INTER-FIRM NETWORKS: ECONOMIC AND SOCIOLOGICAL PERSPECTIVES

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Bastian Westbrock
Utrecht, October 2010

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Chapter 1

Introduction

Inter-firm networks have recently attracted great attention by researchers in the field of the social sciences. Before the 1980s, the gross of industrial production was perceived to be generated either inside the firm or in the market place. A recent account for this is the decision of the 2009 Nobel committee to honor Oliver Williamson for his “transaction cost theory”. In his seminal work from 1975, Williamson distinguishes between the market and the hierarchy as the two basic forms for the organization of economic activity, but gives little credit to the role of cooperative agreements between firms (Williamson, 1975). This view has largely changed since then. Inter-firm networks have become a popular topic in the leading economics and management journals and an important item on the political agenda. A central objective of the Framework Programmes of the European Commission, for example, is the development of a pan-European network of research and development (R&D) partnerships involving the leading European technology companies. The program is spurred on by the belief that such a network is a key prerequisite for the competitiveness and the economic growth in the Euro zone.

But far from just being a popular topic, inter-firm networks are also a striking empirical phenomenon. The number of collaborative agreements between firms has substantively increased over the past three decades. The Thomson SDC database on strategic alliances and joint ventures, as one of the largest databases on this topic, reports for the year 1985 a total of just 488 completed inter-firm partnerships worldwide. This number rose to an unmatched 2,476 in 2005, suggesting that the markets of the 21st century are characterized by cooperative rather than competitive forces. However, a closer look reveals more subtleties in the structure of the networks. Previous research has identified huge differences across firms in terms of the number of their cooperative agreements (Duysters and Vanhaverbeke, 1996; Powell et al., 2005). Moreover, it has been found that the alliance participants vary considerably in terms of their industry- and country-affiliations. In the light of the potential effects from the specific structure of a network, these observations raise two important questions: how can we explain the observed structures of inter-firm networks? Do they support the efficient organization of economic activity? These are roughly the questions addressed in this dissertation.

This introductory chapter presents the theoretical background for the dissertation and formulates more specific research questions, which will guide the topics in the four main chapters. In order to address their empirical and theoretical nature, the thesis makes use of descriptive (Chapter 2), statistical (Chapters 3 and 5), and theoretical (Chapter 4) methods. In this way, it not only aims to contribute to the advancement of the theory, but also to an understanding of the many practical implications from inter-firm networks. For example, a question we will touch upon is how the structure of an inter-firm network affects the innovative performance in a high-tech industry? Moreover, how can policy makers foster the formation of more efficient network structures?

Another feature of this dissertation is that it follows a multidisciplinary research approach. The answers to the posed questions will depend on the types of network effects taken into consideration. Over the past two decades, various theoretical perspectives have been proposed in a wide range of scientific disciplines, which put different aspects of social and economic networks, such as inter-firm networks, into the focus of their analysis.[1] By building on the economic (Chapters 2–4) and the sociological perspective (Chapter 5), the thesis integrates and extends two of the most influential theories.

1.1 Economic perspective on inter-firm networks

The research questions of this dissertation are closely linked to the economic perspective on inter-firm networks. A central problem in economics is how to organize the efficient use of scarce resources (Pindyck and Rubinfeld, 2005, Chapter 1). Even though inter-firm networks can be understood as a means towards this end, there was surprisingly little scope for them in economics

[1] See Gulati (1998), Goyal (2007), and Jackson (2008) for excellent overviews of the different perspectives.

until around the 1980s. Earlier works on the topic perceived the cooperative endeavors of firms mainly as an attempt to coordinate the production and marketing of their products (Stigler, 1950; Friedman, 1971; Porter, 1983). Collaboration was associated with collusion, the formation of market power, and welfare losses.

What this early work overlooked were the ample opportunities arising from inter-firm collaboration, in particular its potential for the exchange of information. Technical know-how and business-related information are not evenly distributed within an economy, but dispersed across people and organizations. Economic actors who closely coordinate their activities do, intentionally or not, transmit part of this information to their business partners. From this perspective, the collaboration between firms can be understood as a means towards the dispersion of existing information and the increase of an economy's knowledge stock.

