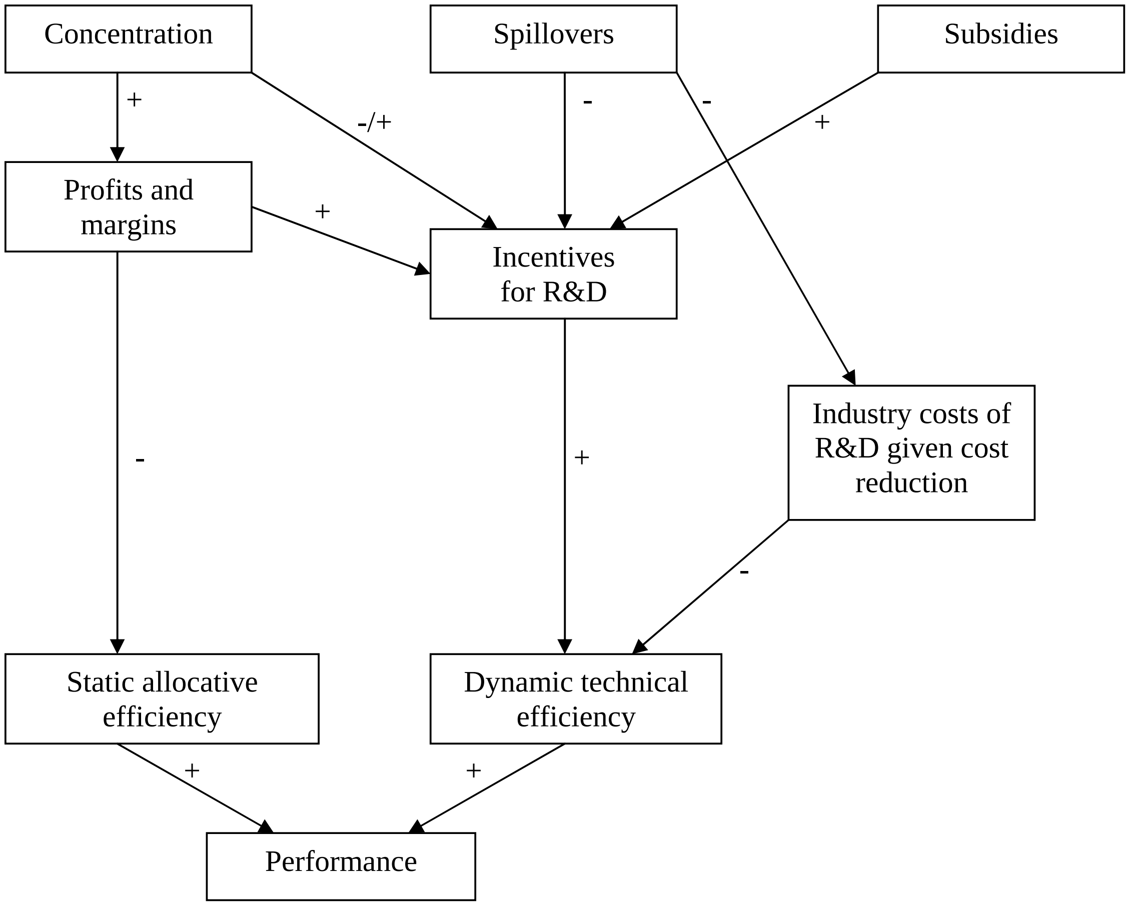


Figure 1.2: R&D market structure relationships, adapted from Spence (1984).

in turn has a negative effect on static allocative efficiency but a positive effect on R&D incentives. The direct effect of market concentration on R&D incentives is ambiguous (see discussion above). Spillovers reduce the appropriability of R&D results and increase the possibility to free ride on competitors' efforts. Thus, the effect on R&D incentives is negative. On the other hand, spillovers make R&D results available for more than just one firm and therefore reduce industry costs for a given cost reduction. Duplication of efforts is avoided or at least reduced. Subsidies simply reduce firms' costs for a certain R&D effort and therefore increase R&D incentives. Dynamic technical efficiency is, of course, influenced positively by R&D incentives and negatively by industry costs of R&D. Static and dynamic efficiency finally cause market performance. A summary of the literature treating the interaction of these elements in more detail is given in Spence (1982). Even though these are only the most important effects influencing R&D incentives and market performance, they already show that theoretical models may lead to different conclusions, depending on the focus of the model.

Another substantial factor that is neglected (or only implicitly included) in Spence's figure is the financing of R&D. This factor is important as access to capital market is sometimes restricted, especially for small firms. Schumpeter (1976) already claims that an efficiently functioning capital market has a positive effect on the rate of innovation. In a survey of the literature on financing of R&D, Hall (2002) argues that the main problem for private investment in innovation is that there is no or little capitalized value for R&D in a firm's balance sheet. Asymmetric information between borrowers and lenders may then cause potential lenders to be reluctant to fund R&D due to its inherent risk, even though the borrower promised high returns. Therefore, small and new innovative firms face high costs of capital, leading to less investments in innovation. Venture capital by experienced and informed investors or government grants may help to close that funding gap.[7]

The incentive to innovate is given by the difference between the profit a firm can make if it invests in R&D compared to what it would earn if it did not invest. This incentive can be distinguished in two effects: The *replacement effect*, first described by Arrow (1962), and the *efficiency effect*, attributed to Gilbert and Newberry (1982).

The replacement effect, which is also called profit effect, compares the profits a firm makes after a successful innovation to profits without the innovation. As a monopolist already earns profits without the innovation, the incentives to innovate are larger in a competitive market.

The efficiency effect, or competitive threat, describes the changed profit if not the firm itself, but a competitor discovers the innovation. As a monopolist has more

[7]Spence's figure also ignores backward effects. Market performance for example has an effect on concentration in the market (see the following section for a brief remark and Mazzucato (2000) for an intense discussion of these effects).

to lose, the efficiency effect is more important to him.[8]

Of course, both effects are described in a very stylized form. Differences in market structure or in the characteristics of innovations on the one hand and the dynamics of the innovation discovery process on the other hand lead to a huge variety of the theoretical relationship between competition and expenditures on R&D or the output of R&D activities. A survey on the competition-innovation debate is given in Gilbert (2006).

### 1.3.2 Mergers & Acquisitions and Innovation

Mergers and acquisitions describe the union of formerly independent companies in one legal entity. Both mergers and acquisitions involve a buyer and a target. The distinction between mergers and acquisition is not consistent in the literature.

If legal independence remains, Jensen (2001) calls the transaction an acquisition; if a new foundation is necessary, he considers the transaction to be a merger.

Weston, Chung, and Hoag (1990) argue that the main difference is the type of agreement. If the agreement is friendly and both companies consider the union to be beneficial, the transaction is considered a merger. If the targeted company does not want to be purchased, the transaction is regarded as an acquisition.

We are aware that there are differences in the company's organization or in the perception of a hostile acquisition and a friendly merger agreement. However, the effect on industry structure and thus on innovation incentives is similar and therefore we will not strictly distinguish between both terms.

Depending on the relatedness of companies one can distinguish the following types of mergers:[9]

In a *horizontal merger*, companies working on the same production level unite, for example two manufacturers of similar goods. Competition authorities usually consider horizontal mergers to be detrimental to consumers because concentration and market power are typically increased. In a seminal paper on horizontal mergers in a Cournot framework, Salant, Switzer, and Reynolds (1983) show that an exogenous merger not generating efficiencies is very likely to cause losses to participating firms, consumer surplus, and social welfare.

[8] For a comprehensive discussion of these effects see for example Tirole (1989) or Schulz (2007).

[9] See Weston et al. (1990) for a more detailed discussion on merger types.

A *vertical merger* is the union of companies working on different production levels, for example a manufacturer and a retailer. As companies can avoid double marginalization problems and pre-merger firms are not in direct competition anyway, vertical mergers are considered to be less critical by competition authorities. However, other anticompetitive effects like foreclosure become important in vertically integrated companies. Hart and Tirole (1990) argue that conditions under which vertical mergers are anticompetitive are extensively discussed. Economic literature on vertical relations and cooperations has been even more growing in recent years.[10]

A *conglomerate merger* is the union of companies which have no common interest, i.e., not the same customers, suppliers, or competitors. The main motive for this type of merger is diversification (see Matsusaka (1993)). Other motives, like economies of scope or tax and accounting incentives, are discussed in Steiner (1975).

While all types of mergers may affect innovation incentives, we focus on horizontal mergers in this thesis. One of the reasons is that efficiencies in R&D are a frequently used argument in favor of merger clearance (see for example Röller, Stennek, and Verboven (2000)) and this is particularly relevant for horizontal mergers.

In the previous section mainly the impact of market structure on innovation incentives was described. Mergers, however, change the market structure, so that it gets more important not only to consider the effect of market structure on innovation but also the backward effect of innovation, i.e., how does the innovative behavior of firms influence market structure, in particular incentives to merge (see Mazzucato (2000)).

In addition to the indirect link between mergers and innovation incentives via market structure, there is also a direct one: Personnel and organizational problems with the merger may affect creative work, the innovation market itself may influence incentives to merge, matching research approaches are important when the strategic fit of companies is analyzed, and finally, strategic buys of innovative companies may substitute or complement internal R&D. We will analyze each of these factors in a little more detail in the following paragraphs.[11]

An important success factor of mergers is how the employees of both companies

[10] An excellent starting point to this literature is the paper on vertical restraints by Rey and Tirole (1986).

[11] A more comprehensive overview of the recent literature on the merger-innovation link is given in Schulz (2007).

react to the merger and how they worked in the pre-merger time when there were discussions about the future development of the merged companies. As a merger is very often connected with extensive economies, reorganization, and dismissals, the staff of both companies is often anxious. This may lead to less effective work both during merger negotiations and afterwards and to less team-work as employees are aiming at showing their irreplaceability. Especially the R&D departments, where creativity and team-work is needed, are threatened of being affected by these problems (see Bommer and Jalajas (1999)). The internal resistance to the merger may lead to several other problems (see Cassiman, Colombo, Garrone, and Veugelers (2005)): Communication problems among new fellow employees, denial of products and processes from the other company, and agency problems that affect the motivation of researchers. Ernst and Vitt (2000) show that key persons in R&D, i.e., those responsible for high quality and high quantity patents, often leave the merged enterprise voluntarily. Reasons for leaving the company may be the fear of key inventors not to have the same power in the merged company or the less friendly working atmosphere during the restructuring process. If the merged company wants to benefit from economies of scale and scope in R&D, the departments must at least be partially merged, implying organizational changes. The organizational duties of employees cost time they normally would have spent on their daily work. Moreover, as they often do not like this paperwork, they get frustrated and even after the restructuring process their performance is reduced. This effect is expected to be more important when the primary objective of the merger is not research oriented (see Cassiman et al. (2005)). Generally, these personnel and organizational problems may reduce efficiencies the companies intended to gain by merging.

When competition authorities analyze a merger in a market where innovation plays an important role, it is crucial not only to consider current but also future market shares. Katz and Shelanski (2004) extensively analyze this issue and argue that two main factors influence competition in innovation markets: First, the uncertainty regarding the success both of research and the resulting products and second, large sunk costs in R&D. It is argued that competition authorities ought to consider the welfare effect of innovation and the competition for innovation in their analyses. They distinguish between the *innovation incentives* and the *innovation impact* criterion. With the first criterion it is assessed whether or not the merged company has more incentives to innovate, for example due to economies of scale. This analysis is related to the discussion about interdependencies of market concentration and innovation. The second criterion is about the effect of innovation on the market, especially comparing the situation before and after the merger. The merged entity might be that superior in R&D that competitors are driven out of the innovation market. Katz and Shelanski emphasize that market assessment has to be done more carefully and analyses of dynamic aspects, like entry barriers and research capacities, have to complement the traditional analysis of price effects and concentration ratios. In particular, the authors claim that agencies should explicitly account for trade-offs between the (rather short-term) effect of product market competition and the (rather long-term) effect of innovation in their merger analyses. This supports a view expressed by Schumpeter when comparing industrial capitalism with perfect competition that "a system [...] that at *every* point of time fully utilizes its possibilities to the best advantage may yet in the long run be inferior to a system that does so at *no* given point in time, because the latter's failure to do so may be a condition for the level or speed of long-run performance" (Schumpeter (1976), p.83). In chapter 2 the changed innovation incentives after a merger are analyzed and compared with the effects of an R&D joint venture.

When it comes to mergers, the strategic fit of companies is important. Compatible approaches and similar values facilitate the post merger integration process and create potentials for economies of scale and scope, not least in the R&D process. Cassiman et al. (2005) and Hagedoorn and Duysters (2000) analyze the effect of technological and market relatedness on post merger performance. Even though some effects depend on the considered industry, the general effect of relatedness on post merger R&D performance is positive. It is important to emphasize that in both papers relatedness does not necessarily mean that similar research paths are used in both companies. Conversely, different approaches in R&D with complementary knowledge in both firms may even lead to better results. Thus, the only importance is a technological fit, i.e., the possibility to combine ideas and create improved products with the conjoint knowledge in both R&D departments.

Finally, acquisitions may essentially serve as a substitute for own R&D. Instead of doing research, large firms invest in small innovation factories and acquire knowledge. In this context, Cohen and Levinthal emphasize the importance of the large firm's absorptive capacity, i.e., the ability to "identify, assimilate, and exploit knowledge from the environment" (Cohen and Levinthal (1989), p.569). Dessyllas and

Hughes (2005) analyze the R&D activity of acquiring companies in high technology industries and find empirical evidence for their hypothesis that firms with lower than average R&D input and output are more likely to acquire small technology based firms. Blonigen and Taylor (2000) find support for the substitutional character of acquisitions for internal R&D, analyzing electronic and electrical equipment industries. Additionally, targets of acquisitions are superior in R&D or possess important technological assets. Cassiman and Veugelers (2006), however, do not support the make or buy hypothesis in R&D. In a study of Belgian manufacturing firms, they find evidence that firms engaging both in internal R&D and in the acquisition of external knowledge show a better innovative performance. Instead of directly acquiring, it is also possible to acquire knowledge through licensing. Using different sources for innovation allows to reduce the risk of failure to develop an invention. High technology firms therefore often use direct equity investment, contract research, and licensing in addition to own R&D efforts.[12] The substitution of own R&D by acquisitions of small innovative firms is treated more closely in chapter 3.

### 1.3.3 Subsidies for Innovation

No matter what the market structure, both theoretical and empirical literature suggest that investment in R&D is very likely to be too low from a social point of view, calling for additional, public investment.[13]

Several federal research institutes in Europe and the US were established in the late nineteenth and early twentieth century, especially in applied physics and chemistry. Since the 1930's, several initiatives to develop new technologies for aviation, space, nuclear energy, health care and so on have been established in many countries.[14] These early research establishments are foundations of current R&D support projects, like the Small Business Innovation Research programm (SBIR) or the

[12]See for example Roberts and Berry (1985) for a detailed description of research strategies in the biotechnology industry.

[13]We are aware of the fact that in some industries R&D investment is even too high. The multiple effort of some firms in patent races, for example, might not justify the (small) increase of the discovery chances. See Dasgupta and Stiglitz (1980) or Katz and Shelanski (2004) for a more thorough discussion.

[14]Geiger (1986) gives an overview of the growth of government research in the US in these decades. Nelson (1993) compares the national innovation system in 14 countries in several studies.

Semiconductor Manufacturing Technology programm (SEMATECH) in the US (see Klette, Møen, and Griliches (2000) for a detailed description) or the Lisbon strategy in the EU that highlights the "importance of public procurement in reinforcing the innovation capabilities of the Union whilst improving the quality and efficiency of public services" (Commission of the European Communities (2007), p. 2).

A government can foster innovation by doing national research in federal institutes or universities. These institutes usually focus on basic rather than applied research (see for example Salter and Martin (2001)). Alternatively, innovation incentives can be increased by government support for private R&D. Basically, there are two ways of supporting: By providing funds for specific R&D projects or by granting tax reductions for innovative firms. Martin and Scott (2000) analyze which sort of public support is best to address certain types of innovation market failures. Hall and van Reenen (2000) assess the effectiveness of tax-based subsidies in OECD countries.

Different countries prefer different types of support. In Germany, public R&D policy mainly provides direct funding of firms' R&D projects and institutional funding for basic research. There are no fiscal measures, like R&D tax credits, in Germany. In Belgium, for example, accelerated depreciation for R&D capital and R&D tax allowances exist in addition to direct R&D funding (see Aerts and Schmidt (2006)). Of course, firms in these countries also qualify for European innovation programs. As table 1.2 shows, state funds account for a considerable amount of R&D expenditure in the G8 countries.

The basic idea of subsidies to R&D is to create additional incentives to invest in innovation when a project is likely to be beneficial for society but not generating enough returns for a private investment. This can be attributed to two types of market failures.

First, returns from R&D are not fully appropriable by the investing firm. Competitors may use part of the value generated for their own innovative activities. Seminal papers on the appropriability problem of R&D are Nelson (1959) and Arrow (1962). Knowledge generated through R&D activity is non-excludable and has some aspects of a public good. Therefore, social returns are greater than private returns, leading to underinvestment from a social perspective. This problem is particularly relevant for basic research.

| | Business Enterprise | Government | Other National Funds | Funds from Abroad |
|---|---|---|---|---|
| Canada | 47.9 | 32.9 | 10.5 | 8.7 |
| France | 52.5 | 38.2 | 1.9 | 7.3 |
| Germany | 67.6 | 28.4 | 0.3 | 3.7 |
| Italy | 39.7 | 50.7 | 1.7 | 8 |
| Japan | 76.1 | 16.8 | 6.8 | 0.3 |
| Russia | 30.0 | 61.9 | 0.5 | 7.6 |
| United Kingdom | 42.1 | 32.8 | 5.9 | 19.2 |
| United States | 64.0 | 30.4 | 5.7 | - |
| **EU 27 total** | **54.1** | **34.7** | **2.3** | **8.9** |
| **OECD** | **62.7** | **29.5** | **4.7** | **-** |

Table 1.2: R&D financing by source of funds (in percent), adapted from IW (2008).

Second, if firms face financial constraints, an information problem between firms conducting R&D and investors might occur, especially concerning risk and expected returns of the investment but also about the spending of external funds to projects. External capital might be very costly or sometimes not even available for R&D projects. Monitoring problems, moral hazard, and information asymmetries are studied for example in Repullo and Suarez (2000) and in Takolo and Tanayama (2008). Both papers emphasize the importance of financial intermediation to improve funding of uncertain R&D projects.

The main focus of empirical literature on R&D subsidies is to find out whether public funds to R&D really increase investment or if subsidies are just replacing private money.[15] Especially in high technology industries, it is difficult for outsiders to identify projects worth subsidizing. Firms have an incentive to ask for subsidies for any kind of R&D project as long as application costs are not substantial. Therefore, agencies have to screen projects and identify those which the firm would not conduct without financial support but which are desirable from a social perspective. Otherwise, there is the substantial risk of subsidies simply crowding

[15] Another related research question not in the focus of our analysis is the impact of R&D subsidies on employment, see for example Lerner (1999).

out private investment. A common strategy to avoid at least a totally crowding out of private investment is to give matching grants (see for example BMBF and BMWA (2003), p. 57). Thus, the subsidy has to be complemented by a significant amount of private investment in the R&D project.

Empirical results are very ambiguous and depend heavily on the econometric method used and on the aggregation level. Most early studies report a positive and significant effect of federal R&D on company R&D expenditure.[16] Lichtenberg (1984, 1987) argues that misspecifications of the private R&D equation in these early studies led to a serious upward bias of the effect of federal industrial R&D on private R&D funding. Klette et al. (2000) argue that the main problem of these empirical studies is to find a valid control group due to the following reasons: First, neither firms receiving support, nor those not applying for grants constitute random samples. Second, those firms not receiving support may still be affected by the program due to spillover effects. The first problem is confirmed by a recent study of Tanayama (2007). She analyzes the application decision for a subsidy and finds that firms which are most likely to have eligible projects are also aware of the R&D subsidy and consequently apply for the R&D subsidy. Results from more recent empirical studies with improved econometric methods range from crowding out dollar for dollar of firm-financed R&D spending by government grants (for example Wallsten (2000)), over mixed results (for example Hujer and Radić (2005)), to significantly increased private innovation incentives and an improved technological performance due to public R&D funds (for example Czarnitzki and Hussinger (2004)). David, Hall, and Toole (2000) survey the empirical literature and find that results are dependent on the aggregation level. For a low level of aggregation (firm level and lower), about one-half of these studies report a crowding out effect. However, if there is a higher aggregation level (industry wide or more), the proportion of studies reporting a substitutional effect of government R&D is significantly lower.

Generally, a government agency's decision is not only based on the firm's R&D project and the respective application for subsidies. Klette et al. (2000) argue that many factors are involved in the political economy process that allocates public funds to R&D projects. Lerner (1999) assumes that distorted incentives for politicians or

[16] See for example Levin (1981), Levy and Terleckyi (1983), and Scott (1984). An exception is Carmichael (1981) who reports at least small crowding out effects.

other decision makers in agencies may select prominent R&D projects that are very likely to produce "visible" results. Then, the policy program "can claim credit for the firms' ultimate success, even if the marginal contribution of the public funds was very low" (Lerner (1999), p. 292). This "picking a winner" strategy is at odds with the original intention of government subsidies for R&D. In industries where technologies are too complex to be understood by outsiders, subsidies are sometimes granted to basically any R&D project (see Fier and Heneric (2005)). The problems of this "watering can policy" are obvious: A significant amount of money is spent on projects not worth subsidizing and public funding becomes arbitrary.

In addition to the funding effect, the subsidy may serve as a signal to private investors. Especially in high technology industries – where an extensive screening process for R&D projects is needed to assess its potential – small and medium sized banks often take a government subsidy as a quality signal. Lerner (1999) emphasizes this effect of the SBIR program on private investors. The signaling effect of subsidies is discussed in more detail in chapter 4.

## 1.4 Outline

This thesis deals with competition policy and innovation in three essays. The first two essays focus on changes in the market structure due to mergers, the last one deals with the signal character of a government subsidy to private investors. The final chapter summarizes main ideas.

The first essay analyzes bilateral mergers in a setup with three firms. These, ex ante identical firms, compete in two stages. In the innovation stage firms can invest in cost reductions. In the product market stage firms compete in quantities. In this setup, three prominent merger modelings and an R&D joint venture are analyzed. In our model setup, with linear demand and constant marginal costs, mergers tend to increase consumer surplus. Changes in the market structure lead to increased investments, lower marginal costs and finally to a higher total output. As empirical literature shows that mergers might lead to inefficiencies in R&D, we account for these problems in a separate section. As expected, inefficiencies in R&D decrease incentives to merge for firms and are also detrimental for consumers. It is shown that optimal investment strategies differ significantly from insider to outsider and depend on the resulting market structure.

The second essay analyzes acquisitions in a patent contest model. Small innovation factories and large companies possess different advantages in the contest. While large firms typically have better access to product markets, small firms often have a superior R&D efficiency. In a setup with two large and two small firms, we model a pre-contest acquisition game where large firms sequentially bid to acquire small firms in order to combine advantages of both types of firms. After possible acquisitions the remaining firms invest in the R&D contest to maximize expected profits. Although the initial situation is basically symmetric, sequential bidding allows the first large firm to bid strategically in order to induce a reaction of its competitor. For high efficiencies both large firms prefer to acquire immediately, leading to a symmetric market structure. For low efficiencies, however, strategic waiting of the first large firm leads to an asymmetric market structure. We also test a changed setup of the acquisition game where the acquisition decision is simultaneous and show that our main results are robust with respect to this modeling strategy. In both setups acquisitions increase the chances for successful innovation.

The third essay deals with government subsidies for R&D. While subsidies primarily provide funds and therefore additional incentives for innovation, an additional effect might be a signal of good investment opportunities for private investors who cannot appropriately screen all R&D projects. Due to more experience and capacities the government agency can distinguish project types, leading to asymmetric information. We use a simple signaling model to capture this phenomenon and allow for two types of risk classes. The agency has a preference for high risk projects as they promise high expected social returns, while banks prefer low risk projects with high private returns. In a setup where the subsidy can only be used to distinguish between high and low risk projects, government agency's signal is not very helpful for banks' investment decision. However, if the subsidy is accompanied by a quality signal, it can lead to increased or better selected private investments.

The last chapter summarizes the main findings and presents some concluding remarks on the results of the essays.

# Chapter 2

# The Effect of Mergers on the Incentives to Invest in Cost Reducing Innovations

## 2.1 Introduction

Mergers and acquisitions are instruments for growth, diversification, and rationalization of companies. Innovation is a way for firms to achieve and maintain a competitive advantage. So both these elements are fundamental to a firm's competitive strategy. To improve our understanding of firms' investment decisions and cooperations it is therefore necessary to comprehend the interdependencies between these important factors.

Moreover, the approval process of mergers is more and more influenced by the impact of mergers on the innovative activities in the market. Mergers are typically considered to harm consumers. Farrell and Shapiro (1990) show in a Cournot oligopoly that for a merger to reduce prices and thus to increase consumer surplus considerable synergies are required. Diffusion of know-how and economies of scale and scope in R&D are typical elements of efficiency defenses of mergers (see Röller, Stennek, and Verboven (2000)). Gilbert and Tom (2001) claim that innovation concerns in merger cases rose significantly in the last decades. However, they argue that it is difficult to assess the immediate impact of innovation on the approval process in these cases. This is at least partly caused by the several opposing effects of mergers on innovation incentives. Katz and Shelanski (2004) argue that innovation – as one of the most important drivers of economic welfare – must be considered when deciding about the approval of a proposed merger. They distinguish between the innovation incentives criterion, i.e., how the merger changes the incentives to innovate and the innovation impact criterion, i.e., how is the effect of innovation on the market, especially comparing the situation before and after the merger. Katz and Shelanski argue that both the effect of market structure on innovation and the backwards effect of innovation on market structure are important in the analysis.

The interdependencies of mergers and innovation have a widespread effect on a firm's strategy. A merger changes the market structure as firm size and concentration are typically increased. This leads to different output levels of firms which in turn influence the firm's investment decisions. Furthermore, the innovation market itself may be affected by the merger. Fewer competitors may increase the probability to win a patent race and lead to more investments. On the other hand, the reduced competitive pressure may lead to a reduction in innovation. Another important effect of mergers is the restructuring process. To capture potential synergies in the innovation sector, R&D departments have to be reorganized which may lead to personnel problems caused by fear of dismissals, loss of key researchers, and changes in the organization structure. Finally, the innovative ability of a firm may be a direct reason for a merger. Firms can substitute own R&D by the acquisition of other companies.

This complexity may be a reason why model-theoretical analysis of the merger-innovation link is sparse. However, if the analysis is focused on certain sub aspects, important conclusions can be drawn. Banal-Estanol, Macho-Stadler, and Seldeslachts (2004) use a three stage game model with three firms to deduct incentives to merge and to innovate in a Cournot market. They analyze situations with and without internal conflict where firms can either invest or not invest in a cost reduction. Their focus is on the internal organization of a firm and the stability of mergers. In contrast to Banal-Estanol et al. (2004) we analyze exogenous mergers and focus on incentives to innovate. Moreover, we do also allow for asymmetric situations after the merger. Jost and van der Velden (2006) analyze mergers in a patent contest model and show that a merger can be beneficial to the merging firms even if synergetic effects are rather low. However, their model fully concentrates on the innovation market as the winner of the patent race is awarded a monopoly profit in the output market. In contrast, we model both competition in the innovation and in the output market. Davidson and Ferret (2007) also use a model where firms compete in a product and in an innovation market. In their oligopoly model with heterogeneous goods a merger is assumed to have two effects. First, the merged company chooses prices (quantities) and R&D effort of both former individual companies to maximize joint profits. Second, the merged firm shares R&D results and generates internal R&D spillovers. These two effects make mergers profitable for insiders and harm outsiders if R&D complementarities are sufficient. In contrast to Davidson and Ferret, we let R&D departments merge totally and analyze different modeling strategies for the merger in the product market.

Other theoretical papers on mergers and innovation rather establish rules of thumb or guidelines for analyzing mergers in an innovation context (see for example Katz and Shelanski (2004)).

Empirical work on this subject can be grouped in two categories: Organizational issues and strategic aspects. The organizational literature deals with the effect of mergers on R&D employees and the internal organization of R&D. Bommer and Jalajas (1999) show that already the threat of organizational downsizing can have a negative impact on the innovative performance, i.e., willingness to make suggestions, risk taking, and job motivation. Internal resistance to the merger may lead to several other problems: Communication problems among new fellow employees, denial of products and processes from the other company, the "not-invented-here" syndrome (Katz and Allen (1982)), and agency problems that affect the motivation of researchers (see Cassiman, Colombo, Garrone, and Veugelers (2005)). A study of Ernst and Vitt (2000) shows that almost a third of key inventors, i.e., persons responsible for high quality and high quantity patents, quit the merged company. This behavior often leads to a dramatic reduction in innovative performance. The personnel problem is directly linked to R&D reorganization. Hagedoorn and Duysters (2000) analyze the impact of organizational differences on the success of mergers. They measure the degree of similarity by the size of companies and find empirical support for their hypothesis of a positive relationship between the similarity in size of the companies to merge and the post merger technological performance, measured by total numbers of patents applied for.

The empirical literature on strategic aspects of mergers deals with a firm's merger and innovation policy and how this policy is influenced by firm's and competitors' characteristics. Cefis, Rosenkranz, and Weitzel (2005) study the effect of mergers on the optimal mix of investments in product and process innovations. They find support for their hypothesis that firms involved in mergers invest more in product than in process innovations. Furthermore, they find that R&D efficiency decreases, which is attributed to post-merger integration problems. Gugler and Siebert (2004) analyze the efficiency effects of mergers and R&D joint ventures with focus on the development of market shares after cooperation. They find positive developments of market shares both for mergers and R&D joint ventures, but stronger and longer lasting effects for joint ventures. However, their study is on the semiconductor industry, which is one of the most R&D intensive and innovative industries. Hagedoorn and Duysters (2000) analyze the effect of strategic fit of companies, measured by technological and product market relatedness, on the success of a merger and find empirical support for their hypothesis that more related companies show a better technological performance after the merger. This effect is attributed to economies of scale and scope in R&D. Another strategic aspect of mergers in innovation context is the substitution of own R&D by the acquisition of R&D active companies. Dessyllas and Hughes (2005) examine the acquirers of these strategic buys. They assume that firms with lower R&D input and output are more likely to acquire R&D active firms, which is supported by their analysis. Moreover, they find empirical evidence of their hypothesis that a certain level of knowledge about technology, measured by stock of patents, is needed to identify potential candidates for acquisition and to use the acquired knowledge efficiently.

It is difficult to identify the main drivers of a successful merger in the R&D context from these strands of literature as the empirical results lead into different directions and focus on different topics.

The aim of this essay is to analyze the impact of horizontal mergers on the innovative efforts of merging and non-merging firms. Firms compete in innovation activities as well as in product markets. We focus our analysis on the minimal structure that allows for the distinction of merging and non-merging firms, i.e., we start from a market structure with three active firms. Depending on the modeling strategy of mergers it is well-known that mergers may turn out to be not profitable if innovation is not modeled. In contrast, we find that the inclusion of competition in innovative activities renders most mergers profitable. This is a first result and confirms a result of Jost and van der Velden (2006) in a different modeling context.

In a first step to explore the impact of a merger on innovative activities we ignore any organizational problems of a merger. Using linear demand and cost structures we find that a merger induces higher innovative efforts of the merging firms. The increased incentive to invest in innovation is driven by scale effects. However, firms can not just spread a fixed sum of innovation costs over more output but on the contrary can invest more in innovation to reduce marginal costs and thus increase their equilibrium output. In order to test the robustness of this finding – and of the other results – we screen the most popular modeling strategies for mergers. They will be spelled out further below. It turns out that this finding is robust in this respect. However, the impact of a merger on the non-merging firm's incentive to innovate depends on the modeling strategy. The same holds true for the impact of a merger on consumer surplus as well as on social surplus although it is positive in most cases.

In a second step we introduce organizational problems of a merger by assuming an increased level of R&D costs for the merging firms. This provides a much richer picture where it is not guaranteed that the merging firms' incentive to innovate increases. Whether a merger induces higher incentives to innovate for any of the firms depends on how mergers are modeled as well as on the level of inefficiencies due to the organizational problems. Interestingly, in most cases a merger still increases social surplus.

Innovation is generally considered to be the introduction of new methods, improved versions of former products and processes or completely new inventions. In our essay we focus on process innovations, i.e., a reengineered or newly developed production process aiming at producing goods more efficiently. Additionally, we assume that all knowledge acquired by innovation efforts stays within the company, i.e., there are no knowledge spillovers.

We analyze mergers for three popular modeling approaches. We also consider R&D joint ventures as they are often considered to have the positive synergy effects of a merger without reducing competition in the output market.

Firms play a noncooperative two stage game under complete information. In the first stage they decide about their investments in process innovations and by doing so set their marginal costs. In the second stage firms choose quantities. The game is solved by backwards induction. This two stage model is similar to a model of R&D joint ventures by Rosenkranz (2003). However, she focuses on the different external effects of process and product innovation while our focus is on the different effects in several forms of mergers. Furthermore, in her analysis all firms remain competitors in the output market while we allow for mergers.

The benchmark case with three identical firms is compared to a situation where two firms merge or cooperate on R&D. We do not consider mergers to monopoly or R&D joint ventures of all firms as these cooperations would lead to no competition in the product or the innovation market.

In the cases of merger, we distinguish three possibilities for the resulting market structure. The first case is the simple closure of one firm. This way of modeling the merger refers to Salant, Switzer, and Reynolds (1983) and is therefore denoted as case SSR. The second type refers to Daughety (1990) and models the merged company as a Stackelberg-Leader in the resulting market. This is denoted as case D. Creane and Davidson (2005) propose another way of modeling the merger. The two companies involved in the merger remain separate divisions but set their quantities sequentially. Thus, one division is a Stackelberg-Leader in the intra-firm game. The outsider is aware of the internal structure but treats each of the merged firm's divisions as a Cournot competitor. This case is referred to as case CD.[1] Finally, the results of an R&D joint venture are analyzed (case JV). We derive optimal investment strategies and quantities and the resulting profits. In order to analyze the impact of our model parameters we calculate some comparative statics. Our results show that optimal investment strategies depend on the resulting market structure and differ significantly from insider to outsider. In some settings mergers are profitable while in other settings outsiders benefit from mergers. The effect on consumer welfare, measured by total output, depends on the resulting market structure. The impact of innovation costs on profits is also ambiguous. We show that some firms prefer low innovation costs while others benefit from increasing innovation costs. This effect is due to the strategic aspect of investment in innovation.

[1]Huck, Konrad, and Müller (2004) provide similar arguments for modeling horizontal mergers that way and derive comparable results. However, their argumentation is a bit different as they use an endogenous timing approach. In our setup, there is no preference for either of these two motivations for the internal structure change due to the merger.

The essay is organized as follows: In section 2.2 we describe our model and analyze the impact of mergers on innovation and product markets, ignoring inefficiencies due to organizational problems. We also report some results on comparative statics. Section 2.3 introduces efficiency losses of the combined R&D department due to internal organization problems. Section 2.4 concludes, discusses limitations of our model and points out interesting topics for further research.

## 2.2 Model

There are three (a priori identical) firms with homogenous products facing a linear inverse demand function: $p = 1 - X$ with $X = \sum x_i$. This demand can be derived using a representative consumer with utility function $U(x, y) = x - \frac{1}{2}x^2 + y$ with $y$ being a numeraire good. In addition to the typical possibility to choose output strategically, firms can influence their marginal costs via process innovations. The costs for these innovations are $K(c_i) = k \cdot (c_i - c^0)^2$ with $0 \leq c_i \leq c^0, k > \frac{6}{5}$.[2] Without innovation, firms have constant marginal costs $c^0 < 1$.[3] Firms are assumed to maximize profits $\pi_i = (p - c_i) \cdot x_i - k \cdot (c_i - c^0)^2$, i.e., product profitability minus total innovation costs. For simplicity, we assume that firms have no fixed costs.[4]

Investment in innovation is done in stage 1, setting of quantities in stage 2. We assume no discounting between these stages.[5] The innovation costs are sunk in the quantity choice stage. Before the investment decision, firms may merge and the new market structure is established. The merger affects the innovation incentives in two ways. At the innovation stage the R&D efforts are pooled, avoiding duplication of innovation costs. Plus, the number of players in the investment game is reduced to two. Furthermore, the merger affects innovation indirectly through the second stage of the game. The nature of product market competition is changed which in turn

[2]The parameter $k$ has to be that high to assure that innovations are nondrastic in all cases, i.e., to guarantee interior solutions. We derive this barrier in the appendix. In the following, we refer to $k$ as innovation costs while $K(c)$ is called total innovation costs.

[3]The lower bound for these initial marginal costs is dependent on the innovation cost parameter $k$ and is derived in the appendix.

[4]This assumption is not necessary in our model. However, some results concerning changes in total profits may change quantitatively, depending on how a merger or an R&D joint venture affects fixed costs.

[5]However, the innovation cost parameter $k$ can be reinterpreted to allow for time preferences.

modifies best-responses at the investment stage. Our setup is clearly quite special, in particular with respect to the inverse demand functions and the cost structure of the firms. This simplification is done for the ease of calculation and notation. Even in this particular setup differences between the considered market structures become obvious and the effects of a merger or a cooperation differ significantly from insider to outsider.

### 2.2.1 Benchmark Case

The benchmark case is a simple Cournot game with the additional possibility to invest in process innovations to reduce marginal cost prior to the quantity setting game. Hence, the optimal quantities are

$$x^*_{i,B} = \frac{1 - 3c_i + c_j + c_k}{4}.$$

The profits in the optimum, depending on the marginal costs, are thus

$$\pi^*_{i,B}(c_i) = \left(\frac{1 - 3c_i + c_j + c_k}{4}\right)^2 - K(c_i) = x^*_{i,B}(c_i)^2 - k(c_i - c^0)^2. \tag{2.1}$$

In the first stage, firms can choose their investment in process innovations. Equation (2.1) is maximized with respect to marginal costs leading to the following first order conditions:[6]

$$\begin{aligned}\frac{\partial pi^*_{i,B}(c_i)}{\partial c_i} &= -\frac{6}{16} \cdot (1 - 3c_i + c_j + c_k) - 2k \cdot (c_i - c^0) \stackrel{!}{=} 0 \\ \Leftrightarrow c^*_{i,B} &= \frac{16kc^0 - 3}{16k - 3}.\end{aligned}$$

Inserting the optimal c in the profit function yields the profits in the optimum:

$$\pi^*_B = \left(\frac{1 - \frac{16kc^0 - 3}{16k - 3}}{4}\right)^2 - k\left(\frac{16kc^0 - 3}{16k - 3} - c^0\right)^2 = \frac{k \cdot (1 - c^0)^2 \cdot (-9 + 16k)}{(3 - 16k)^2}.$$

The benchmark case is now compared with all merger cases and with an R&D joint venture. Our main focus is the investment in innovations, the total output, and the profits of insider and outsider. Without loss of generality, we assume that firms 1 and 2 cooperate. In cases CD and JV we assume that they have a combined R&D department leading to identical marginal costs for firms 1 and 2. In this section,

[6] Second order conditions are satisfied here and in all other cases (see appendix).

we assume that the reduction from two to one R&D department works without problems. Therefore the merged firm has the same cost function for R&D as before. We relax this assumption in section 2.3.

### 2.2.2 Case SSR

This way of modeling a merger refers to Salant et al. (1983). Firms 1 and 2 merge and one of these companies is closed down. In effect, this merger changes the market structure from a symmetric triopoly to a symmetric duopoly. Thus, the optimal quantities are

$$x^*_{i,SSR} = \frac{1 - 2c_i + c_j}{3},$$

leading to the profits depending on marginal costs:

$$\pi^*_{i,SSR}(c_i) = \left(\frac{1 - 2c_i + c_j}{3}\right)^2 - K(c_i) = x^*_{i,SSR}(c_i)^2 - k(c_i - c^0)^2. \qquad (2.2)$$

Maximizing equation (2.2) yields the first order conditions:

$$\begin{aligned} \frac{\partial pi^*_{i,SSR}(c_i)}{\partial c_i} &= -\frac{4}{9} \cdot (1 - 2c_i + c_j) - 2k \cdot (c_i - c^0) \stackrel{!}{=} 0 \\ \Leftrightarrow c^*_{i,SSR} &= \frac{9kc^0 - 2}{9k - 2}. \end{aligned}$$

The optimal investment in cost reducing innovations is higher than in the benchmark case leading to lower marginal costs for the SSR firms: $c^*_{i,SSR} < c^*_{i,B}$. Total innovation costs are better covered with sales due to the increased output level of each individual firm. This result is in accordance with a more general analysis of Vives (2004) that proves in a symmetric market with restricted entry increasing the number of firms tends to reduce R&D effort.

Inserting the optimal $c$ in the profit function yields:

$$\pi^*_{SSR} = \left(\frac{1 - \frac{9kc^0 - 2}{9k - 2}}{3}\right)^2 - k\left(\frac{9kc^0 - 2}{9k - 2} - c^0\right)^2 = \frac{k \cdot (1 - c^0)^2 \cdot (-4 + 9k)}{(2 - 9k)^2}.$$

Comparing this profit with the combined profit of firms 1 and 2 in the benchmark case leads to an interesting result. For $k < 1.99772$ the profit in the duopoly is higher.[7] Thus, the additional innovation stage in our model makes a merger profitable for the merging firms if innovation costs are lower than a certain bound. In

[7] The proof of this and the following statements can be found in the appendix.

the original Salant et al. (1983) model, a merger of two firms without synergies is never profitable. This result is striking as we do not explicitly assume synergies in our model. However, the reduction from two to one R&D department in the merged company can be interpreted as a synergy of this merger. Investment is only made once in the merged company. In the benchmark case, each firm invests in its own cost reduction. Furthermore, each company has a higher output compared to the benchmark case, leading to higher incentives to innovate and an increased profit. The outsider benefits from the merger, as in the Salant et al. (1983) model.

Consumer welfare can simply be compared via total quantity, which is larger in the benchmark case. The optimal quantity is influenced by two opposing forces. The reduction from three to two firms increases output per firm but the overall output is decreased. On the other hand, the firms invest more in innovation leading to lower marginal costs. The reason for this increase in investment is the increased output level of each firm. The firms can spread their total innovation costs over more output. The effect of reduced competition in the output market is stronger and thus the total quantity is lower in case SSR:

$$3x^*_{i,B} - 2x^*_{i,SSR} = 3 \cdot \frac{4(1-c^0)k}{16k-3} - 2 \cdot \frac{3(1-c^0)k}{9k-2} = \frac{6(1-c^0)k(-1+2k)}{6-59k+144k^2} > 0.$$

Thus, a merger in the SSR case is always beneficial to the outsider, can be beneficial to the insider and is never beneficial to consumers. The effect on social surplus depends on the innovation cost parameter. For low innovation costs ($k < 1.56209$) the effect on social surplus is positive. In this parameter range the merger is beneficial for insider and outsider and the reduction in output is low. If innovation cost are above that bound, the negative effect from consumer surplus dominates and the merger is welfare decreasing.

### 2.2.3 Case D

In case D two firms merge and become Stackelberg-Leader in the resulting market. Daughety (1990) justifies this way of modeling a merger. An intuitive idea is that the merged company is somehow bigger than the original company and therefore has a special status. Investment in innovation is still simultaneous.[8] The resulting

[8]If we assume that the merged company is only leader in the innovation market but both firms remain equal competitors in the output market, the leader invests more in R&D than the follower

market structure is thus a Stackelberg market with marginal costs $c_M$ for the leader and $c_O$ for the follower. This leads to the optimal output

$$x^*_{i,D} = \frac{1 - 2c_M + c_O}{2}$$

of the merged company and

$$x^*_{i,O} = \frac{1 - 3c_O + 2c_M}{4}$$

of the outsider.

Resulting profits are

$$\pi^*_{I,D}(c_M) = \frac{(1 - 2c_M + c_O)^2}{8} - K(c_M)$$

$$\pi^*_{O,D}(c_O) = \frac{(1 - 3c_O + 2c_M)^2}{16} - K(c_O).$$

These profits are maximized by choosing optimal investments. Differentiating with respect to marginal costs yields the first order conditions:

$$\frac{\partial pi^*_{I,D}(c_M)}{\partial c_M} = -\frac{1}{2} \cdot (1 - 2c_M + c_O) - 2k \cdot (c_M - c^0) \stackrel{!}{=} 0$$

$$\frac{\partial pi^*_{O,D}(c_O)}{\partial c_O} = -\frac{3}{8} \cdot (1 - 3c_O + 2c_M) - 2k \cdot (c_O - c^0) \stackrel{!}{=} 0.$$

Solving for $c_M$ and $c_O$ leads to:

$$c^*_M = \frac{3 - 4k - 13kc^0 + 16k^2c^0}{3 - 17k + 16k^2}$$

$$c^*_O = \frac{3 - 3k - 14kc^0 + 16k^2c^0}{3 - 17k + 16k^2}.$$

The optimal investment of the Stackelberg-Leader is higher than the one of the follower ($c^*_M < c^*_O$). The leader invests more in cost reducing innovations than the firms in the benchmark case ($c^*_M < c^*_B$) while the follower invests less ($c^*_O > c^*_B$).

The insider's profit

$$\pi^*_{I,D} = \frac{(1 - c^0)^2(3 - 4k)^2k(1 - 2k)}{3 - 17k + 16k^2}$$

while both firms invest more compared to the benchmark case. The merger is still profitable for the merged company if $k < 2.0231$ and always profitable for the outsider. The proof is available from the author upon request.

is larger than two times the profit in the benchmark case, while the outsider's profit

$$\pi^*_{O,D} = \frac{(1-c^0)^2(-1+k)^2k(-9+16k)}{3-17k+16k^2}$$

is smaller than the profit of one firm in the benchmark case.

Without the possibility to innovate, all firms are indifferent to the merger, as in this case the combined profit of firms 1 and 2 would equal the merged firm's profit. The same is true for the outsider.[9] Again the reduction of total innovation costs due to merging and having only one R&D lab makes the merger profitable. This effect has also a negative influence on the outsider: As the insider can spread her R&D costs over more output, she invests more in innovation leading to lower marginal costs. The outsider cannot profitably invest that much in innovation. Thus she has higher marginal costs, lower output, and a lower profit compared to the benchmark case.

Total output in case D is

$$X_D = x^*_M + x^*_O = \frac{2(1-c^0)k(-5+6k)}{3-17k+16k^2},$$

which is higher than in the benchmark case:

$$3x^*_B - X_D = 3 \cdot \frac{4(1-c^0)k}{16k-3} - \frac{2(1-c^0)k(-5+6k)}{3-17k+16k^2} = \frac{2(-1+c^0)k(-3+4k)}{-9+99k-320k^2+256k^3} < 0.$$

In this setting, the reduction from three to two firms has no effect on total output if all firms do not innovate. Thus, only the effect from innovation remains. This effect has to be analyzed separately for insider and outsider. The insider's optimal investment is higher than in the benchmark case, as analyzed above. This leads to an increase of her output. The outsider is negatively influenced by this reduction of the insider's marginal costs and invests less than in the benchmark case. Therefore, the outsider's output is reduced. But as the insider accounts for a larger proportion of output, the overall output is increased.[10]

Comparing the results with the benchmark case, we see that the merging firms and consumers benefit from the merger while it is never beneficial to the outsider. The surplus of insider and consumers is larger than the profit shortfall of the outsider leading to an increase of social surplus.

[9]This can be easily verified looking at the profits of insider and outsider for identical marginal costs and no investment in innovation.

[10]This result is in line with Daughety (1990) who states that mergers and increases in concentration can be socially beneficial if an asymmetric situation occurs.

### 2.2.4 Case CD

In the CD case, it is assumed that the merged company has two independent divisions. This way of modeling a merger refers to Creane and Davidson (2005). The parent company rewards the manager of each division according to her division's profit. Therefore, both managers set their quantities in order to maximize their division's profit. The multidivisional firm encourages competition across its divisions.[11] The two companies involved in the merger do not set their quantities simultaneously, but sequentially. Thus, one division is the Stackelberg-Leader in the intra-firm game. As this division's manager is only concerned about her own profit she becomes more aggressive in the market and increases her division's market share. This strategic change of the company's organization leads to an increased market share of the merged company. Investment in innovation is done in order to maximize the joint profit of both divisions. The new technology can be used by both divisions. We call the leader in the merged company division 1, the follower division 2 and the other firm outsider. The profit of division 2 is given by:

$$\pi_{D2} = x_{D2} \cdot (1 - x_{D1} - x_{D2} - x_O) - c_M x_{D2}. \tag{2.3}$$

Maximizing (2.3) with respect to $x_{D2}$ yields the optimal output of division 2 as a function of the leader's and the outsider's output:

$$x_{D2} = \frac{1 - c_M - x_{D1} - x_O}{2}. \tag{2.4}$$

The leader's profit is thus:

$$\begin{aligned} \pi_{D1} &= x_{D1} \cdot (1 - x_{D1} - x_{D2} - x_O) - c_M x_{D1} \\ &= x_{D1} \cdot \left(1 - x_{D1} - \frac{1 - c_M - x_{D1} - x_O}{2} - x_O\right) - c_M x_{D1}. \end{aligned} \tag{2.5}$$

Maximizing (2.5) with respect to $x_{D1}$ yields:

$$x^*_{D1} = \frac{1 - c_M - x_O}{2}. \tag{2.6}$$

The outsider's profit is given by

$$\pi_{O,CD} = x_O \cdot (1 - x_{D1} - x_{D2} - x_O) - c_O x_O - K(c_O)$$

[11] An overview of empirical evidence for this type of competition in multidivisional firms is given in Creane and Davidson (2005) and in Huck, Konrad, and Müller (2004).

which yields the optimal quantity, depending on the output of division 1 and 2

$$x_O = \frac{1 - c_O - x_{D1} - x_{D2}}{2}. \tag{2.7}$$

Substituting (2.4) in (2.7) yields:

$$x_O = \frac{1 - 2c_O + c_M - x_{D1}}{3}. \tag{2.8}$$

Solving (2.7) and (2.8) for $x_{D1}$ and $x_O$ and inserting the results in (2.4) we obtain the optimal quantities:

$$x^*_{D1} = \frac{2}{5}(1 + c_O - 2c_M)$$
$$x^*_{D2} = \frac{1}{5}(1 + c_O - 2c_M)$$
$$x^*_O = \frac{1}{5}(1 - 4c_O + 3c_M).$$

Note that for identical marginal costs the outsider's and the follower's quantities are the same. The resulting profits for each division are:

$$\pi^*_{D1} = \frac{2}{25}(1 + c_O - 2c_M)^2$$

$$\pi^*_{D2} = \frac{1}{25}(1 + c_O - 2c_M)^2.$$

The entire company has to pay the total innovation costs $K(c_M)$ and thus has combined profits:

$$\pi^*_{I,CD} = \frac{3}{25}(1 + c_O - 2c_M)^2 - K(c_M).$$

The outsider's profits are:

$$\pi^*_{O,CD} = \frac{1}{25}(1 - 4c_O + 3c_M)^2 - K(c_O).$$

It is easy to see that for identical marginal costs, the overall output rises compared to the benchmark case. This result is a replication of the Creane and Davidson (2005) results that any merger in this setting lowers prices. Furthermore, the profit of the outsider decreases. But without the innovation stage, this merger would also reduce profits of firms 1 and 2 as $\frac{3}{25}(1-c)^2 < \frac{1}{8}(1-c)^2$.