Although the foundation for this paradigm shift was set already in the early 1960s by Kenneth Arrow, his work triggered a more benevolent view only twenty-five years after its publication.[2] Ordover and Willig (1985) and Grossman and Shapiro (1986) were among the first to recognize these welfare-enhancing effects. Different types of inter-firm collaboration have been investigated since then. Next to the exchange of information, collaboration provides valuable opportunities for the generation of new information through the combination of distinct units of knowledge. This possibility has been explored under the topic of research joint ventures (Kamien et al., 1992; Rosenkranz, 1995). Also, economists have studied inter-firm agreements aiming at a one-sided transfer of information, such as licensing or counseling agreements. Finally, they have pointed to the benefits for the appropriation of knowledge spillovers from the individual in-house projects of the firms (d'Aspremont and Jacquemin, 1988).

These studies have identified several important conditions under which inter-firm collaboration has welfare-enhancing effects. Yet, they have typically been limited to a comparison of the pros and cons of market-wide collaborative agreements as compared to independently operating firms. In this way, the studies have failed to acknowledge the complexity of "real-

[2] In his seminal paper, Arrow investigated an economy characterized by uncertainties in the production of goods. Producers make decisions on inputs, where the outputs are not completely predictable from the inputs. He concluded that information about the true state of the outputs has economic value, because this information facilitates the allocation of inputs to its most efficient use (Arrow, 1962). Expanding on his work, the benefits from inter-firm partnerships become clear, if assuming that different observations are made about the true state in different parts of the economy.

world" industry structures. However, as empirical research has shown, many markets are characterized by rich network structures of collaborative agreements (Duysters and Vanhaverbeke, 1996; Powell et al., 2005; Rosenkopf and Schilling, 2007). Since the structures of these networks determines the flow of information between firms, they are also likely to influence the desirability of inter-firm collaboration.

The focus of more recent work has, therefore, shifted to an investigation of the structural properties of inter-firm networks. The existing studies on the topic employ game-theoretical models to examine the *equilibrium* networks that arise when firms form partnerships strategically, seeking to maximize their individual profits.[3] By providing detailed predictions for the equilibrium networks, these studies have increased our understanding of the strategic considerations that might determine the formation of inter-firm alliance networks. It is still unclear, however, whether strategic incentives are the driving forces behind the formation of alliances in reality. Other explanations, such as the influence of social ties between the managers of the companies, have been proposed and investigated in the literature (Gulati, 1998; Goyal, 2007; Jackson, 2008). Moreover, it is relatively unkown to what extent the predicted network structures share commonalities with the structures of real-world networks. These issues are picked up in the first research question of this thesis:

Research question 1. *Can the structural properties of inter-firm networks be explained by the strategic formation of partnerships?*

Another open question is whether the predicted networks are desirable, when considering the total welfare which they generate. [4] Previous research has shown that the strategic formation of inter-firm partnerships leads to highly asymmetric network structures, where some firms are even completely excluded from any collaborative activity (Goyal and Joshi, 2003, 2006; Billand and Bravard, 2004). A comparison with the *welfare-maximizing* network structures provides additional insights that might be valuable, not only from a theoretical perspective.

Suppose, for example, that a theoretical analysis of the welfare-maximizing networks shows that they consist of an equal number of partnerships for all firms. Combined with the asymmetric structure of the equilibrium networks, such a finding could be useful for the design of policy programs to

[3]See Bloch (2002) and Goyal and Joshi (2006) for reviews of this literature.

[4]In economics, the total welfare generated in a market is defined as the sum of the profits of all firms operating on the market and the surplus that consumers derive from consuming the goods or services produced by these firms.

foster collaborative activity, such as the European Framework Programmes. It would suggest that an effective program should encourage the formation of alliances between firms that are currently on the periphery of the network. However, the analysis might also show that a welfare-maximizing network is denser, sparser, or even more asymmetric than an equilibrium network. Hence, in order to develop a meaningful policy prescription, researchers and policy makers require a good understanding of the commonalities and differences between the equilibrium and the welfare-maximizing networks. The dissertation elaborates on such a comparison in two separate research questions:

Research question 2. *What are the structural properties of an inter-firm network that maximizes total welfare, when considering the effects on the generation and dissemination of information as well as on the intensity of product market competition?*

Research question 3. *Does the strategic formation of inter-firm partnerships lead to a welfare-maximizing network structure? In which respect does the structure of an equilibrium network deviate from the social optimal network?*

The potential implications for policies trying to stimulate inter-firm collaboration render these questions not only interesting from a theoretical perspective.