Maximizing profits with respect to marginal costs yields the first order conditions:

$$\begin{aligned}
\frac{\partial pi^*_{I,CD}(c_M)}{\partial c_M} &= -\frac{12}{25} \cdot (1 + c_O - 2c_M) - 2k \cdot (c_M - c^0) \stackrel{!}{=} 0 \\
\frac{\partial pi^*_{O,CD}(c_O)}{\partial c_O} &= -\frac{8}{25} \cdot (1 - 4c_O + 3c_M) - 2k \cdot (c_O - c^0) \stackrel{!}{=} 0.
\end{aligned}$$

Solving for $c_M$ and $c_O$ yields:

$$\begin{aligned} c_M^* &= \frac{24 - 30k - 110kc^0 + 125k^2c^0}{24 - 140k + 125k^2} \\ c_O^* &= \frac{24 - 20k - 120kc^0 + 125k^2c^0}{24 - 140k + 125k^2}. \end{aligned}$$

As in case D the optimal investment of the insider is higher than the outsider's optimal investment ($c_M^* < c_O^*$). The insider's optimal investment is higher than the optimal investment in the benchmark case ($c_M^* < c_B^*$) while the outsider's investment is lower ($c_O^* > c_B^*$).

The insider's profit

$$\pi_{I,CD}^* = \frac{3(-1 + c^0)^2(4 - 5k)^2k(-12 + 25k)}{(24 - 140k + 125k^2)^2}$$

is larger than two times the benchmark case profit as long as $k < 9.20472$. This result is different to the original Creane and Davidson (2005) result. In their setup without innovation a bilateral merger is only profitable if there are at least four firms active in the market. In our setting it is profitable for three active firms in the market, if the innovation costs are not too large. The outsider's profit

$$\pi_{O,CD}^* = \frac{(-1 + c^0)^2(6 - 5k)^2k(-16 + 25k)}{(24 - 140k + 125k^2)^2}$$

is smaller than in the benchmark case. Interpretation is quite similar to case D. The insider invests more in R&D and puts pressure on the outsider. This is possible as she can spread her total innovation costs over a larger output. Having less output, the outsider is not able to invest that much in R&D and therefore has higher marginal costs. Thus, she loses profit compared to the symmetric benchmark case.

Total output is

$$X_{CD} = x_{D1}^* + x_{D2}^* + x_O^* = \frac{10(1 - c^0)k(-9 + 10k)}{24 - 140k + 125k^2},$$

which is again larger than in the benchmark case:

$$\begin{aligned} 3x_B^* - X_{CD} &= 3 \cdot \frac{4(1 - c^0)k}{16k - 3} - \frac{10(1 - c^0)k(-9 + 10k)}{24 - 140k + 125k^2} \\ &= \frac{2(1 - c^0)k(-9 - 30k + 50k^2)}{-72 + 804k - 2615k^2 + 2000k^3} < 0. \end{aligned}$$

In the CD case, the effects from changes in the market structure and innovation of the insider on total output go in the same direction. Without innovation the increase in output would be from $\frac{3}{4}(1-c^0)$ to $\frac{4}{5}(1-c^0)$ . This is due to aggressive behavior of division 1, the Stackelberg-Leader in the intra firm game. Furthermore, the merged company invests more in innovation compared to the benchmark case and thus marginal costs are reduced more. This leads to an increase in output. The outsider invests less, causing a reduced output but the effect from the changes in market structure and from the merged company overbalance the outsider's reduction and thus, total output increases.

In this setup, consumers always benefit from the merger, for the merging firms it depends on the innovation cost parameter $k$ while the outsider is always harmed by the merger. The effect on social surplus is always positive.

### 2.2.5 Case R&D Joint Venture

R&D joint ventures are often considered to be consumer friendly as wasteful duplication of R&D efforts is avoided while the output market is still competitive. D'Aspremont and Jacquemin (1988) theoretically analyze the efficiency effects of R&D joint ventures and Gugler and Siebert (2004) provide empirical evidence for these efficiencies in the semiconductor industry. The main difference between R&D joint ventures and mergers is that firms remain competitors in the output market. In our model firms 1 and 2 cooperate only in the first stage, i.e., in the innovation market. In the second stage, the firms compete in quantities as in the benchmark case. [12] Firms 1 and 2 have an R&D joint venture leading to identical marginal costs $c_1 = c_2 = c_{JV}$. Therefore, the resulting quantities for firms 1 and 2 are also identical. Solving the optimization problem of the second stage yields:

$$\begin{aligned} x^*_{1,JV} = x^*_{2,JV} &= \frac{1-2c_{JV}+c_3}{4} \\ x^*_{3,JV} &= \frac{1+2c_{JV}-3c_3}{4}. \end{aligned}$$

The resulting profits, assuming that each firm in the R&D joint venture pays half of the R&D costs, are

[12] This scenario can also be interpreted as a situation where firms merge but output decisions are delegated to managers like in the CD case. However, the managers now move simultaneously rather than sequentially.

$$\begin{aligned}
\pi^*_{i,JV}(c_{JV}) &= \left(\frac{1-2c_{JV}+c_3}{4}\right)^2 - \frac{1}{2}K(c_{JV}) \\
&= x^*_{i,JV}(c_{JV})^2 - \frac{1}{2}k(c_{JV}-c^0)^2 \qquad\qquad i=1,2 \\
\pi^*_{3,JV}(c_3) &= \left(\frac{1+2c_{JV}-3c_3}{4}\right)^2 - K(c_3) = x^*_{3,JV}(c_3)^2 - k(c_3-c^0)^2.
\end{aligned}$$

The combined quantity of firms 1 and 2 is identical to the quantity of the Stackelberg-Leader and the quantity of firm 3 is identical to the one of the follower in case D. This leads to identical optimization problems in the first stage as the combined profit of firms 1 and 2 equals the Stackelberg-Leader's profit and the outsider's profit in the joint venture case is also the same as the follower's profit in case D. Thus, investment in innovation, resulting profit, optimal quantities, and the other results are identical to case D. The occurrence of identical results in these two cases is of course by chance and is heavily dependent on the assumption of linear demand and constant marginal costs. These assumptions cause the Stackelberg-Leader in case D to produce exactly two times the quantity of one firm in the benchmark or the R&D joint venture case. However, in a more general setup we expect the results to be comparable as well. This result is very interesting in the context of merger or R&D joint venture approvals. If a certain market structure establishes after the merger, the effects on consumer welfare of a merger is comparable to that of an R&D joint venture, in our model it is even completely identical. The empirical results of Gugler and Siebert (2004) on market shares at least partly support this view. Both mergers and R&D joint ventures cause market shares of participating firms to increase, even though the effect is more significant for R&D joint ventures.[13]

### 2.2.6 Comparative Statics

In this section we analyze the influence of the model's parameters. By calculating some comparative statics – with respect to the innovation cost parameter $k$ and the initial level of marginal costs $c^0$ – we derive some interesting results concerning the optimal innovation environment for companies and consumers. Please keep in mind that $k > \frac{6}{5}$ is assumed.

[13]The superior performance of R&D joint ventures may be caused by less integration problems of the R&D department. This is addressed in section 2.3.

The more expensive it is to reduce marginal costs, i.e., the higher $k$ is, the lower is the total quantity supplied, i.e.,

$$\frac{\partial X}{\partial k} < 0,$$

in all market structures. This result is not surprising, as the innovation cost parameter influences investments and thus marginal costs. If the reduction of marginal costs gets more expensive, firm's total investment in innovation is decreasing leading to higher marginal costs.[14] Thus, the overall output decreases. In order to improve consumer welfare it is therefore always useful to foster an innovation friendly environment.

An interesting result is the change in profits for increasing innovation costs. While the insiders in cases D, CD, and JV suffer from increasing innovation costs, the profits of the outsiders in these cases as well as the profits of firms in the symmetric cases (benchmark and SSR) increase with innovation costs:

$$\frac{d\pi_a^*}{dk} < 0 \quad \text{for } a \in \{D_I, CD_I, JV_I\},$$

$$\frac{d\pi_a^*}{dk} > 0 \quad \text{for } a \in \{B, SSR, D_O, CD_O, JV_O\}.$$

The reason for this unexpected result is the effect of $k$ on the innovation market. Of course, a decrease of the factor $k$ reduces total innovation costs for a fixed $c$. On the other hand it increases innovation competition. As $k$ increases, total investment in innovations is reduced. This leads to higher marginal costs and lower product profitability. But as all firms have higher marginal costs, this loss is not that high. The outsiders and the firms in the symmetric cases overcompensate the loss in product profitability by the reduced investment in innovations. The insiders in cases D, CD, and JV have a higher output and therefore the loss in product profitability is higher and cannot be covered by the lower investment in innovations. This result shows that not all firms appreciate reductions in innovation costs. If a government reduces innovation costs, for example by facilitating patent approval processes or by granting innovation support programs, only some firms benefit.

[14] There are exceptions for the outsider's investment in cases D and CD for a certain parameter range (proofs are available from the author upon request). However, the insider's effect is dominant.

Looking at the profit function of all firms, we see the factor $(-1 + c^0)^2$ in all cases. Thus, firms' profits fall with increasing initial marginal costs $c^0$:

$$\frac{d\pi^*}{dc^0} < 0.$$

The more efficient firms' initial production is, the higher is the resulting profit.

## 2.3 Decrease of R&D Efficiency due to Post Merger Integration Problems

So far we assumed that the merged firm has the same costs for R&D as the former independent companies. We relax this assumption to allow for organizational problems. As our focus are the effects on innovation, we only consider inefficiencies of the merging R&D departments. Cefis et al. (2005) show that firms involved in acquisitions have a lower efficiency in R&D than independently competing firms. They attribute this efficiency loss to post merger integration problems. The extent of these problems is influenced by the organization of the R&D integration process and similarities between the R&D departments (see Grimpe (2005)). Similarities in the research base, like common skills, shared languages, and related cognitive structures, facilitate joint research after the merger (see Kogut and Zander (1992) and Cassiman et al. (2005)). If post merger integration problems occur, we assume the R&D cost function to be

$$K(c_i) = \alpha k(c_i - c^0)^2,$$

where $\alpha \in (1; 2]$ is an efficiency parameter.[15] Thus, the merged company now faces increased innovation costs $\tilde{k} = \alpha k > k$ compared to the outsider. In this section we analyze the effect of these efficiency losses for each case.[16] As becomes apparent from the appendix, the resulting complexity of terms does not lend itself to proceed analytically for all parameter values simultaneously. However, the impact of the increased cost of R&D for merging firms can be visualized by corresponding plots and the study of some representative values for the innovation cost parameter $k$.

[15] We restrict $\alpha$ by 2 to assure that total innovation costs after integration are not higher than the sum of total innovation costs of the two former independent R&D departments (for a given cost reduction).

[16] Calculations are basically the same as before and are given in the appendix. The innovation decision in the joint venture case is still identical to case D.

### 2.3.1 Case SSR

The situation is no longer symmetric and so we have to distinguish between insider and outsider. Innovation is now more costly for the merged firm leading to higher marginal cost and lower profits for the insider. The outsider benefits from the increased costs of its rival and invests more in innovation. Thus, the efficiency losses lead to lower profits for the insider and increased profits of the outsider. Figure 2.1 shows the change of insider's and outsider's profits compared to the benchmark case for innovation costs between $\frac{6}{5}$ and 5 and efficiency parameter $\alpha$ between 1 and 2. We see that for very small $\alpha$ and $k$ the merger is still profitable for the insider. If $\alpha$ or $k$ increases, the merger gets unprofitable. For the outsider, the merger is always profitable. The outsider's profitability increases in $\alpha$ as its superior position in R&D increases with $\alpha$.

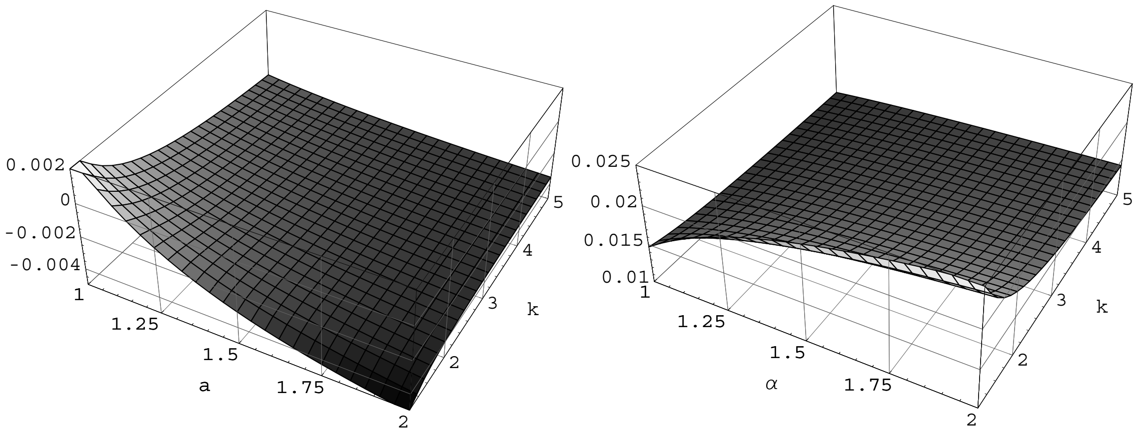


Figure 2.1: Profit comparison case SSR, insider (left) and outsider (right).

The occurrence of integration problems worsens the situation for consumers. The merger leads to a decrease in total output. With increasing integration problems, total innovation costs rise leading to higher marginal costs and a lower output of each firm.

The same is true for social surplus. Only for very small innovation costs and little integration problems the merger can enhance social surplus.

### 2.3.2 Case D

If integration problems occur, the position of the Stackelberg leader is not as dominant as before. The merged company now has increased costs of innovation compared to the outsider while it can still spread these costs over a larger output. The dominating effect is dependent on $\alpha$. For $\alpha < \frac{4}{3}$ the size effect dominates and the insider still invests more in innovation compared to the benchmark case. The outsider invests more if the effect from increased costs dominates, i.e., if $\alpha > \frac{4}{3}$. For $\alpha = \frac{4}{3}$ both the insider and outsider have the same marginal costs as in the benchmark case.

As the Stackelberg-Leader produces exactly twice the quantity of one firm and the follower the same as one firm in a Cournot Triopoly, total output is for $\alpha = \frac{4}{3}$ also identical to the benchmark case. Figure 2.2 shows a comparison of total quantity before and after the merger. We see that consumers benefit from the merger if $\alpha < \frac{4}{3}$, i.e., if the larger firm has lower marginal costs.

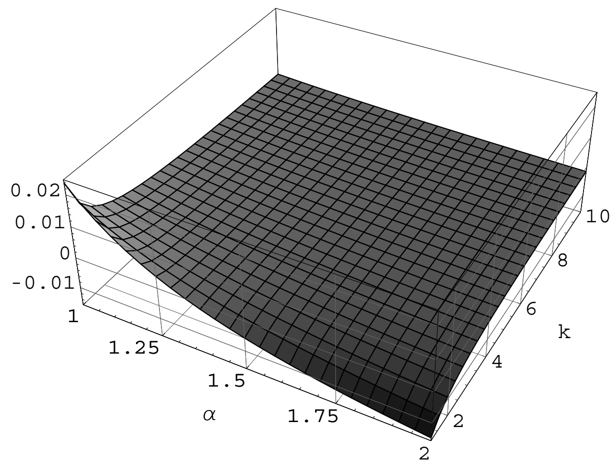


Figure 2.2: Changes in total quantity, case D.

The profit of the insider is increasing, except for high $\alpha$ and small $k$ (see figure 2.3). If $\alpha$ is high, she does not benefit much from its reduction of R&D departments and if $k$ is small, the outsider reduces marginal costs very much, causing a loss of market share for the insider. The outsider benefits from the merger if $\alpha > \frac{4}{3}$. Social surplus is always increasing.

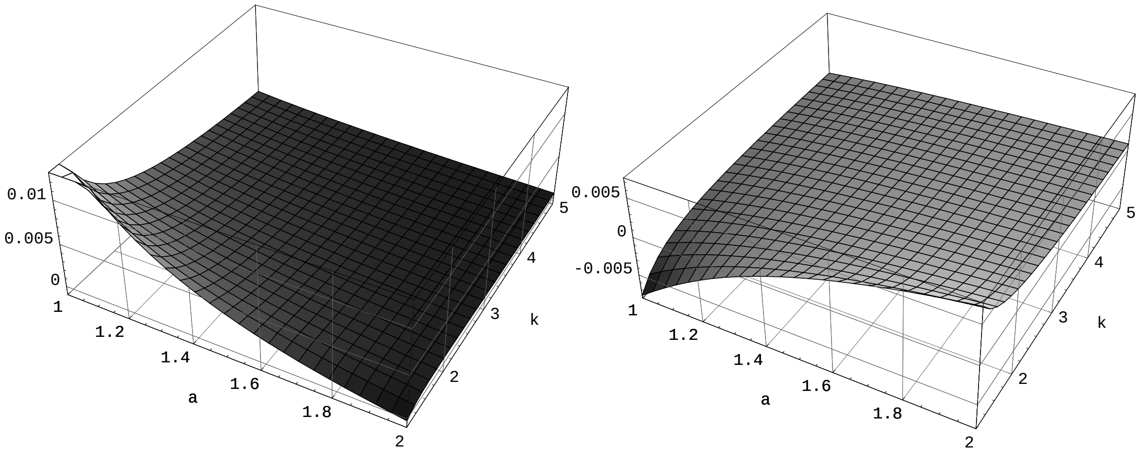


Figure 2.3: Profit comparison case D, insider (left) and outsider (right).

### 2.3.3 Case CD

In the CD case, the insider invests more compared to the benchmark case up to a certain limit of $\alpha$ which depends on $k$. The outsider invests less, except for really low values of $k$ and high values of $\alpha$. The merger is profitable for the insider if integration problems are not too high and is never beneficial for the outsider (see figure 2.4).

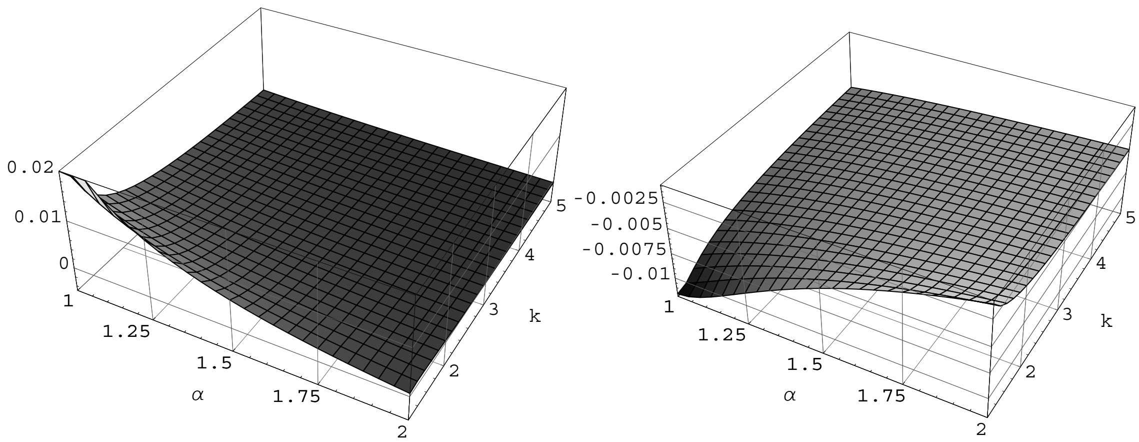


Figure 2.4: Profit comparison case CD, insider (left) and outsider (right).

Total quantity and social surplus are always increased. This is due to the changed organization in the merged company. The aggressive behavior of the intrafirm Stackelberg-Leader causes total quantity to rise significantly and thus leading to higher consumer surplus. If integration problems and innovation costs are very high it is possible that both firms lose profit due to the merger. Even in this situation, the rise in consumer surplus caused by the changed market structure overcompensates this loss, leading to an increase in social surplus.

### 2.3.4 Summary

| | Investment Insider | Investment Outsider | Profits Insider | Profits Outsider | Total Quantity | Social Surplus |
|---|---|---|---|---|---|---|
| SSR $k=\frac{6}{5}$ | $\nearrow$ if $\alpha < 1.13$ | $\nearrow$ | $\nearrow$ if $\alpha < 1.17$ | $\nearrow$ | $\searrow$ | $\nearrow$ if $\alpha < 1.29$ |
| SSR $k=\frac{3}{2}$ | $\nearrow$ if $\alpha < 1.15$ | $\nearrow$ | $\nearrow$ if $\alpha < 1.11$ | $\nearrow$ | $\searrow$ | $\nearrow$ if $\alpha < 1.03$ |
| SSR $k=5$ | $\nearrow$ if $\alpha < 1.18$ | $\nearrow$ | $\searrow$ | $\nearrow$ | $\searrow$ | $\searrow$ |
| D (JV) $k=\frac{6}{5}$ | $\nearrow$ if $\alpha < 1.33$ | $\searrow$ if $\alpha < 1.33$ | $\nearrow$ if $\alpha < 1.96$ | $\searrow$ if $\alpha < 1.33$ | $\nearrow$ if $\alpha < 1.33$ | $\nearrow$ |
| D (JV) $k=\frac{3}{2}$ | $\nearrow$ if $\alpha < 1.33$ | $\searrow$ if $\alpha < 1.33$ | $\nearrow$ | $\searrow$ if $\alpha < 1.33$ | $\nearrow$ if $\alpha < 1.33$ | $\nearrow$ |
| D (JV) $k=5$ | $\nearrow$ if $\alpha < 1.33$ | $\searrow$ if $\alpha < 1.33$ | $\nearrow$ | $\searrow$ if $\alpha < 1.33$ | $\nearrow$ if $\alpha < 1.33$ | $\nearrow$ |
| CD $k=\frac{6}{5}$ | $\nearrow$ if $\alpha < 1.34$ | $\searrow$ if $\alpha < 1.79$ | $\nearrow$ | $\searrow$ | $\nearrow$ | $\nearrow$ |
| CD $k=\frac{3}{2}$ | $\nearrow$ if $\alpha < 1.32$ | $\searrow$ | $\nearrow$ | $\searrow$ | $\nearrow$ | $\nearrow$ |
| CD $k=5$ | $\nearrow$ if $\alpha < 1.29$ | $\searrow$ | $\nearrow$ if $\alpha < 1.52$ | $\searrow$ | $\nearrow$ | $\nearrow$ |

Table 2.1: Comparisons for illustrative innovation cost parameters.

To illustrate results, we analyze the changes compared to the benchmark case for some exemplary innovation cost parameters in table 2.1. If we allow for efficiency losses of the R&D department, we get ambiguous results caused by the effect of innovation costs. In the SSR case the insider is even worse off. Without integration problems she was at least in an identical situation as the outsider, now she suffers from less efficient innovation. The merged firm in cases D and CD can spread its total innovation costs over a larger output but innovation costs increase due to the losses in R&D efficiency. The positive effects on market shares for the insider are reduced because of the integration problems. Still, insiders tend to benefit from mergers in case D and CD but only up to a certain bound $\alpha(k)$. The outsider is always harmed by the merger in case CD, in case D only up to $\alpha = \frac{4}{3}$. In all cases the outsider benefits from an increase in $\alpha$ as this improves her position in the innovation market. The introduction of integration problems also leads to changes in welfare analysis. Less efficient R&D harms consumers as marginal costs after innovation are higher and thus total quantity is lower. In case D a merger without integration problems is always beneficial for consumers while sufficiently large integration problems lead to a decrease in consumer surplus. This result may partly explain the empirical findings of Gugler and Siebert (2004). If we expect the integration problems of R&D joint ventures to be lower than those of mergers, for example because the integration can fully concentrate on R&D issues, the $\alpha$ of R&D joint ventures would be lower compared to mergers. Thus, innovation is more efficiently performed in the joint venture leading to a more significant increase in market shares for firms participating in R&D joint ventures compared to merging firms.

## 2.4 Conclusion

This essay shows – in a simplified framework – the effects of a merger on the incentives to innovate in different market structures. In our three firm model we allow firms to invest in innovation in the first stage and to set optimal quantities in the second. Thus, firms first compete on the innovation market and strategically set their investment in innovation that determines their marginal costs of production. Then they compete in quantities. We compare the basic situation with three identical firms to merger and R&D joint venture situations. In all resulting market structures, a merger can be beneficial to the merging company, depending on the innovation cost parameter $k$. In the SSR and CD case it is only beneficial if innovation costs are sufficiently low while in case D (and for an R&D joint venture) it is beneficial independent of the innovation costs. Except for the SSR case, where insider and outsider are symmetric, the outsider is harmed by the merger. This result is in accordance with empirical results from Banerjee and Eckard (1998) analyzing the first great merger wave. In all asymmetric cases the merger is disadvantageous for the outsider. A characteristic result of all asymmetric situations is that the insider invests more in innovation compared to the benchmark case while the outsider invests less. The reason for this result is that the insider can spread her total innovation costs over more output and therefore has higher incentives to reduce her marginal costs. Consumers benefit from the merger (except for the SSR case). The asymmetric situation leads to higher investments in innovation, lower marginal cost and therefore to a better supply of the good.

If we allow for decreasing R&D efficiency due to the merger, results get ambiguous. The effect of increased innovation costs pushes in the opposite direction as the effect on output caused by the change in market structure. Thus, results depend heavily on the changes in R&D efficiency.

Our model has several limitations. Firstly, we do not consider uncertainty about the results of R&D efforts. While this is certainly a key aspect of innovation, we omit the problem of unknown outcomes of R&D investments and the associated discussion about the degree of risk aversion to have a clear focus on the innovation incentives resulting from changes in market structure.

Secondly, our model is static. We do not consider entry of new competitors in the market that occurs despite of large fixed costs in high technology and R&D intensive markets or follow-up investments in innovation. Hence, an important extension to our model would be a dynamic way of modeling innovation and allowing for entry. Furthermore, we do not consider the possibility to license the improved technology to competitors. As the approval processes of mergers often discuss remedies, like mandatory licensing to outsiders, including the possibility to license innovation would be an extension that makes our model more realistic. However, this would completely change the competition for innovation in our model as these process innovations are then most efficiently performed by only one company and effectively a three firm R&D joint venture without innovation competition is created.

A third simplification of our model is our assumption about the cost structure of innovation and the linear demand for the homogeneous good. We think that our findings do not change qualitatively with more general demand structures and R&D cost functions, although some specific results, like the identical outcomes for cases D and R&D joint ventures, would be altered of course. However, these assumptions simplify notation and analysis, especially the calculations of sub-game perfect equilibria. The preponderance of results concerning the surplus enhancing effect of mergers in an innovation context needs an analysis of more general demand and cost structures.

Further research in this field should concentrate on two related topics: Firstly, the organization of the merger and the integration of the merging firms and secondly, the resulting consequences for R&D efficiency. The organization of the merger has a significant influence on the firm's position in the post merger market and thus influences both the success of a merger and the welfare consequences. R&D efficiency is on the one hand influenced by the organization of the integration process on the other hand by matching R&D principles. In a model with heterogeneous firms, these effects on R&D efficiency and merger success could be used to endogenize the merger decision.

## 2.5 Appendix

**Lower bound for innovation cost parameter $k$:**
If innovation costs are too low, the insider can reduce its marginal costs that much that the outsider is forced to leave the market. The power of the insider is dependent on its market share and is greatest in case CD.

We solve for the innovation costs where the optimal marginal costs of the outsider is identical to the initial marginal costs, i.e., the costs where the outsider does not innovate at all:

$$\begin{aligned} c_O^* = \frac{24 - 20k - 120kc^0 + 125k^2c^0}{24 - 140k + 125k^2} &\overset{!}{=} c^0 \\ \Leftrightarrow 24 - 20k - 120kc^0 + 125k^2c^0 &= c^0(24 - 140k + 125k^2) \\ \Leftrightarrow k &= \frac{6}{5}. \end{aligned}$$

If $k > \frac{6}{5}$, the outsider is not pushed out of the innovation market in equilibrium.

**Second order conditions for the innovation stage:**
To assure concavity of the profit function, the innovation cost parameter $k$ must satisfy the following conditions:

***Benchmark***

$$\frac{\partial pi_{i,B}^*(c_i)}{\partial c_i} = -\frac{6}{16} \cdot (1 - 3c_i + c_j + c_k) + 2k \cdot (c_i - c^0)$$

$$\begin{aligned} \Rightarrow \frac{\partial^2 pi_{i,B}^*(c_i)}{\partial c_i^2} = \frac{9}{8} - 2k &\overset{!}{<} 0 \\ \Leftrightarrow k &> \frac{9}{16} \end{aligned}$$

***SSR***

$$\frac{\partial pi_{i,SSR}^*(c_i)}{\partial c_i} = -\frac{4}{9} \cdot (1 - 2c_i + c_j) + 2k \cdot (c_i - c^0)$$

$$\begin{aligned} \Rightarrow \frac{\partial^2 pi_{i,SSR}^*(c_)}{\partial c_i^2} = \frac{8}{9} - 2k &\overset{!}{<} 0 \\ \Leftrightarrow k &> \frac{4}{9} \end{aligned}$$

***D(JV)***

$$\frac{\partial pi^*_{I,D}(c_M)}{\partial c_M} = -\frac{1}{2} \cdot (1 - 2c_M + c_O) - 2k \cdot (c_M - c^0)$$

$$\Rightarrow \frac{\partial^2 pi^*_{I,D}(c_M)}{\partial c_M^2} = 1 - 2k \overset{!}{<} 0$$

$$\Leftrightarrow k > \frac{1}{2}$$

$$\frac{\partial pi^*_{O,D}(c_O)}{\partial c_O} = -\frac{3}{8} \cdot (1 - 3c_O + 2c_M) - 2k \cdot (c_O - c^0)$$

$$\Rightarrow \frac{\partial^2 pi^*_{O,D}(c_O)}{\partial c_O^2} = \frac{9}{8} - 2k \overset{!}{<} 0$$

$$\Leftrightarrow k > \frac{9}{16}$$

***CD***

$$\frac{\partial pi^*_{I,CD}(c_M)}{\partial c_M} = -\frac{12}{25} \cdot (1 + c_O - 2c_M) - 2k \cdot (c_M - c^0)$$

$$\Rightarrow \frac{\partial^2 pi^*_{I,CD}(c_M)}{\partial c_M^2} = \frac{24}{25} - 2k \overset{!}{<} 0$$

$$\Leftrightarrow k > \frac{12}{25}$$

$$\frac{\partial pi^*_{O,CD}(c_O)}{\partial c_O} = -\frac{8}{25} \cdot (1 - 4c_O + 3c_M) - 2k \cdot (c_O - c^0)$$

$$\Rightarrow \frac{\partial^2 pi^*_{O,CD}(c_O)}{\partial c_O^2} = \frac{32}{25} - 2k \overset{!}{<} 0$$

$$\Leftrightarrow k > \frac{16}{25}$$

In all cases, the second order conditions are satisfied as $k > \frac{6}{5}$ is assumed.

**Lower bound for initial costs:**

To assure nonnegative marginal costs, it is necessary that the initial costs $c^0$ are higher than a certain bound.

***Benchmark***

$$\begin{aligned} c^*_{i,B} = \frac{16kc^0 - 3}{16k - 3} &\overset{!}{\geq} 0 \\ \Leftrightarrow c^0 &\geq \frac{3}{16k} \end{aligned}$$

***SSR***

$$\begin{aligned} c^*_{i,SSR} = \frac{9kc^0 - 2}{9k - 2} &\overset{!}{\geq} 0 \\ \Leftrightarrow c^0 &\geq \frac{2}{9k} \end{aligned}$$

***D (JV)***

$$\begin{aligned} c^*_M = \frac{3 - 4k - 13kc^0 + 16k^2c^0}{3 - 17k + 16k^2} &\overset{!}{\geq} 0 \\ \Leftrightarrow c^0 &\geq \frac{4k - 3}{16k^2 - 13k} \end{aligned} \tag{2.9}$$

$$\begin{aligned} c^*_O = \frac{3 - 3k - 14kc^0 + 16k^2c^0}{3 - 17k + 16k^2} &\overset{!}{\geq} 0 \\ \Leftrightarrow c^0 &\geq \frac{3k - 3}{16k^2 - 14k} \end{aligned}$$

***CD***

$$\begin{aligned} c^*_M = \frac{24 - 30k - 110kc^0 + 125k^2c^0}{24 - 140k + 125k^2} &\overset{!}{\geq} 0 \\ \Leftrightarrow c^0 &\geq \frac{30k - 24}{125k^2 - 110k} \end{aligned} \tag{2.10}$$

$$\begin{aligned} c^*_O = \frac{24 - 20k - 120kc^0 + 125k^2c^0}{24 - 140k + 125k^2} &\overset{!}{\geq} 0 \\ \Leftrightarrow c^0 &\geq \frac{20k - 24}{125k^2 - 120k} \end{aligned}$$

The critical bounds are (2.9) and (2.10), leading to the following condition for initial marginal costs:

$$c^0 \geq \max\left\{\frac{4k - 3}{16k^2 - 13k}, \frac{30k - 24}{125k^2 - 110k}\right\}.$$

Bound (2.9) is critical for $k > 1.4131$, bound (2.10) for $k < 1.4131$.[17]

[17] For $k = \frac{6}{5}$ we have the highest lower barrier $c^0 \geq 0.25$.

**Profit comparisons:**

***Benchmark vs. SSR***

Comparing the combined profit of two firms in the benchmark case with the insider's profits in case SSR yields:

$$\begin{aligned}2\pi_B^* - \pi_{SSR}^* &= 2 \cdot \frac{k(1-c^0)^2(-9+16k)}{(3-16k)^2} - \frac{k(1-c^0)^2(-4+9k)}{(2-9k)^2} \\ &= (1-c^0)^2 k \cdot \frac{-36+311k-722k^2+288k^3}{(6-59k+144k^2)^2}.\end{aligned}$$

The denominator is positive for all admissible values of $k$. The sign of the numerator depends on the term $-36+311k-722k^2+288k^3$ which is negative for $k \in [\frac{6}{5}, 1.9977)$ and positive for $k \in (1.9977, \infty)$. Thus the merger is profitable for the merging firms if $k$ is below that bound. The outsider's profit is always larger than the profit of a single firm in the benchmark case as

$$\begin{aligned}\pi_B^* - \pi_{SSR}^* &= \frac{k(1-c^0)^2(-9+16k)}{(3-16k)^2} - \frac{k(1-c^0)^2(-4+9k)}{(2-9k)^2} \\ &= -(1-c^0)^2 k^2 \cdot \frac{77-583k-1008k^2}{(6-59k+144k^2)^2} < 0.\end{aligned}$$

***Benchmark vs. D (JV)***

The combined profit of two firms in the benchmark case is always smaller than the insider's profit in case D:

$$\begin{aligned}2\pi_B^* - \pi_{I,D}^* &= 2 \cdot \frac{k(1-c^0)^2(-9+16k)}{(3-16k)^2} - \frac{(1-c^0)^2(3-4k)^2 k(1-2k)}{(3-17k+16k^2)^2} \\ &= -(-1+c^0)^2 k \cdot \frac{81-882k+3282k^2-4928k^3+2560k^4}{(9-99k+320k^2-256k^3)^2} < 0.\end{aligned}$$

The benchmark case profit of one firm is always higher than the outsider's profit:

$$\begin{aligned}\pi_B^* - \pi_{O,D}^* &= \frac{k(1-c^0)^2(-9+16k)}{(3-16k)^2} - \frac{(1-c^0)^2(-1+k)^2 k(-9+16k)}{(3-17k+16k^2)^2} \\ &= 4(-1+c^0)^2 k^2 \frac{-27+210k-432k^2+256k^3}{(9-99k+320k^2-256k^3)^2} > 0.\end{aligned}$$

***Benchmark vs. CD***

Comparing the combined profit of two firms in the benchmark case with the insider's profits in case CD yields:

$$2\pi_B^* - \pi_{I,CD}^* = 2 \cdot \frac{k(1-c^0)^2(-9+16k)}{(3-16k)^2} - \frac{3(-1+c^0)^2(4-5k)^2 k(-12+25k)}{(24-140k+125k^2)^2}$$

$$= (-1+c^0)^2 k \cdot \frac{-5184+60336k-239844k^2+382085k^3-222850k^4+20000k^5}{(72-804k+2615k^2-2000k^3)^2}.$$

The sign of this expression depends on the sign of the numerator which is negative for $k < 9.20472$ and positive for $k > 9.20472$. Thus, a merger in case CD is profitable if $k$ is below that bound. The benchmark case profit of one firm is always higher than the outsider's profit:

$$\pi^*_B - \pi^*_{O,CD} = \frac{k(1-c^0)^2(-9+16k)}{(3-16k)^2} - \frac{(-1+c^0)^2(6-5k)^2k(-16+25k)}{(24-140k+125k^2)^2}$$
$$= 4(-1+c^0)^2k^2 \cdot \frac{-2340+5196k+60415k^2-154225k^3+90000k^4}{(72-804k+2615k^2-2000k^3)^2} > 0.$$

**Investment comparisons:**

***Benchmark vs. SSR***

The optimal marginal costs in case SSR are lower than in the benchmark case:

$$c^*_{i,SSR} - c^*_{i,B} = \frac{9kc^0-2}{9k-2} - \frac{16kc^0-3}{16k-3} = \frac{5(1-c^0)k}{6-59k+144k^2} < 0.$$

***Benchmark vs. D (JV)***

The Stackelberg-Leader invests more in cost reducing innovations than the firms in the benchmark case which invest more than the followers ($c^*_M < c^*_B < c^*_O$):

$$\begin{aligned} c^*_M - c^*_B &= \frac{3-4k-13kc^0+16k^2c^0}{3-17k+16k^2} - \frac{16kc^0-3}{16k-3} \\ &= \frac{(-1+c^0)k(-9+16k)}{-9+99k-320k^2+256k^3} < 0 \\ c^*_O - c^*_B &= \frac{3-3k-14kc^0+16k^2c^0}{3-17k+16k^2} - \frac{16kc^0-3}{16k-3} \\ &= -\frac{6(-1+c^0)k}{-9+99k-320k^2+256k^3} > 0 \end{aligned}$$

$$\Rightarrow c^*_M < c^*_B < c^*_O.$$

***Benchmark vs. CD***

The insider's investment in cost reducing innovations is higher than the one of a firm in the benchmark case which is again higher than the investment of the outsider ($c^*_M < c^*_B < c^*_O$):

$$\begin{aligned} c^*_M - c^*_B &= \frac{24-30k-110kc^0+125k^2c^0}{24-140k+125k^2} - \frac{16kc^0-3}{16k-3} \\ &= \frac{3(-1+c^0)k(-18+35k)}{-72+804k-2615k^2+2000k^3} < 0 \end{aligned}$$

$$\begin{aligned} c_O^* - c_B^* &= \frac{24 - 20k - 120kc^0 + 125k^2c^0}{24 - 140k + 125k^2} - \frac{16kc^0 - 3}{16k - 3} \\ &= -\frac{(-1 + c^0)k(24 + 55k)}{-72 + 804k - 2615k^2 + 2000k^3} > 0 \\ &\Rightarrow c_M^* < c_B^* < c_O^*. \end{aligned}$$

**Social surplus:**

Social surplus $W$ is given by the sum of the firm's profit plus consumer surplus, which is half the total quantity squared in our case of linear demand.

***Benchmark***

$$W_B = 3 \cdot \frac{k(1 - c^0)^2(-9 + 16k)}{(3 - 16k)^2} + \frac{1}{2}\left(3\frac{4(1 - c^0)k}{16k - 3}\right)^2 = \frac{3(1 - c^0)^2k(-9 + 40k)}{(3 - 16^k)^2}.$$

***SSR***

$$\begin{aligned} W_{SSR} &= 2 \cdot \frac{k(1 - c^0)^2(-4 + 9k)}{(2 - 9k)^2} + \frac{1}{2}\left(2 \cdot \frac{3(1 - c^0)k}{9k - 2}\right)^2 = \frac{4(1 - c^0)^2k}{-2 + 9k} \\ W_B - W_{SSR} &= \frac{(1 - c^0)k(18 - 99k + 56k^2)}{(3 - 16k)^2(-2 + 9k)}. \end{aligned}$$

Social surplus is thus larger in the benchmark case if $18 - 99k + 56k^2 > 0$, which is true for $k > 1.56209$.

***D(JV)***

$$\begin{aligned} W_D &= \frac{(1 - c^0)^2(3 - 4k)^2k(1 - 2k)}{(3 - 17k + 16k^2)^2} + \frac{(1 - c^0)^2(-1 + k)^2k(9 + 16k)}{(3 - 17k + 16k^2)^2} \\ &+ \frac{1}{2}\left(\frac{2(1 - c^0)k(-5 + 6k)}{3 - 17k + 16k^2}\right)^2 \\ &= \frac{3(1 - c^0)^2k(-6 + 42k - 75k^2 + 40k^3)}{(3 - 17k + 16k^2)^2} \\ W_B - W_D &= -\frac{3(1 - c^0)^2k(27 - 324k + 1302k^2 - 1984k^3 + 1024k^4)}{(9 - 99k + 320k^2 - 256k^3)^2} < 0. \end{aligned}$$

***CD***

$$\begin{aligned} W_{CD} &= \frac{3(-1 + c^0)^2(4 - 5k)^2k(-12 + 25k)}{(24 - 140k + 125k^2)^2} \\ &+ \frac{(-1 + c^0)^2(6 - 5k)^2k(-16 + 25k)}{(24 - 140k + 125k^2)^2} + \frac{1}{2}\left(\frac{10(1 - c^0)k(-9 + 10k)}{24 - 140k + 125k^2}\right)^2 \\ &= \frac{2(1 - c^0)^2k(-576 + 4276k - 7400k^2 + 3750k^3)}{(24 - 140k + 125k^2)^2} \end{aligned}$$

$$W_B - W_{CD}$$
$$= -\frac{(1-c^0)^2 k(5184 - 63018k - 248688k^2 - 339900k^3 - 113075k^4 + 45000k^5)}{(72 - 804k + 2615k^2 - 2000k^3)^2} < 0.$$

**Comparative statics:**

***Total quantity***

The overall output is decreasing with innovation costs in all cases:

$$\begin{aligned}
\frac{\partial X_B}{\partial k} &= \frac{\partial}{\partial k}\left(3 \cdot \frac{4(1-c^0)k}{16k-3}\right) = 12 \cdot \frac{-1+c^0}{(3-16k)^2} < 0 \\
\frac{\partial X_{SSR}}{\partial k} &= \frac{\partial}{\partial k}\left(2 \cdot \frac{3(1-c^0)k}{9k-2}\right) = 6 \cdot \frac{-1+c^0}{(2-9k)^2} < 0 \\
\frac{\partial X_D}{\partial k} = \frac{\partial X_{JV}}{\partial k} &= \frac{\partial}{\partial k}\left(\frac{2(1-c^0)k(-5+6k)}{3-17k+16k^2}\right) \\
&= 2 \cdot \frac{(-1+c^0)(15-36k+22k^2)}{(3-17k+16k^2)^2} < 0 \\
\frac{\partial X_{CD}}{\partial k} &= \frac{\partial}{\partial k}\left(\frac{10(1-c^0)k(-9+10k)}{24-140k+125k^2}\right) \\
&= 10 \cdot \frac{(-1+c^0)(216-480k+275k^2)}{(24-140k+125k^2)^2} < 0.
\end{aligned}$$

***Profits***

Differentiating firms' profits in the symmetric cases and outsider's profits with respect to innovation costs leads to:

$$\begin{aligned}
\frac{\partial \pi_B^*}{\partial k} &= \frac{\partial}{\partial k}\left(\frac{k \cdot (1-c^0)^2 \cdot (-9+16k)}{(3-16k)^2}\right) = \frac{3(-1+c^0)^2(9+16k)}{(16k-3)^3} > 0 \\
\frac{\partial \pi_{SSR}^*}{\partial k} &= \frac{\partial}{\partial k}\left(\frac{k \cdot (1-c^0)^2 \cdot (-4+9k)}{(2-9k)^2}\right) = \frac{8(-1+c^0)^2}{(9k-2)^3} > 0 \\
\frac{\partial \pi_{O,D}^*}{\partial k} &= \frac{\partial \pi_{O,JV}^*}{\partial k} = \frac{\partial}{\partial k}\left(\frac{(1-c^0)^2(-1+k)^2 k(9+16k)}{(3-17k+16k^2)^2}\right) \\
&= \frac{(-1+c^0)^2(-27+51k+63k^2-199k^3+112k^4)}{(3-17k+16k^2)^3} > 0 \\
\frac{\partial \pi_{O,CD}^*}{\partial k} &= \frac{\partial}{\partial k}\left(\frac{(-1+c^0)^2(6-5k)^2 k(-16+25k)}{(24-140k+125k^2)^2}\right) \\
&= \frac{4(-1+c^0)^2(-3456+2160k+19800k^2-34750k^3+15625k^4)}{(24-140k+125k^2)^3} > 0.
\end{aligned}$$

Thus, these firms benefit from increasing innovation costs. On the other hand, the derivative of insider's profit in case D (JV) and CD is negative and therefore they suffer losses from higher innovation costs:

$$\begin{aligned}
\frac{\partial \pi^*_{I,D}}{\partial k} &= \frac{\partial \pi^*_{I,JV}}{\partial k} = \frac{\partial}{\partial k}\left(\frac{(1-c^0)^2(3-4k)^2k(1-2k)}{(3-17k+16k^2)^2}\right) \\
&= -\frac{(-1+c^0)^2(-27-99k+144k^2-128k^3+64k^4}{3-17k+16k^2)^3} \\
\frac{\partial \pi^*_{I,CD}}{\partial k} &= \frac{\partial}{\partial k}\left(\frac{3(-1+c^0)^2(4-5k)^2k(-12+25k)}{(24-140k+125k^2)^2}\right) \\
&= -\frac{12(-1+c^0)^2(1152-3480k+5400k^2-550k^3+3125k^4}{(24-140k+125k^2)^3}.
\end{aligned}$$

**Optimal investment and quantities with integration problems:**
***SSR***

Optimal quantities in an asymmetric Duopoly are:

$$x^*_{i,SSR} = \frac{1-2c_i+c_j}{3},$$

leading to the profit function depending on investments in innovation:

$$\pi^*_{A,SSR} = \left(\frac{1-2c_A+c_B}{3}\right)^2 - K(c_A) = x^*_A(c_A)^2 - \alpha k(c_A-c^0)^2$$

$$\pi^*_{B,SSR} = \left(\frac{1-2c_B+c_A}{3}\right)^2 - K(c_B) = x^*_B(c_B)^2 - k(c_B-c^0)^2,$$

where A indicates the merged company and B the outsider.

This yields the first order conditions:

$$\frac{\partial \pi^*_A(c_A)}{\partial c_A} = -\frac{4}{9}\cdot(1-2c_A+c_B) - 2\alpha k\cdot(c_A-c^0) \stackrel{!}{=} 0$$

$$\frac{\partial \pi^*_B(c_B)}{\partial c_A} = -\frac{4}{9}\cdot(1-2c_B+c_A) - 2k\cdot(c_B-c^0) \stackrel{!}{=} 0.$$

Solving for $c_A$ and $c_B$ leads to:

$$c_A = -\frac{-4+6k+6c^0k+12\alpha c^0k-27\alpha c^0k^2}{4-12k-12\alpha k+27\alpha k^2}$$

$$c_B = -\frac{-4+6\alpha k+12c^0k+6\alpha c^0k-27\alpha c^0k^2}{4-12k-12\alpha k+27\alpha k^2}.$$

This leads to the optimal profits:

$$\pi^*_A = \frac{\alpha(1-c^0)^2k(2-3k)^2(-4+9\alpha k)}{(4-12k-12\alpha k+27\alpha k^2)^2}$$

$$\pi_B^* = \frac{(1-c^0)^2 k(-4+9k)(2-3\alpha k)^2}{(4-12k-12\alpha k+27\alpha k^2)^2}.$$

One easily verifies $c_A = c_B$ and $\pi_A = \pi_B$ for $\alpha = 1$.

Inserting the optimal marginal costs in equation for optimal quantities and adding up these quantities yields the total quantity:

$$X_{SSR,\alpha}^* = \frac{3k(-1+\alpha(-1+3k))}{4-12k-12\alpha k+27\alpha k^2}.$$

The resulting social surplus is:

$$\begin{aligned} W_{SSR,\alpha} &= \frac{1}{2}(X_{SSR,\alpha}^*)^2 + \pi_A + \pi_B \\ &= \frac{k(-8+27k+9\alpha^2 k(3-14k+18k^2) - 2\alpha(4-33k+63k^2))}{2(4-12k-12\alpha k+27\alpha k^2)^2}. \end{aligned}$$

***D***

Optimal quantities in an asymmetric Stackelberg market are

$$x_M^* = \frac{1-2c_M+c_O}{2}$$

of the merged company and

$$x_O^* = \frac{1-3c_O+3c_M}{4}$$

of the outsider. Resulting profits are:

$$\pi_{I,D}^*(c_M) = \frac{(1-2c_M+c_O)^2}{8} - K(c_M) = \frac{(1-2c_M+c_O)^2}{8} - \alpha k(c_M-c^0)^2$$

$$\pi_{O,D}^*(c_O) = \frac{(1-3c_O+2c_M)^2}{16} - K(c_O) = \frac{(1-3c_O+2c_M)^2}{16} - k(c_O-c^0)^2.$$

This yields the first order conditions:

$$\frac{\partial \pi_{I,D}^*(c_M)}{\partial c_M} = -\frac{1}{2}\cdot(1-2c_M+c_O) - 2\alpha k(c_M-c^0) \stackrel{!}{=} 0$$

$$\frac{\partial \pi_{O,D}^*(c_O)}{\partial c_O} = -\frac{3}{8}\cdot(1-3c_O+2c_M) - 2k(c_O-c^0) \stackrel{!}{=} 0.$$

Solving for $c_M$ and $c_O$ leads to:

$$\begin{aligned} c_M^* &= \frac{3-(4+(4+9\alpha)c^0)k+16\alpha k^2 c^0}{3-(8+9\alpha)k+16\alpha k^2} \\ c_O^* &= \frac{3-8kc^0+\alpha k(-3+2c^0(-3+8k))}{3-(8+9\alpha)k+16\alpha k^2}. \end{aligned}$$

Thus, optimal profits are:

$$\begin{aligned}
\pi^*_{I,D} &= \frac{\alpha(-1+c^0)^2 k(3-4k)^2(-1+2\alpha k)}{(3-(8+9\alpha)k+16\alpha k^2)^2} \\
\pi^*_{O,D} &= \frac{(-1+c^0)^2 k(-9+16k)^2(-1+\alpha k)^2}{(3-(8+9\alpha)k+16\alpha k^2)^2}.
\end{aligned}$$

Total output in case D is:

$$X^*_D = x^*_I + x^*_O = \frac{2(1-c^0)k(-2+\alpha(-3+6k))}{3-(8+9\alpha)k+16\alpha k^2}.$$

Social Surplus is:

$$\begin{aligned}
W_{D,\alpha} &= \frac{1}{2}(X^*_D)^2 + \pi^*_{I,D} + \pi^*_{O,D} \\
&= \frac{3(1-c^0)^2 k(-3+8k+\alpha(-3+k(22-32k+\alpha(12+k(-43+40k)))))}{(3-(8+9\alpha)k+16\alpha k^2)^2}.
\end{aligned}$$

***CD***

Using the profit functions derived in section 2.4 with changed innovation cost functions for the insider

$$\begin{aligned}
\pi^*_{I,CD} &= \frac{3}{25}(1+c_O-2c_M)^2 - \alpha k(c_M-c^0)^2 \\
\pi^*_{O,CD} &= \frac{1}{25}(1-4c_O+3c_M)^2 - k(c_M-c^0)^2,
\end{aligned}$$

we derive the first order conditions:

$$\begin{aligned}
\frac{\partial \pi^*_{I,CD}(c_M)}{\partial c_M} &= -\frac{12}{25}\cdot(1+c_O-2c_M) - 2\alpha k(c_M-c^0) \stackrel{!}{=} 0 \\
\frac{\partial \pi^*_{O,CD}(c_O)}{\partial c_O} &= -\frac{8}{25}\cdot(1-4c_O+3c_M) - 2k(c_O-c^0) \stackrel{!}{=} 0.
\end{aligned}$$

Solving for $c_M$ and $c_O$ leads to:

$$\begin{aligned}
c^*_M &= \frac{24-30k-30kc^0-80\alpha kc^0+125\alpha k^2c^0}{24-60k-80\alpha k+125\alpha k^2} \\
c^*_O &= \frac{24-20\alpha k-60kc^0-60\alpha kc^0+125\alpha k^2c^0}{24-60k-80\alpha k+125\alpha k^2}.
\end{aligned}$$

This yields the optimal profits:

$$\begin{aligned}
\pi^*_{I,CD} &= \frac{3\alpha(-1+c^0)^2(4-5k)^2 k(-12+25\alpha k)}{(24-60k-80\alpha k+125\alpha k^2)^2} \\
\pi^*_{O,CD} &= \frac{(-1+c^0)^2(-16+25k)k(6-5\alpha k)}{(24-60k-80\alpha k+125\alpha k^2)^2}.
\end{aligned}$$

Total output in case CD is:

$$X_D^* = x_I^* + x_O^* = \frac{10(1-c^0)k(-3+2\alpha(-3+5k))}{24-60k-80\alpha k+125\alpha k^2}.$$

Social Surplus is:

$$\begin{aligned}
&W_{CD,\alpha} = \frac{1}{2}(X_{I,CD}^*)^2 + \pi_{I,D}^* + \pi_{O,CD}^* \\
&= \frac{2(1-c^0)^2k(9(-32+75k)) + 50\alpha^2k(30-94k+75k^2) - 12\alpha(24-175k+225k^2)}{(24-60k-80\alpha k+125\alpha k^2)^2}.
\end{aligned}$$

# Chapter 3

# Acquisitions in a Patent Contest Model with Large and Small Firms

## 3.1 Introduction

In R&D intensive industries firms often do not only rely on their own research capabilities but use the results of competitors via licensing or even acquire other firms to directly benefit from their innovation efforts. Theoretical literature, based on transaction costs economics and property rights (Coase (1937), Arrow (1962)), argues that internal development and external sourcing are substitutes. Empirical evidence is mixed. Veugelers and Cassiman (1999) show that – especially large companies – use both internal and external sources for innovations. Roberts and Berry (1985) provide evidence that acquisition of small technology based companies is often used to get access to new innovative markets. In a study of the electronic and electrical equipment industries, Blonigen and Taylor (2000) find evidence for the substitutional character of acquisitions for internal R&D.

Different types of firms are likely to possess different advantages in a patent contest. While large firms typically have better access to product markets, small firms often have a superior R&D efficiency. The aim of this essay is to model these advantages and use them to explain acquisitions of small firms in innovative industries.

There are several empirical studies showing the superior R&D efficiency of small firms. Acs and Audretsch (1990) show that small firms contribute as many innovations as large firms and – in terms of innovations per employee – outperform large firms. They use a dataset by the U.S. Small Business Administration consisting of 8,074 innovations introduced in the United States in 1982. Rothwell (1989), Santarelli and Sterlacchini (1990), and van Dijk, den Hertog, Menkveld, and Thurik (1997) provide similar results for the UK, Italy, and the Netherlands, respectively.

Other studies from Cohen and Levin (1989) and Kamien and Schwartz (1982) also show that small firms can keep up with large firms in the field of innovation. They spend relatively more on R&D and are more efficient in using this R&D for innovative output.

An explanation for this superior R&D efficiency may be the less bureaucratic atmosphere in small firms. Creative minds tend to dislike paperwork and may be frustrated and therefore less effective in a large firm where reporting and formal documentation is necessary (see Ernst and Vitt (2000)). Furthermore, the organization of internal communication – which can be less formal in small companies – encourages faster and more creative ways of problem solving and a fast adaptation to changes in the external environment (see Rothwell and Zegveld (1982)).

On the other hand, large firms have a better position in the product market. An explanation given by Rothwell (1989) are large firms' comprehensive distribution networks and service facilities. Economies of scope puts them in a superior position. They can offer a range of complementary products and use their market power of existing products. Moreover, in case of a patent infringement, they can afford to litigate in order to defend their patents and avoid misuse. What is more, the marketing of complex high technology goods often requires a qualified after sales service difficult to provide for small firms.

These different advantages immediately lead to the question of cooperations between firms. Lindholm (1996a, 1996b) shows for a Swedish case that small firms actively engage in being taken over by large firms to get access to international markets and use their global market presence. A recent analysis of an acquisition in the optics industry also shows the problem of small firms (Competition Commission (2004)). Bio Rad's microscopes business unit was acquired by Zeiss. Although this business unit was in possession of important licenses in 3D light microscope systems, the unit was not profitable. One of the reasons was that this unit was not providing own microscope stands but only equipping competitors' stands with their technique. A very critical detail in the commission's analysis is the conclusion that Bio Rad would not remain an independent supplier in the long run whether or not the merger takes place. The small business unit did not have enough capacities to survive in this market alone. Therefore – if the merger was blocked – Bio Rad's microscopes business unit would either drop out of the market or eventually get acquired by a different competitor.

Our essay is related to the patent races and patent contest literature. Reinganum (1989) provides a very good overview of this literature up to that point. More recent literature on patent races focuses on optimal patent design (Denicolò (1996)) and races with multiple prizes (Dorazelski (2003), Hörner (2004)). In the latter literature, firms' past R&D efforts influence their chances in a new race. This improves the description of the dynamics of innovation competition. Zachau (1987) analyzes mergers using a simple patent race model. Firms are symmetric at start but a merger is assumed to have synergetic effects and increases R&D efficiency of the merged firm. He allows for mergers of any number of firms and shows that in an $n$-firm industry the number of firms merging that maximizes merged firm's profits is typically less than $n$. Jost and van der Velden (2006) provide a similar analysis using a contest model proposed by Dixit (1987). As in Zachau's paper a merger is assumed to increase R&D efficiency of the merged firm. They show that only little efficiency gains are needed to make a bilateral merger profitable. They also show that in the presence of knowledge spillovers more efficiency gains are needed to make a merger profitable. In contrast to both these papers, our model starts with an asymmetric situation where firms possess different advantages. Furthermore, we allow for a sequence of acquisitions to analyze the strategic effect of a merger. Nilssen and Sørgard (1998) analyze sequential acquisitions, in particular the strategic impact of an acquisition on subsequent merger decisions. The authors show in a linear Cournot model that the decision to merge or not to merge can either trigger or prevent follow-up merger. A recent example from the telecommunications industry is the acquisition of Tele Atlas by TomTom,[1] which at least partly triggered the acquisition of Tele Atlas' competitor Navteq by Nokia.[2] Fumagalli and Nilssen (2008) also analyze strategic waiting in a merger game. Depending on the cost advantages of firms and the position of the antitrust authority towards mergers there are three different effects that induce firms to pass up on an opportunity to merge. We do also analyze the strategic effect of an acquisition but in contrast to both these papers we focus on

[1]See for example Tele Atlas' press release under: http://www.teleatlas.com/WhyTeleAtlas/Pressroom/PressReleases/TA_CT018103.

[2]See for example Nokia's press release under: http://www.nokia.com/A4136002?newsid=-6233.

the implications of mergers on the innovation market.

In this essay, we model a patent contest with heterogenous competitors. There are small research firms that have a better R&D efficiency and large firms that benefit from their better access to the product market. We use the Dixit (1987) model to describe the contest but in contrast to Jost and van der Velden (2006) we allow for initial differences in R&D efficiency. To the best of our knowledge there exists no paper that deals with this kind of asymmetry in an R&D contest.[3] Firms compete for an exclusive patent that gives them a fixed return in the product market. In contrast to Jost and van der Velden, the amount of this return depends on the product market power of the winning firm. Prior to the innovation stage, we allow for acquisitions of small firms by large firms. Large firms sequentially bid for small firms. After an acquisition the merged firm combines the respective advantages of large and small firms. Thus, heterogeneity of firms is the source of efficiencies from a merger. We show that the resulting market structure depends on efficiencies. For high efficiencies both large firms prefer to acquire immediately leading to a symmetric market structure. For low efficiencies strategic waiting of the first large firm leads to an asymmetric market structure.

The essay is organized as follows: The next section presents the patent contest and the way respective advantages for large and small firms are modeled. Then, the game structure is described and the game is solved. Thereafter, we analyze the impact of timing on results of the game. The final section concludes, discusses limitations of our model, and points out interesting topics for further research.

## 3.2 Model

In the initial setup there are two identical small firms $S_1$ and $S_2$ and two identical large firms $L_1$ and $L_2$. Firms are competing for an exclusive prize $V_i$. They simultaneously choose an effort level $z_i$ which affects their own – and thus competitors' – chances of winning the contest. The probability of winning is the own effort level

[3] Asymmetry in an R&D race is often modeled with an incumbent and an entrant in a market, usually with some advantages for the incumbent. See for example Gilbert and Newberry (1982) or Harris and Vickers (1985).

divided by the sum of all efforts multiplied by an innovation efficiency parameter $\alpha_i < 1$, thus

$$p_i = \alpha_i \cdot \frac{z_i}{\sum z_j} \qquad i = 1, ..., n.$$[4]

Throughout the essay we assume that large firms have advantages in the product market by realizing a value $V_L$ if they win the contest, while small firms only realize a value $V_S < V_L$. On the other hand, small firms have a greater chance of winning the contest with the same investment in R&D, i.e., $\alpha_S > \alpha_L$. We assume that overall efficiency is the same for large and small firms:[5]

$$\alpha_S \cdot V_S = \alpha_L \cdot V_L$$

or

$$\alpha_S = x \cdot \alpha_L \text{ and } V_S = \frac{V_L}{x}, \tag{3.1}$$

where $x > 1$ is a measure of difference between large and small firms, which is the source of efficiencies of mergers. Thus, $x$ is the potential efficiency of a merger. To simplify notation in the following $\alpha_S := \alpha$ and $V_S := V$ is used. In the next section we first describe the time structure of the game. Then, the R&D games for different outcomes of the acquisition game are analyzed. Finally, the game is solved by backward induction to find sub-game perfect strategies for the bidding of large firms and acceptance decisions of small firms.

### 3.2.1 Sequential Acquisitions

In this section we analyze sequential acquisitions. There are two stages in the game: The acquisition stage where large firms bid to acquire small firms and the R&D stage where remaining independent firms make their investment decisions. An acquisition is assumed to have the following effect: The large firm quits its own research and only uses the small firm's research facilities. Thus, the firm can now operate with the high research ability $\alpha_S$ and at the same time using the large firm's market power, meaning that winning the contest leads to a prize $V_L$. The number of active firms in the market is reduced by one. This way of modeling the acquisition can also be

[4]As $\alpha_i$ is smaller than 1 there is a chance that no firm will win the patent contest.

[5]This assumption is made to keep the model analytically tractable and it is clearly restricting. However, from our results tendencies for more general cases can be deviated. If overall efficiency is different, the efficiency effect of an acquisition is increased.

interpreted as ex ante licensing or contract research.[6] The acquisition has both a positive and a negative effect on the merged company. The positive one, which we call efficiency effect, is that it now operates more efficiently than its competitors in the innovation or the product market. The negative one, which we call concentration effect, is that the former two firms now only operate as one.[7] Without efficiencies, this leads to a loss in terms of expected profits for the merged company. The reason is that before the merger, both the large and the small firm had a chance to win the contest while now there is only one firm competing in the contest. The merger exhibits externalities on the outsiders. While they suffer from the efficiency effect, the externality of the concentration effect is positive.[8] A second acquisition by the same large firm has no effect on its R&D efficiency as the merged firm is already using the small firms R&D facilities. The acquisition just reduces the number of competitors again and prevents the other large firm from enjoying the efficiencies of a merger. It is assumed that a large firm cannot buy the other large firm for reasons of competition law.

In the acquisition stage large firms successively bid for small firms. After each bid the small firm decides whether to accept the offer or not. We assume that the game starts with the first large firm's bid for the first small firm. Each large firm only bids one time for each small firm. The acquisition game ends either when both small firms are acquired or both large firms made their bids for both small firms.[9] After the acquisition game the remaining independent firms make their investments in the patent contest. The game structure is summarized in figure 3.1. Each decision point is numbered to make reference in the acquisition section. Large firms

[6]Important for our way of modeling is that the small firm still performs R&D in the same way as before the acquisition. Otherwise, the superior R&D efficiency would be lost.

[7]Without efficiencies investment of the merged firm is smaller than combined investment of the two former independent firms. The result is comparable to the output reduction and subsequent reduced profit of a merged firm in the Salant, Switzer, and Reynolds (1983) model without cost efficiencies.

[8]This externality is also comparable to Salant et al. (1983). Without cost efficiencies, the outsider reacts to the output reduction of the merged firm with an expansion of her own output and therefore her profits rise.

[9]The resulting market structure in equilibrium is the same for most parameter values if the acquisition game is simplified in a way that large firms just pay the current expected profits of small firms when they want to acquire. That is, if small firms do not expect further changes in the market structure and act myopic in the acquisition game.

have the possibility to bid continuously, $p_{ij} \in [0, \infty)$. Strategies for small firms are Accepting (A) and Denying (D) the offers.

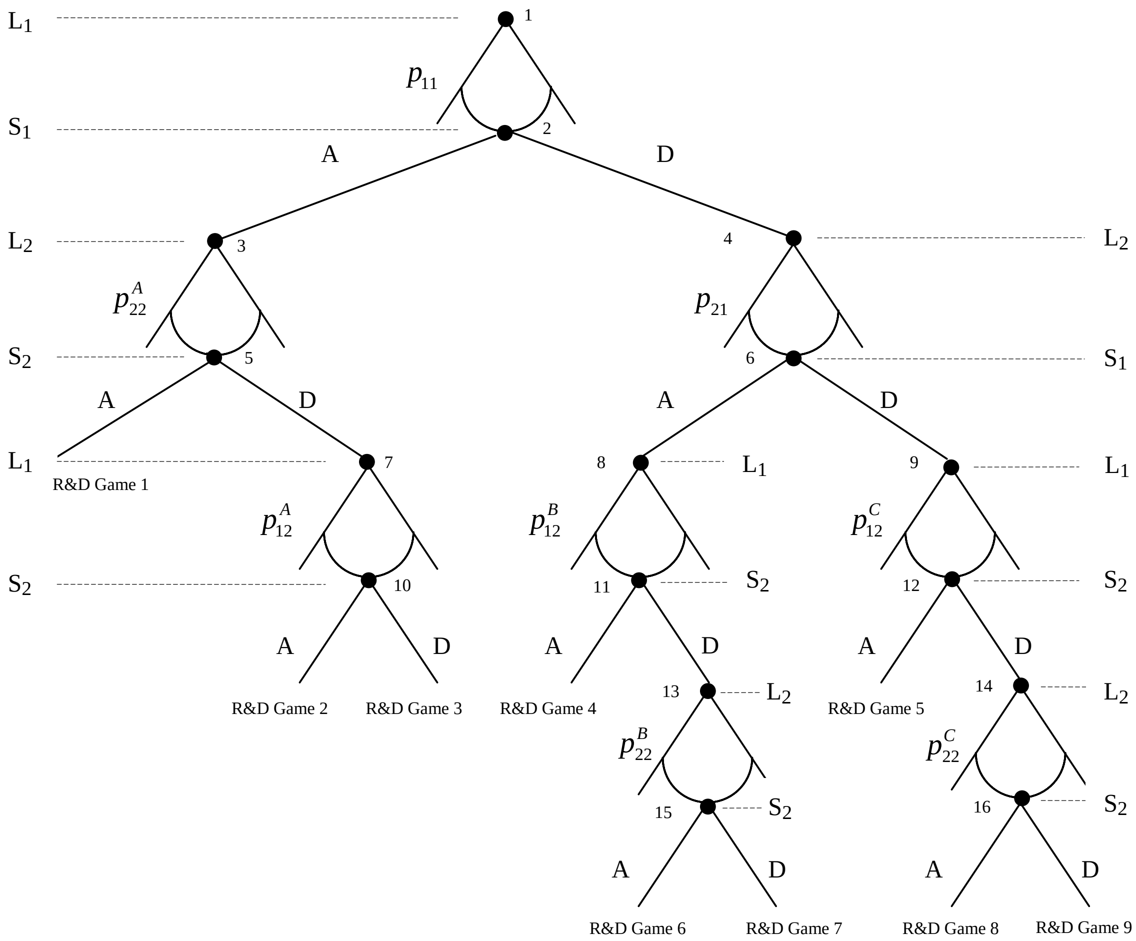


Figure 3.1: Game structure.

#### 3.2.1.1 R&D Games - Second Stage

To deduct optimal investment and acquisition strategies, the game is solved by backward induction. In this section optimal investment strategies and resulting expected profits of the R&D game for all possible outcomes of the acquisition game are derived. Firms choose $z_i$ in order to maximize their expected profits

$$E[\pi_i] = p_i \cdot V_i - z_i = \alpha_i \cdot \frac{z_i}{\sum z_j} \cdot V_i - z_i \qquad i = 1, ..., n \qquad (3.2)$$

which yields the first order conditions:

$$\alpha_i \cdot \frac{\sum_{j \neq i}^{n} z_j}{(\sum_j z_j)^2} \cdot V_i - 1 \stackrel{!}{=} 0 \qquad\qquad i = 1, ..., n. \tag{3.3}$$

Firms thus increase their investments in R&D in order to improve their chances to win the contest until marginal benefits of the investments equal marginal costs.

If no firm decides to merge, there are four active firms in the market: Two respectively identical small and large firms. This is the situation in R&D game 9. Using assumption (3.1), first order conditions (3.3) can be solved for

$$z_i = \frac{\alpha \cdot V}{16} \qquad i = 1, ...4.$$

Thus, both types of firms invest the same in R&D as their overall efficiency is the same. Inserting equilibrium investments in the profit functions (3.2) yields[10]

$$E[\pi_S^{R\&D_9}] = E[\pi_L^{R\&D_9}] = \frac{\alpha V}{16}.$$

In R&D games 1 and 4 each of the small firms is acquired by one large firm, i.e., we have a situation where only two identical firms remain in the market. Both have small firms' R&D efficiency $\alpha$ and large firms' product market efficiency $V_L = x \cdot V$. Using these parameters in equations (3.3) yields the first order conditions

$$\alpha \frac{z_j}{(z_i + z_j)^2} - \frac{1}{x \cdot V} \stackrel{!}{=} 0 \qquad i = 1, 2. \tag{3.4}$$

With $z_1 = z_2$ due to symmetry equations (3.4) can be solved for

$$z_1 = z_2 = \frac{\alpha x V}{4}.$$

Resulting expected profits are

$$E[\pi_M^{R\&D_1}] = \frac{\alpha x V}{4}.$$

Small firms get the price the large firms bid in the acquisition game as payoffs. This is important for small firms' acceptance decisions in the first stage of the game.

[10] We use the indices S, L, and M to denote small, large, and merged firms respectively.

In R&D games 3, 5, 7, and 8 only one large firm acquires one small firm, the other two firms stay independent. The respective first order conditions for the small, the merged, and the large firm are

$$\begin{aligned}
\alpha \frac{z_L + z_M}{(z_S + z_L + z_M)^2} - \frac{1}{V} &\overset{!}{=} 0 \\
\alpha \frac{z_S + z_L}{(z_S + z_L + z_M)^2} - \frac{1}{xV} &\overset{!}{=} 0 \\
\frac{\alpha}{x} \frac{z_S + z_M}{(z_S + z_L + z_M)^2} - \frac{1}{xV} &\overset{!}{=} 0.
\end{aligned}$$

Solving for $z_S$, $z_L$, and $z_M$ yields

$$\begin{aligned}
z_S &= z_L = \frac{2\alpha x V}{(1+2x)^2} \\
z_M &= \frac{2\alpha x V}{(1+2x)^2}(2x-1).
\end{aligned}$$

Thus, the merged firm invests more than its competitors. Resulting profits are

$$\begin{aligned}
E[\pi_S^{R\&D_3}] &= E[\pi_L^{R\&D_3}] = \frac{\alpha V}{(1+2x)^2} \\
E[\pi_M^{R\&D_3}] &= \frac{\alpha x V}{(1+2x)^2}(2x-1)^2.
\end{aligned}$$

As with investments, the expected profit of the merged firm is larger since $x > 1$. The acquired small firm gets the price bid in the acquisition game as payoff.

In R&D games 2 and 6 one large firm acquires both small firms. There is thus one firm with high and one firm with low R&D efficiency in the market. Both firms have high product market efficiency. That yields the first order conditions

$$\begin{aligned}
\frac{\alpha}{x} \frac{z_M}{(z_L + z_M)^2} - \frac{1}{xV} &\overset{!}{=} 0 \\
\alpha \frac{z_L}{(z_L + z_M)^2} - \frac{1}{xV} &\overset{!}{=} 0.
\end{aligned}$$

Solving for $z_L$ and $z_M$ yields

$$\begin{aligned}
z_L &= \frac{\alpha x V}{(1+x)^2} \\
z_M &= \frac{\alpha x^2 V}{(1+x)^2}.
\end{aligned}$$

Resulting expected profits are

$$E[\pi_L^{R\&D_2}] = \frac{\alpha V}{(1+x)^2}$$
$$E[\pi_M^{R\&D_2}] = \frac{\alpha x^3 V}{(1+x)^2}.$$

As before in the triopoly game, the more efficient firm invests more in R&D and has higher expected profits. Small firms get the price the acquiring large firm bid in the acquisition game as payoffs.

If a large firm acquired one or two small firms, the price it paid has to be subtracted from its expected profits in order to make payoffs comparable.

#### 3.2.1.2 Acquisition Game - First Stage

Large firms decide on their bid in each decision point; small firms make their acceptance decisions.[11] In the acquisition game there are two critical barriers for the bids of large firms and acceptance decisions of small firms. The first is the profit of an independent firm if no acquisition takes place: $p_N = \frac{\alpha V}{16}$; the second is the profit of an outsider in a triopoly: $p_O = \frac{\alpha V}{(1+2x)^2}$.[12] These are the two possible expected profits a small firm can achieve if it has not been acquired and remains an independent firm in the R&D game.

**Proposition 3.1.** *In subgame-perfect equilibrium the acquisition game ends in a symmetric duopoly with accepted bids* $p_{11} = p_{22} = p_O$ *for* $x \geq 1.18731$ *and the two firms* $\{L_1, S_1\}$ *and* $\{L_2, S_2\}$*, in an asymmetric duopoly with accepted bids* $p_{21} = p_{22} = p_O$ *for* $1.18731 > x \geq 1.05678$ *and accepted bids* $p_{21} = p_N$*,* $p_{22} = p_O$ *for* $1.0333 > x$ *and the two firms* $\{L_1\}$ *and* $\{L_2, S_1, S_2\}$*, and in a triopoly where only* $S_2$ *is acquired for* $p_{22} = p_N$ *if* $1.05678 > x \geq 1.0333$ *with the three firms* $\{L_1\}$*,*$\{S_2\}$ *and* $\{L_2, S_2\}$.

*Proof.* See the appendix.

The resulting sub-game perfect equilibria can be characterized as follows. For high efficiencies ($x \geq 1.18731$) large firms bid $p_O$ in every decision point (except

[11] If a large firm is indifferent concerning acquiring and not acquiring, we assume it is acquiring; if a small firm is indifferent concerning accepting and denying an offer, we assume it is accepting.

[12] Note that $p_N \leq p_O \Leftrightarrow x \leq 1.5$. Thus, small firms only prefer $p_N$ to $p_O$ for very high efficiencies.

for the decision point 14 where $L_2$ bids $p_N$) and the small firms accept every offer greater or equal than this offer. The reason for these equilibrium strategies is that for large efficiencies every merger is beneficial for the merging parties and it would also be beneficial to prevent the other firm from enjoying these efficiencies (off the equilibrium path strategies).

For lower efficiencies large firms prefer the other large firm to acquire. For intermediate efficiencies ($1.18731 > x \geq 1.05678$), even if the first acquisition would still be beneficial, the positive externality of the concentration effect exceeds the negative externality of the efficiency effect making it more profitable to let the other firm acquire. Therefore, $L_1$ never acquires in decision point 1. $L_2$ has the disadvantage of making the final offer to $S_1$. It is more profitable for $L_2$ to acquire both firms than to wait and let the acquisition game end up with three or four independent firms. On the equilibrium path $L_2$ therefore always bids $p_O$ in decision points 4 and 13 and acquires $S_1$ and $S_2$.

For even lower efficiencies ($1.05678 > x \geq 1.0333$) it is too costly for $L_2$ to acquire both small firms for $p_O$. However, $S_1$ is not accepting the lower offer $p_N$ in decision point 6 knowing that if it denies the offer, $L_2$ later acquires $S_2$ (for $p_N$) giving $S_1$ profits $p_O$. Therefore, the game ends in a triopoly for these parameter values. Thus, the fact that $S_1$ knows that $L_2$ will acquire $S_2$ later in the game increases the price $L_2$ has to pay for $S_1$. Therefore, it is no longer profitable for $L_2$ to acquire both small firms.

If efficiencies are in the lowest segment ($1.0333 > x$), it is no longer profitable for $L_2$ to acquire only one small firm, even for $p_N$. However, it is still profitable for $L_2$ to acquire both small firms (one for $p_N$, the other for $p_O$). Expecting that $L_1$ will not acquire $S_2$ if it has not already acquired $S_1$, $S_1$ is accepting the offer $p_N$ in decision point 6. In this case and the game ends in an asymmetric duopoly again.

Although consumer welfare is not explicitly included in the model, it is possible to compare potential outcomes of the acquisition game by the probability of a successful innovation. This probability for the four possible outcomes of the acquisition game is

$$p^1_{ges} = \alpha \cdot \left(\frac{\frac{\alpha x V}{4}}{2\frac{\alpha x V}{4}}\right) \cdot 2 = \alpha$$

in the symmetric duopoly,

$$p^2_{ges} = \left(\frac{\alpha}{x} \cdot \frac{\alpha x V}{(1+x)^2} + \alpha \cdot \frac{\alpha x^2 V}{(1+x)^2}\right) \frac{1}{\frac{\alpha x V}{(1+x)^2}} = \frac{\alpha(1+x^2)}{x(1+x)}$$

in the asymmetric duopoly,

$$\begin{aligned} p^3_{ges} &= \left(\left(\alpha + \frac{\alpha}{x} \cdot \frac{2\alpha x V}{(1+2x)^2}\right) + \alpha \cdot \frac{2\alpha x V}{(1+2x)^2}(2x-1)\right) \frac{1}{2 \cdot \frac{2\alpha x V}{(1+2x)^2} + \frac{2\alpha x V}{(1+2x)^2}(2x-1)} \\ &= \frac{\alpha(1+2x^2)}{x(1+2x)} \end{aligned}$$

in the triopoly, and

$$p^4_{ges} = 2 \cdot \left(\alpha + \frac{\alpha}{x}\right) \frac{\frac{\alpha \cdot V}{16}}{4 \cdot \frac{\alpha \cdot V}{16}} = \frac{\alpha(1+x)}{2x}$$

in the initial situation with four independent firms.

**Proposition 3.2.** *The probability of a successful innovation is highest in the symmetric duopoly, followed by the triopoly and the asymmetric duopoly. Chances are lowest in the initial situation with four independent firms.*

*Proof.* The elements of the proposition are shown consecutively:

$$\begin{aligned} p^1_{ges} - p^3_{ges} &= \alpha - \frac{\alpha(1+2x^2)}{x(1+2x)} = \frac{\alpha(x-1)}{x(1+2x)} > 0, \\ p^3_{ges} - p^2_{ges} &= \frac{\alpha(1+2x^2)}{x(1+2x)} - \frac{\alpha(1+x^2)}{x(1+x)} = \frac{\alpha(x-1)}{1+3x+2x^2} > 0, \\ pp^2_{ges} - p^4_{ges} &= \frac{\alpha(1+x^2)}{x(1+x)} - \frac{\alpha(1+x)}{2x} = \frac{\alpha(x-1)^2}{2x(1+x)} > 0. \end{aligned}$$

Thus, $p^1_{ges} > p^3_{ges} > p^2_{ges} > p^4_{ges}$. □

The intuition for this result is that the total probability of a successful innovation is influenced by two effects in the model: First, a higher investment by firms with a high R&D efficiency and second, elimination of firms with low R&D efficiency in the R&D games. A policy that favors at least one acquisitions is therefore beneficial for innovation in this model.

For all asymmetric cases, payoffs are larger for $L_1$ than for $L_2$. In the symmetric case, payoffs are identical. Thus, there is a first-mover advantage in the game for large firms. Small firms' payoffs are identical for $x \geq 1.05678$. If $1.05678 > x > 1.0333$, $S_1$ can profitably deny a low offer of $L_2$ and get a higher profit as an independent firm than $S_2$ that gets acquired in equilibrium. For even lower efficiencies $S_1$ can no longer profitably deny a low offer and the situation turns around as then the price of $S_2$ that gets acquired later is higher. Thus, there is no clear first-mover advantage or disadvantage for small firms.

### 3.2.2 Robustness

In this section we check for the sensitivity of results to the proposed timing structure in the acquisition game. We first generally discuss the strategic effect of the known timing structure, especially that $L_1$ firm knows that there is still a bidding decision of $L_2$ after its second bid while $L_2$ knows that the acquisition game ends after its second bid. Then, we analyze an alternative modeling with simultaneous acquisition decisions.

#### 3.2.2.1 Time Structure

In this section we analyze the impact of the time structure on the game's results. Timing influences firms' strategic decisions. In section 3.2.1.2 we found that payoffs for $L_1$ and $L_2$ differ for low efficiencies and there is a first-mover advantage since $L_1$ can simply wait to let $L_2$ acquire one or both small firms and benefit from the externalities of the merger. It is crucial for $L_1$'s strategic decision to wait that it knows that $L_2$ cannot simply wait as well but will acquire either one or both small firms since this is more profitable than not acquiring at all and leaving the situation with four independent firms for $L_2$. If there was no such final bidding round in the acquisition game, a hold up problem between $L_1$ and $L_2$ would occur: The first large firm to acquire would make less expected profits and thus both firms would wait for the other firm to move.

#### 3.2.2.2 Simultaneous Acquisitions

A way to react to the problem of a first-mover advantage in the acquisition game – which is somehow critical since firms are ex ante symmetric – is to let large firms decide simultaneously whether to acquire one of the small firms or not.[13] That is described in this section.

If both large firms decide to acquire, the number of firms is reduced from four to two. Both merged firms enjoy the same efficiencies and the resulting situation is

[13]We abstract from the coordination problem which small firm is acquired by which large firm.

symmetric. If only one firm decides to acquire, we have an asymmetric situation with one large, one small, and the merged firm. If no large firm decides to acquire, the situation remains unchanged.

**R&D Stage**

Investments depend on the market structure after the acquisition stage. Optimal investments and resulting expected profits are the same as in the equivalent situations arising from sequential acquisitions.

**Both large firms acquire:** In this situation only two identical firms remain in the market. Both companies have small firms' R&D efficiency $\alpha_S$ and large firms' product market efficiency $V_L = x \cdot V_S$. The situation is equivalent to the situation in R&D game 1 described above. Therefore resulting expected profits are

$$E[\pi_M^{R\&D_1}] = \frac{\alpha x V}{4}.$$

**Only one large firm acquires:** This is an asymmetric situation with one large, one small, and the merged firm. The situation is equivalent to the R&D game 3 described above. Resulting expected profits are thus

$$E[\pi_M^{R\&D_3}] = \frac{\alpha x V}{(1+2x)^2}(2x-1)^2$$

for the merged firm and

$$E[\pi_S^{R\&D_3}] = E[\pi_L^{R\&D_3}] = \frac{\alpha V}{(1+2x)^2}$$

for the outsiders.

**No large firm acquires:** In this case, there are four firms in the market, two small firms with higher R&D efficiency and two large firms with superior product market efficiency. The situation is equivalent to R&D game 9 and therefore expected profits are

$$E[\pi_S^{R\&D_9}] = E[\pi_L^{R\&D_9}] = \frac{\alpha V}{16},$$

both for large and small firms.

### Acquisition Stage

Taking optimal decisions in the investment stage as given, expected profits for the three situations described above are given in the following matrix (table 3.1). To make results comparable, we show the combined profits of one large and one small firm in the non-acquisition cases.[14]

| | | $L_2$ | | | |
|---|---|---|---|---|---|
| | | Acquire | | Not Acquire | |
| $L_1$ | Acquire | $\frac{\alpha x V}{4}$ | $\frac{\alpha x V}{4}$ | $\frac{\alpha x V}{(1+2x)^2}(2x-1)^2$ | $2\frac{\alpha V}{(1+2x)^2}$ |
| | Not Acquire | $2\frac{\alpha V}{(1+2x)^2}$ | $\frac{\alpha x V}{(1+2x)^2}(2x-1)^2$ | $2\frac{\alpha V}{16}$ | $2\frac{\alpha V}{16}$ |

Table 3.1: Payoffs for the simultaneous acquisition game.

Looking at the payoffs for $L_1$ if $L_2$ acquires, we see that

$$\frac{\alpha x V}{4} - 2\frac{\alpha V}{(1+2x)^2} = \frac{1}{4}\alpha V \left( x - \frac{8}{(1+2x)^2} \right) > 0$$

for $x > 1$. Thus, it is always optimal to acquire if the other large firm is acquiring. If $L_2$ does not acquire, we see that

$$\frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - 2\frac{\alpha V}{16} = \alpha V \left( \frac{(2x-1)^2 x}{(1+2x)^2} - \frac{1}{8} \right) > 0$$

for $x > 1.0333$. Thus, for $x > 1.0333$ "Acquire" is a strict dominant strategy for large firms. If $x \leq 1.0333$, the game has two Nash-Equilibria in pure strategies (Acquire, Acquire) and (Not Acquire, Not Acquire).[15] The intuition for this result is that with enough efficiencies a merger by itself is profitable and therefore each of the large firms wants to acquire a small firm. The result is therefore comparable to the one with sequential acquisitions. For high efficiencies large firms want to acquire no matter how the other large firm is responding. If efficiencies are low, the negative effect that two former independent firms now operate as one overweighs the efficiency effect such that firms prefer not to merge unless the other firms merge as well.

[14] This is equivalent to an analysis with a bidding price $p_0$ if the other large firm acquires and a price $p_N$ if the other large firm does not acquire.

[15] There is also an equilibrium in mixed strategies which is not of particular interest in this analysis.

## 3.3 Conclusion

This essay analyzes innovation incentives for large and small firms in different strategic contexts. We model a patent contest with four heterogeneous firms and a fixed prize for the winner. Small firms have a superior R&D efficiency while large firms benefit from a better product market power. This presumption of asymmetries between large and small firms led to questions of cooperations. Therefore we allow large firms to bid in order to acquire small firms in the acquisition stage prior to the innovation stage.

In the first setup, large firms sequentially decide on acquiring small firms in order to combine the respective advantages of each type of firm. While the reduction of competitors exhibits a positive effect on the outsiders of that merger, the merged firm is now at least as efficient as competitors in one sector and more efficient in the other. We show that firms prefer to merge if the merger creates large efficiencies. For intermediate levels of efficiencies the first acquisition is still beneficial. However, the first large firms prefers to pass up on the opportunity to merge and to let the other firm acquire. This is due to the positive externality of the concentration effect. So the first large firm free rides on the acquisition activities of the second large firm. The probability of a successful innovation is enhanced by the acquisition process and highest in the symmetric duopoly. In the sequential acquisition game there is a first-mover advantage since the second large firm prefers to acquire at least one small firm than to leave the market unchanged with four independent firms.

If the acquisition decision is simultaneous, results are comparable: For large efficiencies there exists only one equilibrium in dominant strategies where both large firms acquire. For low efficiencies there are two equilibria in pure strategies. In one equilibrium both small firms are acquired. Pairwise merging is beneficial as both merged firms enjoy the externality of the reduction of firms in the contest. In the other equilibrium, however, no small firm is acquired. The reason is that efficiencies are too low and therefore the acquisition is only beneficial if the other small firm is acquired as well. Of course, the effect of strategic waiting disappears as the acquisition decision is simultaneous.

Our model has several limitations. First, we use a contest model in the R&D game. This simplification allows to focus on the different effects a merger has on different types of firms and to get closed form solutions in all analyzed cases. This comes to the expense that timing effects of R&D investments cannot be analyzed.

Second, we assume product market profits to be fixed. While this simplification is used in various papers analyzing R&D incentives, it is still a critical assumption. This is particularly relevant as we model acquisitions, i.e., events that change the market structure and which are therefore likely to have an effect on the product market and thus on firms' profits.

We do not model spillovers in the patent contest. However, the effects of spillovers in this model is straightforward. Since merged firms invest more in the contest, there is more knowledge to spill over from these firms on competitors. Thus, the inclusion of spillovers in this model leads to a reduction of efficiencies and therefore reduces incentives to merge. This is in line with the results of Jost and van der Velden (2006).

Finally, acquisitions are modeled as simply as possible. Potential inefficiencies of an acquisition are not modeled and the merged firm enjoys complete advantages of both types of firms in the contest. Changes to these assumptions would lead to a dramatic increase in the complexity of the model – particularly with regards to the sequential acquisition game – but would not lead to more insights. On the contrary, it could hinder the insights with respect to the effects we want to focus on.

The results of our essay lead to questions concerning the organization of R&D in large and small companies. Why do small and large firms have these advantages and how can the firms strategically act to improve their advantages or to reduce disadvantages? Furthermore, we totally abstracted from reorganization issues connected with the merger. What exactly happens after a merger? Which advantages can be kept, which might be lost and what trade-offs does the merged firm face? A theoretical model that answers these questions would be very helpful to improve the understanding of different R&D approaches. What is more, it could help to allocate (public) R&D funds to the most promising approaches.

We have seen that strategic waiting of firms to merge might delay acquisitions. A negative position of competition authorities towards mergers, demanding remedies to clear mergers which decrease efficiencies, might even increase reluctance of firms to merge. However, in our model acquisitions lead to increased chances of a successful innovation, with potential benefits to consumers. Therefore, we think that our essay provides another argument in favor of a more dynamic analysis in merger clearance decisions.

## 3.4 Appendix

*Proof of Proposition 3.1.* To prove proposition 3.1, the acquisition game is solved by backward induction, taking optimal decisions in the R&D stage as given.

At decision point 16 $S_2$ has to decide whether to accept the price $p_{22}^C$ offered by $L_2$ or denying the offer and getting a payoff of $\frac{\alpha V}{16}$. Thus, $S_2$ accepts every offer $p_{22}^C \geq p_N$ and denies any other offer.

Expecting this decision from $S_2$, $L_2$ makes her offer in decision point 14. If $S_2$ denies the offer, the game ends without any acquisition and $L_2$ gets the payoff $\frac{\alpha V}{16}$. If $S_2$ accepts, $L_2$ gets the payoff of R&D game 8, the triopoly with one merged, one small, and one large firm. If $L_2$ decides to acquire, it makes the lowest offer $S_2$ accepts, i.e., $p_{22}^C = p_N$. Thus, $L_2$ decides to make an offer if

$$\frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - \frac{\alpha V}{16} \geq \frac{\alpha V}{16}.$$

This inequality holds for $x \geq 1.0333$.

If $S_2$ accepts the offer in decision point 12, it gets the payoff $p_{12}^C$. If not, it either gets $p_{22}^C = p_N$ if $x \geq 1.0333$ resulting from an acceptable offer by $L_2$ or $\frac{\alpha V}{16}$ if $x < 1.0333$ as an independent firm in R&D game 9. Thus, $S_2$ accepts any offer by $L_1$ that is greater or equal than $p_N$.

In decision point 9 $L_1$ has to offer at least $p_{12}^C = p_N$ if it wants $S_2$ to accept. If $S_2$ accepts the bid, $L_1$'s payoff is

$$\frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - p_{12}^C.$$

If $S_2$ denies the offer, $L_1$ gets the payoff of an outsider in R&D game 8 when $x \geq 1.0333$, i.e., in the situation where $L_2$ decides to acquire in decision point 14. This payoff is

$$\frac{\alpha V}{(1+2x)^2}.$$

If $x < 1.0333$, $S_1$ gets $\frac{\alpha V}{16}$ as payoff. Consider first the case $x \geq 1.0333$: $L_1$ acquires if

$$\frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - \frac{\alpha V}{16} \geq \frac{\alpha V}{(1+2x)^2}.$$

This inequality holds for $x \geq 1.10933$. In the case $x < 1.0333$ $L_1$ acquires if

$$\frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - \frac{\alpha V}{16} \geq \frac{\alpha V}{16}.$$

This inequality never holds since $x < 1.0333$. Thus, $L_1$ decides to acquire in decision point 9 if $x \geq 1.10933$.

In decision point 15 $S_2$ gets the payoff of an outsider in R&D game 7 if it denies the offer. Therefore $S_2$ accepts every offer $p_{22}^B \geq p_O$.

In decision point 13 $L_2$ has already acquired $S_1$ for $p_{21}$. If $L_2$ acquires $S_1$, the situation is an asymmetric duopoly where $L_2$ has acquired both small firms. $L_2$'s payoff if it acquires is

$$\frac{\alpha x^3 V}{(1+x)^2} - p_{21} - p_{22}^B,$$

where $p_{22}^B = p_O$ is the lowest offer $S_2$ accepts. If $L_2$ does not acquire, its payoff is the payoff of the merged firm in R&D game 7 minus the price paid for $S_1$:

$$\frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - p_{21}.$$

Thus, $L_2$ acquires if

$$\frac{\alpha x^3 V}{(1+x)^2} - p_{21} - \frac{\alpha V}{(1+2x)^2} \geq \frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - p_{21}.$$

This inequality holds for every $x \geq 1$ and therefore $L_2$ always bids $p_{22}^B = p_O$ and acquires $S_2$ in decision point 13.

In decision point 11 $S_2$ accepts any offer $p_{12}^B \geq p_O$.

In decision point 8 $L_1$ has to offer at least $p_{12}^B = p_O$ if it wants $S_2$ to accept. If $S_2$ accepts, the resulting situation is R&D game 4, a symmetric duopoly. If $S_2$ denies the offer, $L_1$ gets the profit of an outsider in an asymmetric duopoly in R&D game 6 since $L_2$ always makes an offer that $S_2$ accepts in decision point 13. $L_1$ therefore decides to offer $p_{12}^B = p_O$ and to acquire $S_2$ if

$$\frac{\alpha x V}{4} - \frac{\alpha V}{(1+2x)^2} \geq \frac{\alpha V}{(1+x)^2}.$$

This inequality holds for $x \geq 1.18731$.

If $S_1$ denies the offer in decision point 6, the acquisition game ends in an asymmetric triopoly (where $S_1$ is an outsider) for $x \geq 1.0333$ and in R&D game 9 for $x < 1.0333$. Thus, $S_1$ accepts every offer $p_{21} \geq p_O$ for $x \geq 1.0333$ and every offer $p_{21} \geq p_N$ for $x < 1.0333$.

If $L_2$ decides to acquire $S_1$ in decision point 4, the acquisition game ends in R&D game 4 for $x \geq 1.18731$ and in R&D game 6 for $x < 1.18731$. If $L_2$ does not acquire

$S_1$, the acquisition game ends in R&D game 5 for $x \geq 1.10933$, in R&D game 8 for $1.10933 > x \geq 1.0333$, and in R&D game 9 for $x < 1.0333$. Consider first the case $x \geq 1.18731$: The payoff for $L_2$ in R&D game 4 is $\frac{\alpha x V}{4} - p_{21}$; in R&D game 5 it is $\frac{\alpha V}{(1+2x)^2}$. The payoff in R&D game 4 is larger for the lowest accepted offer $p_{21}$. For $x \geq 1.18731$ $L_2$ therefore bids $p_{21} = p_O$ and acquires $S_1$. The next case to consider is $1.18731 > x \geq 1.10933$: The payoff for $L_2$ if it acquires $S_1$ is given by R&D game 6 and is thus $\frac{\alpha x^3 V}{(1+x)^2} - p_{21} - p_{22}^B$, where $p_{22}^B = p_O$ and the lowest accepted offer is $p_{21} = p_O$. If $L_2$ does not acquire, its payoff is given by R&D game 5 and it is $\frac{\alpha V}{(1+2x)^2}$. Thus, $L_2$ acquires if

$$\frac{\alpha x^3 V}{(1+x)^2} - 2 \cdot \frac{\alpha V}{(1+2x)^2} \geq \frac{\alpha V}{(1+2x)^2}.$$

This inequality holds for every $1.18731 > x \geq 1.10933$. The third case is $1.10933 > x \geq 1.0333$: The payoff for $L_2$ if it acquires is the same as in the previous case. If $L_2$ does not acquire, its payoff is given by R&D game 8 and it is $\frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - p_{22}^C$ with $p_{22}^C = p_N$. Thus, $L_2$ acquires if

$$\frac{\alpha x^3 V}{(1+x)^2} - 2 \cdot \frac{\alpha V}{(1+2x)^2} \geq \frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - \frac{\alpha V}{16}.$$

This inequality holds for $x \geq 1.05678$. The last case to consider is $x < 1.0333$. The payoff for $L_2$ if it acquires is again given by R&D game 6, but $L_2$ only has to pay $p_{21} = p_N$ to make $S_1$ accept the offer. If $L_2$ does not acquire, its payoff is given by R&D game 9 and it is $\frac{\alpha V}{16}$. Thus, $L_2$ acquires if

$$\frac{\alpha x^3 V}{(1+x)^2} - \frac{\alpha V}{(1+2x)^2} - \frac{\alpha V}{16} \geq \frac{\alpha V}{16}.$$

This inequality holds for every $x < 1.0333$. Thus, in decision point 4 $L_2$ bids $p_{21} = p_O$ and acquires $S_1$ for $x \geq 1.05678$, does not acquire $S_1$ for $1.05678 > x \geq 1.0333$, and bids $p_{21} = p_N$ and acquires $S_1$ for $x < 1.0333$.

In decision point 10 $S_2$ accepts every offer that gives it a higher payoff than the payoff as an outsider in R&D game 3. Thus, $S_2$ accepts every offer $p_{12}^A \geq p_O$.

In decision point 7 $L_1$ has already acquired $S_1$ for $p_{11}$. If $L_1$ acquires $S_2$, $L_1$ is the merged firm in R&D game 2 and has a payoff $\frac{\alpha x^3 V}{(1+x)^2} - p_{12}^A - p_{11}$, where the lowest accepted offer is $p_{12}^A = p_O$. If it decides not to acquire, its payoff is the one of the merged firm in a triopoly, i.e, $\frac{\alpha x V}{(1+2x)^2}(2x-1)^2 - p_{11}$. Thus, $L_1$ acquires if

$$\frac{\alpha x^3 V}{(1+x)^2} - \frac{\alpha V}{(1+2x)^2} \geq \frac{\alpha x V}{(1+2x)^2}(2x-1)^2.$$

This inequality always holds and thus $L_1$ always bids $p_{12}^A = p_O$ and acquires $S_2$ in decision point 7.

In decision point 5 $S_2$ accepts every offer $p_{22}^A \geq p_O$.

In decision point 3 $L_2$ has to decide whether to acquire $S_2$ and create a symmetric duopoly in R&D game 1 or not to acquire $S_2$ and become the outsider in the asymmetric duopoly in R&D game 2. If $L_2$ acquires, its payoff is $\frac{\alpha x V}{4} - p_{22}^A$, where the lowest accepted offer is $p_{22}^A = p_O$. If $L_2$ does not acquire, its payoff is $\frac{\alpha V}{(1+x)^2}$. Thus, $L_2$ acquires if

$$\frac{\alpha x V}{4} - \frac{\alpha V}{(1+2x)^2} \geq \frac{\alpha V}{(1+x)^2}.$$

This inequality holds for $x \geq 1.18731$ and therefore $L_2$ acquires $S_2$ for $x \geq 1.18731$ in decision point 3.

If $S_1$ denies the offer in decision point 2, the acquisition game ends with a payoff of $\frac{\alpha V}{(1+2x)^2}$ for $S_1$.[16] Thus, $S_1$ accepts every offer $p_{11} \geq p_O$.

If $L_1$ decides to acquire in decision point 1, the acquisition game ends with R&D game 1 for $x \geq 1.18731$ and with R&D game 2 if $x < 1.18731$. If $L_1$ decides not to acquire, the acquisition game ends with R&D game 4 for $x \geq 1.18731$, with R&D game 6 for $1.18731 > x \geq 1.05678$ or $x < 1.0333$ and with R&D game 8 for $1.05678 > x \geq 1.0333$. Consider first the case $x \geq 1.18731$: $L_1$'s payoff if it acquires is then given by R&D game 1 minus the price $p_{11}$ paid for $S_1$. The lowest price accepted by $S_1$ is $p_O$. If $L_1$ decides not to acquire in decision point 1, the game ends in R&D game 4 where $L_1$'s expected profit is the same and the price paid to acquire $S_2$ is $p_O$. Thus, for $x \geq 1.18731$ $L_1$ is indifferent between acquiring now or later and due to our assumption given in footnote 11 $L_1$ acquires $S_1$ for $p_{11} = p_O$. For all other cases $L_1$'s payoff if it acquires is given by R&D game 2 and $L_1$ has to pay $p_{11} = p_{12}^A = p_O$. Thus, $L_1$'s payoff if it acquires is

$$\frac{\alpha x^3 V}{(1+x)^2} - 2\frac{\alpha V}{(1+2x)^2}. \tag{3.5}$$

$L_1$'s payoff if it decides not to acquire depends on $x$. If $1.18731 > x \geq 1.05678$ or $x < 1.0333$, $L1$'s payoff is given by R&D game 6 and it is

$$\frac{\alpha V}{(1+x)^2}.$$

[16] Either acquired by $L_2$ for $x \geq 1.05678$ or $x < 1.0333$ or as an independent firm in a triopoly for $1.05678 > x \geq 1.0333$.

This is larger than the payoff given by (3.5) for $x < 1.22364$. If $1.05678 > x \geq 1.0333$, $L_1$'s payoff is given by R&D game 8 and it is

$$\frac{\alpha V}{(1+2x)^2}.$$

This is larger than the payoff given by (3.5) for $x < 1.09021$. Thus, in decision point 1 $L_1$ bids $p_{11} = p_O$ and acquires $S_1$ for $x \geq 1.18731$ and does not acquire $S_1$ for $x < 1.18731$. $\square$

# Chapter 4

# Government R&D Subsidies as a Signal for Private Investors

## 4.1 Introduction

Government subsidies for R&D are intended to promote projects with high returns to society but too little private returns to be beneficial for private investors. This may be caused by spillovers of ideas to competitors or a low appropriability rate. Especially basic research is affected by this issue. Most public R&D policies are justified by this stylized fact. R&D subsidies are an important tool to support technology policy in OECD countries. In 2005 roughly one third of funds for R&D are provided by the government (EU 27: 34.7%, US: 30.4%, source: IW (2008)).

A difficult problem for government agencies is, however, to identify projects which are beneficial for society but need additional funds to be executed as private returns are too low. If an R&D project is publicly funded, there is a certain risk that private investment is simply replaced. In economic literature this crowding out effect is widely discussed and the evidence is mixed. David, Hall, and Toole (2000) survey the empirical literature and find that results are dependent on the aggregation level. For a low level of aggregation the proportion of studies reporting a crowding out effect is significantly higher. Lichtenberg (1984, 1987) claims that it is difficult to find a valid control group and in several earlier studies a selection bias led to an overestimation of the positive effect of government funded R&D. Klette, Møen, and Griliches (2000) and Lerner (1999) argue that also political influence and distorted incentives for decision makers may lead to subsidies for the "wrong" R&D projects.

While the empirical literature on the impact of R&D subsidies on firms' innovation incentives is growing, theoretical papers are scarce. In a seminal paper, Spence (1984) analyzes firms' incentives to invest in oligopolies when spillovers are present. He shows that without subsidies social welfare eventually decreases as the number of firms increases. This result is driven by the interaction of three simultaneously occurring market failures. First, as R&D expenditures are to a large extend fixed costs, markets are likely to be concentrated and thus imperfectly competitive, leading to allocative inefficiencies. Second, free riding on rivals' R&D creates an incentive problem for firms. Finally, if firms use a similar approach to reduce costs, there is a wasteful duplication of R&D efforts. If the number of firms increases, the positive effect on allocative efficiency gets smaller while the negative incentive and duplication of R&D efforts effect is still present. Hence, the optimal number of firms is finite.[1] Spence shows that in a market with sufficient spillovers it is more efficient to overcome the incentive problem by subsidizing firm's R&D than by allowing for R&D cooperations.

Romano (1989) analyzes optimal subsidization in research markets depending on the length of patent life, the character of innovation competition, and the extent of excess burdens associated with the generation of funds for subsidies. He shows that if there is a monopoly in the research market, the optimal subsidy is always positive, independent of the patent life and the amount of the excess burden.[2] In contrast, in a competitive research market, the optimal subsidy is zero for a "long" patent life or a "high" excess burden.

Hinloopen (1997, 2000) studies how the effect of R&D subsidies depends on the degree of cooperation of firms. He introduces taxes that are used to provide firms with R&D subsides into d'Aspremont and Jacquemin's (1988) model. He shows that this policy can increase private R&D investments, output, and social welfare. Further, he shows that subsidizing noncooperative R&D is more effective in raising private R&D efforts than permitting RJVs or R&D cartels and in most cases also more effective than permitting RJV cartels.[3]

[1] In fact, depending on parameter combinations this number is small.

[2] The additional costs to generate funds for the subsidy are called "excess burden" in Romano's model.

[3] Hinloopen uses the Kamien, Muller, and Zang (1992) differentiation for types of R&D cooperatives.

This essay addresses an additional effect of subsidies. Apart from the direct funding of these projects, government grants may serve as a signal for good investments to private investors.

Lerner (1999) analyzes the SBIR program (initiated in 1982) that was intended to stimulate innovation in small high tech firms. The study evaluates the performance of firms receiving SBIR rewards in the period of 1983 to 1985. SBIR awardees grew significantly faster in terms of sales and employment compared to similar non-supported firms, from 1985 to 1995. He attributes capital market imperfections, specifically the difficulty to raise capital for uncertain R&D projects due to information asymmetries as a source of difference in performance. The SBIR program could play an important role in certifying firms' quality and technological merits of the firms' projects, thereby alleviating capital market imperfections. In line with this interpretation is the importance of the *first* award compared to subsequent ones. Lerner assumes that this signal to investors is particularly important in high tech industries where it is difficult for smaller banks to analyze risk and potential benefits of research projects. Also, a recently released report of the National Governors Association (NGA) claims that "an SBIR award provides a signal to angel investors that these technologies hold promise and an opportunity to leverage their investments with another source of early-stage funding" (NGA (2008), p.7).

A more recent empirical analysis of Meuleman and de Maeseneire (2008) confirms Lerner's conclusion. In a study of Belgian small and medium sized firms' access to external financing, they find a positive certification effect of obtaining an R&D grant. Furthermore, the certification effect is stronger for start-up firms. Thus, again, when projects are difficult to evaluate, as in high technology industries or new markets, the R&D grant is more important to secure private funding.

In an interview study of firms that applied to the 1998 US Advanced Technology Program, Feldman and Kelley (2006) find that receipt of a government R&D subsidy increased the external funding possibilities. These private funds are important, especially for small- and medium-sized firms.

A survey of possible underinvestment in R&D caused by capital market imperfections is given in Hall (2002). Generally, she finds that a problem for private investment in research is that there is no capitalized value for R&D in a firm's balance sheet. Asymmetric information between borrowers and lenders may then cause potential lenders to be reluctant to fund R&D due to its inherent risk, even if the borrower promised high expected returns. Even venture capitalists, specialized in providing risky capital may fail to provide a solution to capital constraints in R&D. First, only a small number of firms in specific sectors receive funds. More importantly, as argued in Bhattacharya and Ritter (1983) or Ueda (2004), the threat of expropriation may limit screening activities. If the firm has to reveal valuable private information about the R&D projects to a private investor to get funds, there is a certain risk that the financier will steal the information.

Our essay is related to the theoretical literature on entrepreneurial finance.[4] Repullo and Suarez (2000) and Da Rin, Nicodano, and Sembanelli (2006) emphasize the importance of informed financiers, like venture capitalists, to reduce the monitoring or moral hazard problem. In contrast, our model focusses on asymmetric information. Takolo and Tanayama (2008) adapt Holmstrom and Tirole's (1997) framework with financial intermediation in a market where firms are capital constrained to model a signaling effect of R&D subsidies. In a model with high and low quality entrepreneurs, subsidies reduce capital costs related to the innovation projects and provide a signal to investors. Their model differs in two important ways. First, the focus is on the finance effect of the subsidy. A project without subsidies will never be executed in the considered equilibria. Second, the government agency and private investors prefer the same type of projects, namely high *quality* projects. In contrast, we model high and low *risk* projects, where the low risk type is preferred by private investors and the high risk type is preferred by the government agency, imposing conflicting interests between these two actors.

We use a signaling model to capture the problem of asymmetric information between banks, firms, and a government agency. The agency screens R&D projects and decides on granting a subsidy. Banks observe this signal and then give loans to firms or not. Thus, we assume that firms first seek public funding. However, our results are not altered if we assume that firms first contact private investors who make their funding decisions contingent on the public funding decision. We solve for perfect Bayesian equilibria in two setups. If the subsidy can only be used to distinguish between high and low risk projects, the government agency's signal is not very helpful for banks' investment decision. An equilibrium where the agency is pooling its signal for both project types is very likely. However, if the subsidy is

[4]For a recent overview of that literature, see Boadway and Keen (2006).

accompanied by a quality signal, it can lead to increased and better selected private investments.

The essay is organized as follows: First, the general signaling model is described. Then, equilibria for both setups are derived. The final section concludes, discusses limitations of our model, and points out interesting topics for further research.

## 4.2 Model

To show the potential certification character of a government subsidy, a simple signaling model is used. As argued in Czarnitzki and Hussinger (2004) or Czarnitzki and Toole (2006) firms have an incentive to apply for government grants for any project, i.e., not only those where private returns are not sufficient, unless there are significant costs of application. Thus, all projects eligible for subsidies have to be reviewed by the agency.[5] For simplification, we assume that there are only two risk classes of projects: High and low risk.

Basic research projects are usually more risky, as the final result is unclear and therefore commercial applications are difficult to foresee. The appropriability level of expenditures for basic research is low (see for example Beise and Stahl (2002)). Furthermore, these projects usually generate high spillovers to competitors. Funk (2002) shows that spillovers from basic research are significantly larger than from developmental research. However, it is necessary for society that these projects are executed as they generate foundations for further research. Thus, we assume that high risk projects are beneficial to society even though they are not privately beneficial. For example, the German Federal Government justifies public R&D funds where research has long time horizons, a high economic risk and great financial needs. It is argued that this type of research is very likely to be beyond the possibilities of individual companies (BMBF (1993)).

Low risk projects, like improvement of already existing products, are expected to be privately beneficial for companies. Projects of this risk type generate enough private returns to be funded by private investors. On the other hand, social benefits do not exceed investments for this type of projects. Therefore, the agency does not

[5] In the first setup these are all projects, in the second only those meeting the quality requirement, compare sections 2.1 and 2.2.

want to grant subsidies for this risk type.

Agency's capital is restricted in a way that it is costly for the agency to subsidize projects. More formally, we assume that the social return function $I(x)$ – which is the agency's objective function – of high and low risk projects is of the following type:

$$I_H(0) = I_L(0) = 0,$$
$$I'_H(x) > 1,\ 0 < I'_L(x) < 1,$$

where $H$ and $L$ indicate high and low risk projects respectively. Projects can be executed with private investment only (social return $I(P)$), with subsidies only ($I(S)$), or with a combination of private investment and subsidies ($I(S+P)$). We assume that the private investment $P$ is the same for a subsidized and non subsidized projects or in other words we are not modeling crowding out effects. However, if we allow the private investment to depend on the project being subsidized or not, general results are not altered if we make some reasonable assumptions on the difference between private funding for subsidized and non subsidized projects.[6]

To model capital market imperfections, we assume that firms do not have funds on their own to perform their R&D projects but need loans from banks to do so. Asymmetric information in this market is modeled in the way that banks cannot distinguish high and low risk projects. A government agency, due to more experience with similar projects in the past, can. This assumption is in line with the empirical analysis of Lerner (1999) and the modeling of Takolo and Tanayama (2008). Lerner shows that due to more intensive analysis venture capitalists and government agencies perform a significantly better screening and thus have an improved perception of the project's riskiness.[7]

The agency can use subsidies to promote projects of its interest. Moreover, and that is the focus of the analysis, it can grant subsidies (or not) to signal project types to private investors.[8]

[6] Arguing and calculations are in some cases simply more complex and this way of modeling does not lead to more insights.

[7] Of course, the assumption that banks have no information on the project type and that agency's screening is perfect is for simplification.

[8] The analysis focuses on the asymmetric information problem concerning the project's risk type. We abstract from other information or observation problems, like moral hazard for firms' utilization of investment.

### 4.2.1 Subsidies without Quality Signal

Firms apply for subsidies for all of their projects. Therefore, the game structure only shows Nature's random choice of project type. The proportion of high risk projects is $\alpha$, the proportion of low risk projects $1 - \alpha$. The agency observes for what type of project the firm is applying and then decides on granting a subsidy (S) or not (nS). Banks observe the agency's decision but not the project type and decide on investing in that project (L) or not (nL). Finally, payoffs are realized. The game structure is shown in figure 4.1.

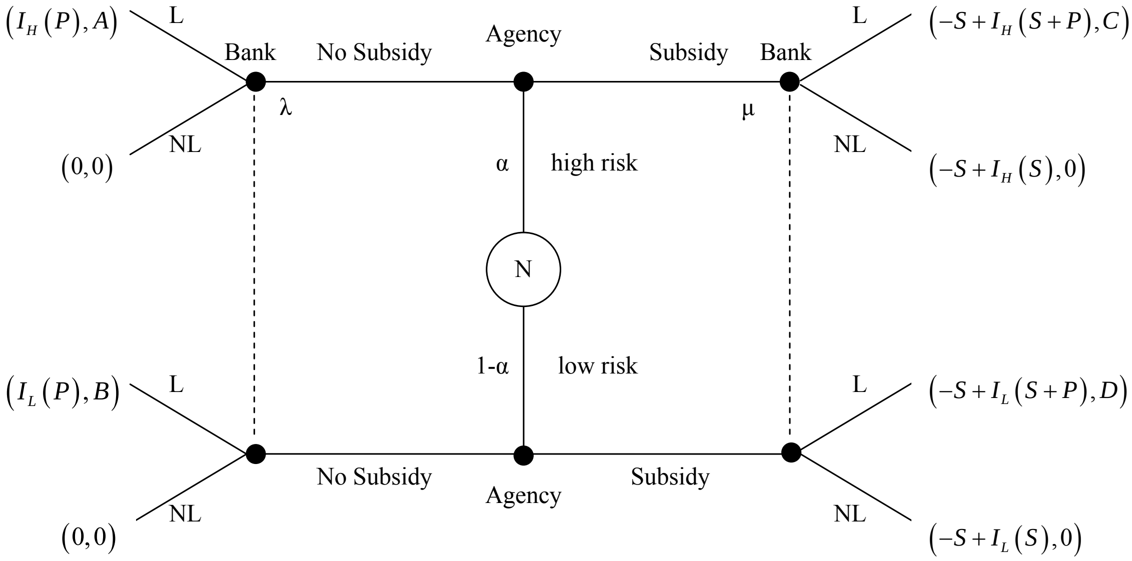


Figure 4.1: Game structure without quality signal.

Both the agency and banks are assumed to be risk neutral. Expected payoffs are denoted in brackets, agency's on the left, banks' on the right.[9] Banks beliefs are $\lambda$ in the no subsidy information set and $\mu$ in the subsidy information set. As explained above, we assume that banks prefer low risk projects. To have a non-trivial decision for banks, we further assume that banks' expected payoffs for high risk projects are negative, while they are positive for low risk projects. If banks do not invest, their

[9]Banks' payoffs are denoted by $A$, $B$, $C$, and $D$. Conditions on the relationship between these parameters are established on the following pages.

payoff is zero.[10] Thus, the parameters must fulfill the following conditions:[11]

$$A < 0 < B; \qquad C < 0 < D.$$

For illustration of strategies, beliefs, and payoffs, assume that a firm is applying for subsidies for a high risk project, the agency decides on giving no subsidies to the project, and banks have the belief $\lambda = 0.5$ on the project type and therefore decide to give a loan. Payoffs arising from these strategies are $I_H(P)$ for the agency and $A$ for banks.

In the following propositions we identify for what parameter combinations perfect Bayesian equilibria in pure strategies exist.[12]

**Proposition 4.1.** *There is no separating equilibrium where subsidies are granted for low risk projects and no subsidies are granted for high risk projects.*

*Proof.* See the appendix.

This type of equilibrium would, of course, not be in the interest of the agency anyway and it is pretty intuitive that these strategies can never be an equilibrium. As the strategies clearly indicate the type of project to banks, they will give loans only to their preferred projects, i.e., the low risk ones. Additionally, the agency grants subsidies to the project type it does not prefer. Therefore, the agency has a clear incentive to deviate from this strategy since the agency grants subsidies only to its not preferred projects and only these projects receive private funding.

The agency's most preferred equilibrium would be one where subsidies are granted to high risk projects only. However, as the following proposition shows, this equilibrium only exists under very strict assumptions to the social return function.

[10]Note that this formulation is equivalent to assume higher and lower payoffs than payoffs for an outside option for low risk and high risk projects respectively.

[11]The investment $P$ is already included in banks' expected payoffs.

[12]We restrict attention to pure strategies for the agency because in that way the agency can define a strict policy and the subsidy decision is not taken randomly. For banks, the decision to give loans or not is based on the expected profit and is therefore – except for the case of equality of both decisions – a pure strategy in equilibrium. We do also only consider equilibria where the equilibrium strategy makes the player strictly better off than the deviation strategy. However, a change of this assumption would not alter our results.

**Proposition 4.2.** *A separating equilibrium where subsidies are granted for high risk projects and no subsidies are granted for low risk projects exists only if*

$$I_H(P) < -S + I_H(S). \tag{4.1}$$

*In this equilibrium banks give no loans to subsidized projects and give loans to the non subsidized ones.*

*Proof.* See the appendix.

As before, the signal perfectly reveals project types to banks with the same implication for banks' strategies. In contrast to the candidate equilibrium in proposition 4.1, the agency at least subsidizes its preferred project type. For the "desired" equilibrium – where the agency only grants subsidies to projects with a high social return and a private return that is too little to guarantee private investment – to exist, the very strict condition (4.1) on the social return function and the amount of subsidy $S$ in comparison to the private investment $P$ must hold. First, the subsidy must be larger than the private investment. Second, the slope of $I_H$ must be large between $P$ and $S$ to offset for the agency's investment $S$ in the payoff function. Even if this equilibrium exists, the socially preferred projects then only receive public and no private funding.

In addition to the candidate equilibria considered so far, there is also the possibility that the agency is making no difference between the type of project and thus revealing no information on the riskiness of projects to banks.

**Proposition 4.3.**

*a) There is an equilibrium where the agency is pooling on S if*
  *a1)* $\alpha \cdot C + (1-\alpha) \cdot D > 0$,
  *a2)* $\lambda \cdot A + (1-\lambda) \cdot B < 0$, *and*
  *a3)* $-S + I_L(S+P) > 0$.
  *Banks beliefs in this equilibrium are* $\mu = \alpha$ *and* $\lambda > \frac{B}{B-A}$ *and they give loans to subsidized projects and no loans to non subsidized projects.*

*b) There is an equilibrium where the agency is pooling on nS if*
  *b1)* $\alpha \cdot A + (1-\alpha) \cdot B > 0$,
  *b2)* $\mu \cdot C + (1-\mu) \cdot D < 0$, *and*

*b3)* $-S + I_H(S) < I_H(P)$.
*Banks' beliefs in this equilibrium are* $\lambda = \alpha$ *and* $\mu > \frac{D}{D-C}$ *and they give loans to non subsidized projects and no loans to subsidized projects.*

*Proof.* See the appendix.

The intuition for the equilibrium pooling on S is the following. First, banks' expected profits if a project is subsidized must be positive ($a1$). Otherwise, banks would not give loans and there would be an incentive to deviate for low risk types. Second, beliefs $\lambda$ off the equilibrium path must be in a way that expected profits for non subsidized projects are negative ($a2$). Again, else there would be an incentive to deviate for low risk types as the agency prefers low risk projects to be solely privately financed instead of being publicly and privately financed. As only subsidized projects get loans, there is clearly no incentive to deviate for high risk projects since subsidizing these projects is in the interest of the agency anyway. Finally, the private investment has to be high enough that the agency prefers the low risk projects to be both publicly and privately financed instead of not being financed at all ($a3$).[13]

For the equilibrium pooling on nS, the intuition is similar. Expected profits for non subsidized projects must be positive ($b1$) or else there is an incentive to deviate for high risk projects. Also, beliefs $\mu$ off the equilibrium path must be in a way that expected profits for subsidized projects are negative ($b2$). Otherwise there is again an incentive to deviate for high risk projects. If these two conditions hold, there is no incentive to deviate for low risk projects as deviating would only result in subsidizing the not preferred project *and* reducing private investment. For this equilibrium to exist it is again necessary that private investment is large enough. Otherwise the agency would prefer to give subsidies to high risk projects even though that would lead to no private investment for these projects ($b3$).

In this first setup, the role of the agency is thus not very fulfilling. Only if a very strict condition on the social return function and the amount of subsidy in comparison to the private investment holds, there is a real impact of the agency's strategy on the outcome of the game. In the pooling equilibria the signal has no impact at all. In other words: The mere fact that the agency is able to distinguish

[13] If we require beliefs to be justifiable in the sense of McLennan (1985), the belief $\lambda$ as given in part $a$) of proposition 4.3 is not possible and there is no equilibrium where the agency is pooling on S. The proof is given as a remark on proposition 4.3 in the appendix.

between basic and applied research is useless for private investors, if the agency decides not to forward this information.

Thus, for the government agency to play an important role and to have a real (and hopefully positive) impact on innovation investments, there must be another factor when granting subsidies. One factor might be that the agency acts as a filter for low quality projects. In the following section we add this property to the agencies signal.

### 4.2.2 Subsidies with Quality Signal

The game has the same structure as before, with the exception that only some R&D projects qualify for subsidies. The idea is that only a proportion $p$ of projects in both risk classes met certain requirements of the agency, like the size of the R&D laboratory or a minimum number of researchers with a certain experience in the particular field of technology. Projects that fail these pre-screening quality requirements are automatically rejected without any explicit decision from the agency. That is, the agency cannot grant a subsidy to these projects even if it wanted to. These projects are of lower quality than the other projects. As before, banks can neither distinguish between high and low risk nor high and low quality projects. The information subset now contains four nodes with beliefs $\lambda_1$ to $\lambda_4$.[14] The changed game structure is shown in figure 4.2.

We assume that banks' expected payoffs for low quality projects are $2x$ lower than expected payoffs for high quality projects. To assure comparability of the two setups, ex ante expected payoffs for banks remain unchanged. Banks' expected profit can be split up in two groups for low and high quality projects:

$$Y = (\tilde{Y} + x) \cdot p + (\tilde{Y} - x) \cdot (1 - p)$$

where $Y \in \{A, B, C, D\}$. However, depending on the agency's subsidizing strategy banks can update their beliefs and recalculate expected payoffs.

If a project is not subsidized, there are now two possibilities. Either the agency *choose* not to, or the project did not even *qualify to apply* for subsidies and is

[14]Theoretically, we could also include nodes in the game tree for low quality projects which receive subsidies. However, these nodes cannot be reached as low quality projects cannot receive subsidies. Therefore these nodes are omitted.

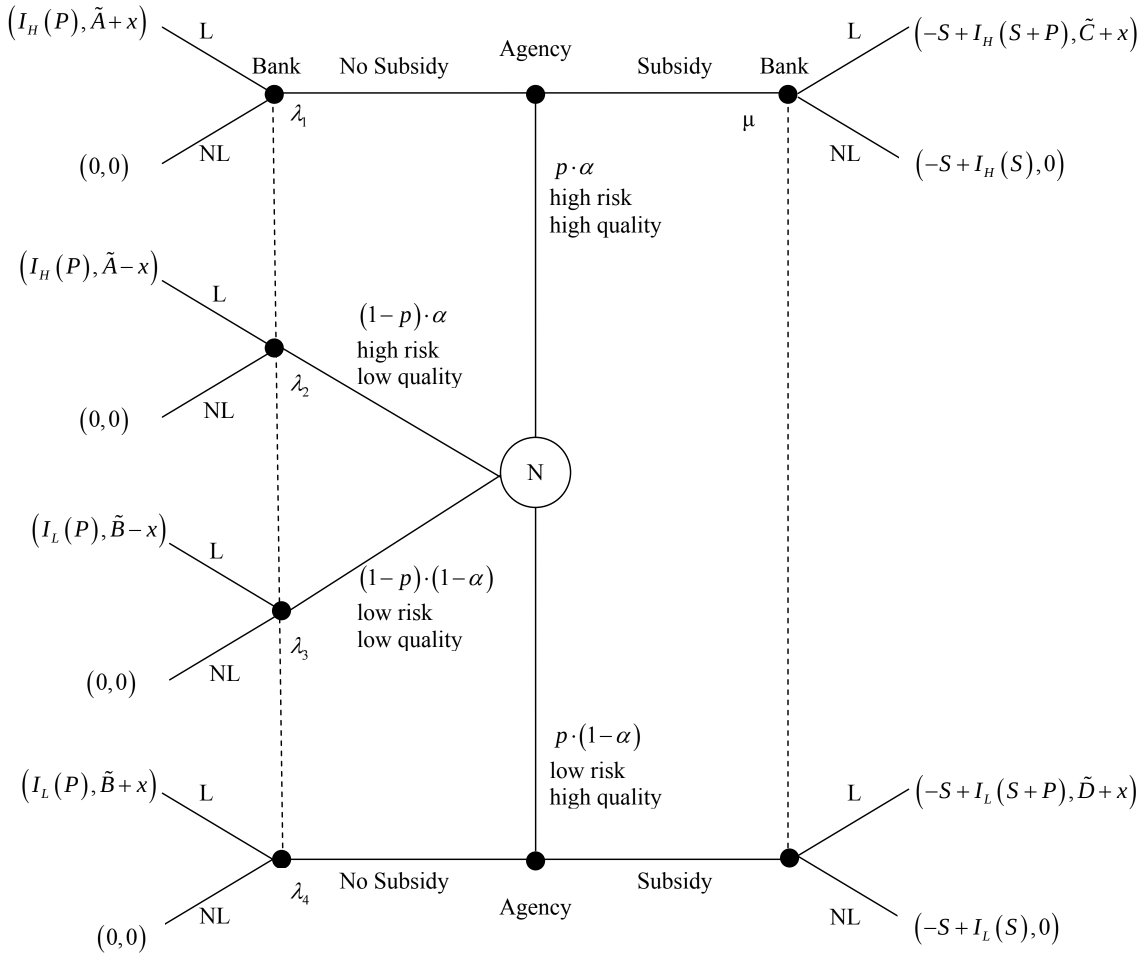


Figure 4.2: Game Structure with Quality Signal.

therefore of lower quality. If a project is subsidized on the other hand, banks can be sure it is high quality type. This changes the variety of possible equilibria.

**Proposition 4.4.** *There is no separating equilibrium where subsidies are granted for low risk projects and no subsidies are granted for high risk projects.*

*Proof.* See the appendix.

The intuition for the non-existence of this type of equilibrium is the same as in the previous setup. Subsidizing clearly indicates low risk projects to banks and hence loans are given to this type of projects. Therefore, the agency has an incentive to deviate for high risk projects.

However, the new property of subsidizing, i.e., the included quality signal, makes conditions for the agency's preferred equilibrium less restrictive.

**Proposition 4.5.** *There is a separating equilibrium where subsidies are granted for high risk projects and no subsidies are granted for low risk projects if*

*a)* $\tilde{C}+x>0$, $\lambda_2\cdot\left(\tilde{A}-x\right)+\lambda_3\cdot\left(\tilde{B}-x\right)+\lambda_4\cdot\left(\tilde{B}+x\right)>0$, *i.e., loans are given to both types of projects, or*

*b)* $\tilde{C}+x<0$ *and* $\lambda_2\cdot\left(\tilde{A}-x\right)+\lambda_3\cdot\left(\tilde{B}-x\right)+\lambda_4\cdot\left(\tilde{B}+x\right)<0$, *i.e., no loans are given to both types of projects, or*

*c)* $\tilde{C}+x>0$, $\lambda_2\cdot\left(\tilde{A}-x\right)+\lambda_3\cdot\left(\tilde{B}-x\right)+\lambda_4\cdot\left(\tilde{B}+x\right)<0$ *and* $-S+I_L(S+P)<0$, *i.e., loans are given to high risk projects only and the agency prefers low risk projects rather to be not financed than to be financed both privately and publicly, or*

*d)* $\tilde{C}+x<0$, $\lambda_2\cdot\left(\tilde{A}-x\right)+\lambda_3\cdot\left(\tilde{B}-x\right)+\lambda_4\cdot\left(\tilde{B}+x\right)>0$ *and* $I_H(P)<-S+I_H(S)$, *i.e., the same condition as in the previous setup: Only low risk projects are privately financed and the agency prefers a solely publicly financed to a solely privately financed high risk project.*

*In all cases, banks' beliefs are* $\lambda_1=0$, $\lambda_2=(1-p)\cdot\frac{\alpha}{1-\alpha\cdot p}$, $\lambda_3=(1-p)\cdot\frac{1-\alpha}{1-\alpha\cdot p}$, $\lambda_4=p\cdot\frac{1-\alpha}{1-\alpha\cdot p}$, *and* $\mu=1$.

*Proof.* See the appendix.

If a subsidy is a real signal for quality, chances that the agency's (and thus, society's) preferred equilibrium exists are increased. For banks it is important to adjust their beliefs $\lambda_i$ if no subsidy is observed, because although we are considering a separating equilibrium, there are still three possibilities for the project type. There are high risk projects that did not qualify for subsidies ($\lambda_2$) and low risk projects which are either of low quality and therefore not subsidized ($\lambda_3$) or of high quality and the agency chooses not to subsidize ($\lambda_4$). Banks' belief $\lambda_2$ for example must therefore be calculated as the conditional probability of a high risk project, given that the project is not subsidized. Compared to the ex ante situation, the expected payoff is modified in two ways. First, the expected payoff for high risk projects is decreased as all high risk projects are now of low quality. Second, the proportion of low risk type projects

– the ones banks prefer – is increased. Therefore, it is not clear whether loans to non subsidized projects in the changed situation are more likely. With beliefs $\lambda_i$ and $\mu$ banks calculate expected payoffs and decide to give loans or not. Given these decisions, it is intuitive that the agency has no incentive to deviate in cases $a$) and $b$). Either both types of project or no type of project are privately funded and the agency thus only chooses to subsidize the projects it prefers, i.e., the high risk type projects. In case $c$) the quality restriction makes high risk, high quality projects profitable for private investors. On the other hand, the negative effect of low quality projects is high such that private investors do not want to finance projects that did not meet the agency's quality restriction. An additional condition on the agency's payoff has to hold such that there is no incentive to deviate for low risk projects from the candidate equilibrium. Case $d$) is equivalent to the condition in proposition 4.2 in the previous setup.

The extended setup, with pre-screening quality restrictions, also changes conditions for the pooling equilibria. This is particularly striking for the equilibrium where the agency is pooling on S. Due to the automatically rejected projects the non subsidy information set is still reached on the equilibrium path.

**Proposition 4.6.**

a) *There is an equilibrium where the agency is pooling on S if*
*(a1)* $\alpha \cdot \left(\tilde{C} + x\right) + (1-\alpha)\left(\tilde{D} + x\right) > 0,$
*(a2)* $\alpha \cdot \left(\tilde{A} - x\right) + (1-\alpha)\left(\tilde{B} - x\right) < 0,$ *and*
*(a3)* $-S + I_L(S+P) > 0.$
*Banks' beliefs in this equilibrium are* $\lambda_1 = \lambda_4 = 0$, $\lambda_2 = \alpha$, $\lambda_3 = 1-\alpha$, $\mu = \alpha$ *and they give loans to subsidized projects and no loans to non subsidized projects.*

b) *There is an equilibrium where the agency is pooling on nS if*
*(b1)* $\alpha \cdot A + (1-\alpha) \cdot B > 0,$
*(b2)* $\mu \cdot \left(\tilde{C} + x\right) + (1-\mu)\left(\tilde{D} + x\right) < 0,$ *and*
*(b3)* $-S + I_H(S) < I_H(P).$
*Banks' beliefs in this equilibrium are* $\lambda_1 = p\cdot\alpha$, $\lambda_2 = (1-p)\cdot\alpha$, $\lambda_3 = (1-p)\cdot(1-\alpha)$, $\lambda_4 = p\cdot(1-\alpha)$, *and* $\mu > \frac{D}{D-C}$ *and they give loans to non subsidized projects and no loans to subsidized projects.*

*Proof.* See the appendix.

Comparing requirements for equilibria in proposition 4.3 and 4.6, we see that the conditions for the equilibrium where the agency is pooling on S get less strict while they get more restrictive for the nS pooling equilibrium. Consider first the equilibrium where the agency grants subsidies to both types of projects. The first condition requires the expected profit for the combination of subsidized high and low risk projects to be positive. In proposition 4.6, however, this expected profit only includes high quality projects. The condition is therefore less restrictive. The problem with the second condition is that in proposition 4.3 beliefs $\lambda$ can be chosen as high as needed that the condition holds while in proposition 4.6 $\lambda_2 = \alpha$ is required because the information set is reached in equilibrium.[15] The argumentation is therefore only true for $\lambda = \alpha$. In this case the second condition requires that expected profits for the combination of non subsidized high and low risk projects is negative. As in proposition 4.6 only the low quality projects are included, this condition is less restrictive.[16]

The opposite is true for the equilibrium where the agency is giving no subsidies to any project. The first and the last condition is the same in both cases. The second condition, however, is more restrictive in proposition 4.6 as banks know that subsidized projects are of high quality. Therefore, the condition that the expected profit of the combination of high and low risk projects is negative is less likely to hold.[17]

## 4.3 Conclusion

This essay analyzes the impact of a government subsidy as a signal to private investors. In our simplified framework it is assumed that firms apply for subsidies for any type of project. In the model's first setup, there are projects of two risk types: High risk projects with little private but high social returns, preferred by the agency and low risk projects with high private but little social returns, preferred by private

[15]Since $\lambda_1 = \lambda_4 = 0$, $\lambda_2$ has to be compared with $\lambda$ and $\lambda_3$ with $1 - \lambda$.

[16]Another indicator that conditions for the pooling equilibrium on S get less restrictive is that beliefs in proposition 4.3 are not justifiable.

[17]In this case, beliefs $\mu$ can be chosen freely for both conditions. However, with the same beliefs the condition in proposition 4.6 is less likely to hold. Furthermore, if $\tilde{C} + x > 0$, there are no beliefs for this condition to hold as $\tilde{D} + x > 0$.

investors. A government agency screens projects and observes their types. Then the agency decides on granting a subsidy. Banks only observe the agency's decision but not the project type and give loans to projects or not.

In the first formulation, the agency's subsidy gives no quality signal. We show that in this setup an equilibrium where the agency is pooling its strategy for both risk types either on S or on nS is very likely. For an equilibrium where the agency is only subsidizing those projects where private returns are not sufficient, a very strict condition on the social return function and the amount of private and public investment must hold.

This changes if there is a pre-screening quality requirement for subsidies. In this setup only a certain proportion of projects meet the agency's quality standard. Only for these projects the agency is deciding on granting subsidies. It is shown that the agency can now effectively differentiate between project types and thus fulfill its role of being a sponsor for projects that are socially desirable. Conditions for this separating equilibrium are likely to hold. Thus, for the signal to be socially beneficial, it is important that it also reveals quality information on projects.

Lerner's (1999) study generally shows the positive impact of a signaling effect of the subsidy. In the light of our results it would be interesting to redo a similar study that explicitly controls for the contained quality information in the signal.

Our model has several simplifying assumptions. We totally abstract from firms' decisions. This is done because firms have an incentive to apply for subsidies for any type of project in the short run. In the long run, however, firms could adapt their research strategies, depending on agency's and banks' behavior. This would then in turn influence conditions for equilibria.

Projects are restricted to be of two different types and we assume perfect screening by the agency and no screening by banks. A setup where projects differ gradually and agency's screening is just superior to banks' screening would be more realistic, yet not analytically tractable.

Finally, we abstract from other information or observation problems. While it would be interesting to study moral hazard for firms' utilization of investment, this essay restricts attention to the asymmetric information problem, which is definitely of importance for investors in uncertain R&D projects.

Our model confirms the empirical observations of Lerner (1999), Feldman and Kelley (2006), and Meuleman and de Maeseneire (2008): Subsidies can have a signaling character if a government agency is better informed about projects than private investors. However, as we have shown in the second setup, it is crucial that the signal reveals quality information about projects to private investors.

## 4.4 Appendix

*Proof of Proposition 4.1.* If there was such an equilibrium, banks beliefs must be $\lambda = 1$ and $\mu = 0$. Therefore, banks decide to give no loan if they observe no subsidy for a project (since $A < 0$) and give loans if a subsidy is observed (since $D > 0$). That gives the agency an incentive to deviate if a project is of high risk type, because the payoff when deviating to grant a subsidy ($-S + I_H(S + P) > 0$) is higher than the agency's payoff when sticking to the no subsidy strategy. $\square$

*Proof of Proposition 4.2.* In the candidate equilibrium, banks beliefs must be $\lambda = 0$ and $\mu = 1$. Therefore banks decide to give no loan if a subsidy is observed (since $C < 0$) and give loans if a subsidy is observed (since $B > 0$). The agency has no incentive to deviate for low risk types as $I_L(P) > -S + I_L(S)$. For high risk types, agency's payoff is $-S + I_H(S)$. If the agency deviates and gives no subsidy to high risk types its payoff changes to $I_H(P)$. Thus, there is no incentive to deviate if $-S + I_H(S) > I_H(P)$. $\square$

*Proof of Proposition 4.3*

a) If the agency decides on subsidizing both types of project, banks' belief $\mu = \alpha$. Therefore, banks decide to give loans when a subsidy is observed if

$$\alpha C + (1 - \alpha)D > 0. \tag{4.2}$$

Off the equilibrium path, banks give loans if

$$\lambda A + (1 - \lambda)B > 0. \tag{4.3}$$

If both (4.2) and (4.3) hold, there is an incentive to deviate for low risk types since $-S + I_L(S + P) < I_L(P)$.

If (4.2) holds and (4.3) does not hold, there is an incentive to deviate for low risk types if $-S + I_L(S + P) < 0$. There is no incentive to deviate for high risk types since $-S + I_H(S + P) > 0$.

If (4.2) does not hold there is an incentive to deviate for low risk types since $-S + I_L(S) < \min\{I_L(P), 0\} = 0$.

Thus, there is an equilibrium where the agency is pooling on S if $\alpha C + (1 - \alpha)D > 0$, $\lambda A + (1 - \lambda)B < 0$ and $-S + I_L(S + P) > 0$. In this equilibrium the agency always grants a subsidy, banks give no loans if no subsidy is observed and give loans if a subsidy is observed. Banks' beliefs are $\mu = \alpha$ and $\lambda > \frac{B}{B-A}$.[18]

b) If the agency decides on subsidizing neither type of project banks' belief $\lambda = \alpha$. Therefore, banks decide to give loans when no subsidy is observed if

$$\alpha A + (1-\alpha)B > 0. \tag{4.4}$$

Off the equilibrium path, banks give loans if

$$\mu C + (1-\mu)D > 0. \tag{4.5}$$

If (4.4) holds and (4.5) does not hold, there is no incentive to deviate for low risk types since $I_L(P) > -S + I_L(S)$, and no incentive to deviate for high risk types if $-S + I_H(S) < I_H(P)$.
If (4.4) and (4.5) hold, there is an incentive to deviate for high risk types since $I_H(P) < -S + I_H(S+P)$.
If (4.4) does not hold, there is an incentive to deviate for high risk types since $0 < \min\{-S + I_H(S), -S + I_H(S+P)\} = -S + I_H(S)$.

Thus, there is no incentive to deviate from the candidate equilibrium if (4.4) holds, (4.5) does not hold and $-S+I_H(S) < I_H(P)$. Beliefs in this equilibrium are $\lambda = \alpha$ and $\mu > \frac{D}{D-C}$.[19] □

*Remark on proposition 4.3 a)*:

Beliefs $\lambda$ are not justifiable for the following reason: The agency would never deviate for high risk types (no matter what strategy the banks are using when no subsidy is observed) because $-S+I_H(S+P) > \max\{0, I_H(P)\}$. For low risk types the deviation would make sense, if a deviation induces banks to give a loan. Hence, banks could infer from agency's payoffs that a deviation from the candidate equilibrium would only make sense if the project is of low risk type. Therefore, banks have to assign zero probability to the node belonging to high risk types, i.e., $\lambda = 0$. If the belief is

[18] The boundary for belief $\lambda$ is derived from (4.3) not holding.

[19] The boundary for belief $\mu$ is derived from (4.5) not holding.

$\lambda = 0$, banks would indeed give loans if no subsidy is observed as $B > 0$. In this case, the agency has an incentive to deviate for low risk types. Thus, there is no perfect Bayesian equilibrium with justifiable beliefs where the agency is pooling on S.

*Proof of Proposition 4.4.* The proof works in a similar way as in the first setup. If a subsidy is observed, banks' belief is still $\mu = 0$. Therefore, banks decide to give a loan if a subsidy is observed ($\tilde{D} + x > 0$). However, banks can no longer be sure of the project type if there is no subsidy observed, because it is also possible, that the project did not even qualify for subsidies. So banks have to calculate conditional probabilities for their beliefs $\lambda_i$. However, no matter if banks decide to give a loan when no subsidy is observed or not, there is always an incentive to deviate for high risk projects since $-S + I_H(S + P) > \max\{I_H(P), 0\} = I_H(P)$. $\square$

*Proof of Proposition 4.5.* In the proposed equilibrium the agency grants a subsidy for all high risk projects that qualify and grants no subsidy for low risk projects. Thus, if no subsidy is observed, a project is either low risk type, or high risk type and low quality. Banks can therefore update beliefs $\lambda_i$. Belief $\lambda_1 = 0$ since high risk projects of high quality receive a subsidy. The probability that a project is non subsidized is

$$\text{prob (non subsidized)} = \underbrace{(1-p)\cdot\alpha}_{\text{prob (high risk} \wedge \text{low quality)}} + \underbrace{(1-\alpha)}_{\text{prob(low risk)}} .$$

Therefore

$$\lambda_2 = \text{ prob (high risk|non subsidized)} = \frac{(1-p)\cdot\alpha}{(1-p)\cdot\alpha + (1-\alpha)} = \frac{(1-p)\cdot\alpha}{1-\alpha\cdot p},$$

and

$$\lambda_3 + \lambda 4 = \text{ prob (low risk|non subsidized) } = 1 - \lambda_2 = \frac{1-\alpha}{1-\alpha\cdot p}.$$

The ratio $\frac{\lambda_3}{\lambda_4}$ must equal the ratio of low quality to high quality projects $\frac{1-p}{p}$. Therefore

$$\lambda_3 = (1-p)\cdot\frac{1-\alpha}{1-\alpha\cdot p},$$
$$\lambda_4 = p\cdot\frac{1-\alpha}{1-\alpha\cdot p}.$$

If a subsidy is observed, banks can be sure that the project is of high risk type, thus $\mu = 1$. Banks will therefore decide to give a loan when no subsidy is observed if

$$\lambda_2 \cdot \left(\tilde{A} - x\right) + \lambda_3 \cdot \left(\tilde{B} - x)\right) + \lambda_4 \cdot \left(\tilde{B} + x\right) > 0, \tag{4.6}$$

and give a loan when a subsidy is observed if

$$\tilde{C} + x > 0. \tag{4.7}$$

a) If both equations hold, the agency has no incentive to deviate for high risk types since

$$-S + I_H(S) > I_H(P),$$

and no incentive to deviate for low risk types since

$$I_L(P) > -S + I_L(S + P).$$

b) If both equations do not hold, the agency has no incentive to deviate since for the high risk types the payoff is

$$-S + I_H(S) > 0,$$

and for the low risk types the payoff is

$$0 > -S + I_L(S).$$

c) If (4.6) does not hold and (4.7) holds, the agency's payoff is 0 for low risk type projects and it therefore has no incentive to deviate if $-S + I_L(S + P) < 0$. For high risk type projects the agency never has an incentive to deviate since $-S + I_H(S + P) > 0$.

d) If (4.7) does not hold and (4.6) holds, the agency's payoff for high risk projects is $-S + I_H(S)$ and it has no incentive to deviate for high risk projects if $I_H(P) < -S + I_H(S)$. For low risk type projects the agency never has an incentive to deviate since $I_L(P) > -S + I_L(S)$.

Thus, if one of the four conditions holds, there is an equilibrium where high risk projects are subsidized and low risk projects are not. □

*Proof of Proposition 4.6*

a) If the agency is always granting a subsidy, it is still possible to be in the no subsidy information set in equilibrium because of the automatically rejected projects. Therefore, banks are not free to choose their beliefs $\lambda_i$. The nodes belonging to $\lambda_1$ and $\lambda_4$ are not reached in equilibrium, therefore $\lambda_1 = \lambda_4 = 0$. Nodes belonging to $\lambda_2$ and $\lambda_3$ are reached in equilibrium with a priori probabilities for high and low risk projects. Thus, $\lambda_2 = \alpha$, $\lambda_3 = 1 - \alpha$. If a subsidy is granted, the belief is calculated as $\mu = \frac{p\alpha}{p} = \alpha$. The rest of the proof works similar to the previous pooling equilibrium. Banks decide to give loans when a subsidy is observed if

$$\alpha \cdot \left(\tilde{C} + x\right) + (1 - \alpha)\left(\tilde{D} + x\right) > 0, \tag{4.8}$$

and when no subsidy is observed if

$$\alpha \cdot \left(\tilde{A} - x\right) + (1 - \alpha)\left(\tilde{B} - x\right) > 0. \tag{4.9}$$

If (4.8) holds, there is no incentive to deviate for the high risk types since $-S + I_H(S + P) > \max\{I_H(P), 0\} = I_H(P)$.
If (4.8) and (4.9) hold, there is an incentive to deviate for the low risk types since $-S + I_L(S + P) < I_L(P)$.
If (4.8) holds and (4.9) does not hold, there is an incentive to deviate for low risk types if $-S + I_L(S + P) < 0$. There is no incentive to deviate for the high risk types since $-S + I_H(S + P) > 0\}$.
If (4.8) does not hold, there is an incentive to deviate for the low risk types since $-S + I_L(S) < \min\{I_L(P), 0\} = 0$.
Thus, there is an equilibrium where the agency is pooling on S if $\alpha \cdot \left(\tilde{C} + x\right) + (1-\alpha)\left(\tilde{D} + x\right) > 0$, $\alpha \cdot \left(\tilde{A} - x\right) + (1-\alpha)\left(\tilde{B} - x\right) < 0$ and $-S + I_L(S+P) > 0$.
In this equilibrium the agency always grants a subsidy, banks give no loans if no subsidy is observed and give loans if a subsidy is observed. Banks' beliefs are $\lambda = \mu = \alpha$.

b) This proof exactly works as the proof for proposition 4.3 b). As banks cannot differentiate between low and high quality projects, the situation if no subsidy is observed is the same. For the argumentation off the equilibrium path, i.e., when a subsidy is observed, only banks' payoffs have to be adjusted. □

# Chapter 5

# Concluding Remarks

All the essays in this thesis deal with the economics of innovation. However, there is a different focus in each essay. The first essay is mainly concerned about the impact of market power and mergers on innovation incentives. The second essay deals with competitive advantages of different types of firms in innovation markets and how these advantages can be combined. The focus of the third essay is how government subsidies to R&D projects can possibly help to reduce problems arising from information asymmetries in innovation markets.

With respect to the different categories of models for innovation mentioned in the introduction, we see that in the first essay a non-tournament model is used to capture process innovations. In the second essay we use a tournament model to describe the search for a patent. Finally, in the third essay, a signaling model is used to describe a market where firms have the possibility to do basic and applied research. So not only the treated elements vary, but the modeling approach is different, too.

Even though three different issues are analyzed, the variety of interesting topics in the economics of innovation is much larger. Other prominent topics are for example intellectual property rights, including discussions on optimal patent systems and licensing (see for example Shapiro (1985)), collusion in innovation markets (see for example Baumol (1992)), or the effects of parallel R&D efforts with discussions on excessive duplication and knowledge spillovers from R&D activity (see for example Nelson (1961)).

However, there is, of course, no paper available that is able to capture all elements in one big picture. Interdependencies between a huge variety of factors and a large scope of actions for agents make it impossible to do a thorough analysis of the considered markets. This may lead to different conclusions, depending on the model used. Gilbert (2006) for example argues that the problem is not to find a model of market structure and R&D, but rather to find the one out of the many existing models which is appropriate for the considered market context. As innovation markets are complex and several opposing factors interact it is crucial to have a good understanding of the relevant market in order to include the factors most important to the specific case.

Even though the variety of topics treated in this thesis makes it difficult to conclude the analysis, there is one common result of the three models: The analysis of agents' interactions is very important. Static analysis of actions might lead to myopic conclusions which are not appropriate, especially in the context of uncertain and dynamic R&D efforts. It is important to consider possible tradeoffs between short and long term efficiency. While the inclusion of dynamic aspects in merger assessment, an examination that accounts for the interdependencies of product and innovation markets, or more specific and fact intensive case by case inquiries might complicate the analysis, we think the improved results justify the effort. We hope that the analyses in our essays will help to improve understanding of the respective sections of the economics of innovation. However, we are aware that several important research questions still remain unanswered, or in other words:

> "We have not succeeded in answering all our problems. The answers we have found only serve to raise a whole new set of questions. In some ways we feel we are as confused as ever, but we believe we are confused on a higher level and about more important things."
>
> – *Lawrence Watkin* –

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