1.2 Sociological perspective on inter-firm networks

While economists perceive inter-firm collaboration as a means to generate and diffuse information, sociological work on this topic asks why there is collaboration in the first place. Taking the assumptions underlying Arrow's (1962) economy seriously, there should be a general level of mistrust among economic actors. A peculiarity of the commodity information is namely that its full value is only known to those who have utilized it. Hence, while the managers of a company, for example, do not know a great deal about the value of the know-how offered by a potential alliance partner, they risk giving away valuable technical or economic insights themselves. Thus, anticipating this risk of adverse selection correctly, a rational manager should turn the partnership down. How can the large number of inter-firm alliances be reconciled with the information asymmetries and moral hazards, which are aligned with the formation of collaborative partnerships?

The embeddedness framework offers an important sociological approach to this question (Granovetter, 1985; Powell, 1990; Gulati, 1998). In his pioneering work, Mark Granovetter acknowledges the assumption of purposive economic actors. However, he recognizes that markets are penetrated by networks of social relations between firms, their managers, and customers. These relations range from the close bonds of kinship or exclusive business partnerships to the weak linkages of one-time business transactions, and since they add social context to a business transaction, they are valuable resources for the actors embedded in them (Granovetter, 1985, p. 490). Different dimensions of embeddedness have been investigated in the years which followed Granovetter's seminal paper. Next to the direct social relations between two actors, sociologists have recognized the importance of indirect ties through commonly shared partners and the position of an actor in the overall network of social relations (Granovetter, 1992; Buskens and Raub, 2002; Buskens et al., 2003). A consistent finding in this work is that embeddedness helps economic actors by providing them with access to trustworthy information sources and guiding their selection of business partners. Following these arguments, we empirically test whether embeddedness can explain the formation of inter-firm partnerships:

Research question 4. *Does the embeddedness of firms in networks of social relations determine which firms form new partnerships with each other?*

The findings from such a test not only improve our understanding of the criteria that determine the selection of alliance partners, they also provide important insights into how social embeddedness shapes the structure of an inter-firm network. Because the social relations between firms are likely to differ in terms of their quality and intensity, the preference for embedded partnerships is principally able to explain the rich structural properties of the network of formal alliances and joint ventures between them.

Another ambition of the sociological approach is to show that embeddedness determines the benefits and costs of inter-firm partnerships. One argument propagated in the literature is that embeddedness has value-enhancing effects (Coleman, 1988; Powell and Smith-Doerr, 1994; Podolny and Page, 1998). In the absence of any social bonds between two collaborating companies, their managers require formal contracts to manage the moral hazards associated with the partnership. Yet, the drafting and enforcement of these contracts is costly and time-consuming (Lerner and Merges, 1998; Rosenkranz and Schmitz, 2003). By building on trust and implicit norms of behavior, embeddedness can offer valuable alternatives to contracts which serve as cheaper and more efficient forms of governance (Gulati, 1995a; Robinson and Stuart, 2007).

However, there is another stream in the literature that points to the potential costs of embeddedness. By repeating the alliance with a former business partner or by relying on a familiar informant, a firm can benefit from a trustworthy environment, but it may also neglect some valuable alliance partners outside its personal network. In particular, taken the argument seriously that information is heterogeneous and dispersed among economic actors, the firm might risk to forego access to new sources of information (Granovetter, 1973; Burt, 1992; Uzzi, 1997).

In order to investigate the circumstances under which the benefits of embeddedness outweigh the costs, the focus of more recent work has, therefore, shifted to integrating the two arguments (Mizruchi and Stearns, 2001; Burt, 2005). The questions and findings of this work have important implications for the topic of this dissertation. One additional and so far unexplored aspect of inter-firm networks is however that, next to the benefits and costs for the collaborating firms themselves, also the effects on the other market participants, such as their competitors and the consumers, have to be taken into consideration. What if there is a tension between the effects of embeddedness on the profitability of the collaborating firms and the quality of their products and services? This is the final question investigated in this thesis:

Research question 5. *Does the embeddedness of firms in networks of social relations facilitate, or hinder, the formation of welfare-improving inter-firm partnerships?*

1.3 Description of the main chapters

The following chapters of the dissertation are devoted to a detailed investigation of the research questions. In Chapters 2–4, we elaborate on the economic perspective and examine the role of the network structure for information dissemination and the creation of market power, while abstracting from problems of trust and social bonds. The latter are introduced and examined in Chapter 5. Chapter 6 discusses the general implications arising from our analysis, where the focus is on a comparison of the virtues and the limitations of the economic and the sociological perspectives.

Before we proceed with an outline of the chapter contents, a remark is appropriate about the ambitions of this thesis. Even though it is our aim to infer on the general economic and sociological aspects of inter-firm networks, we cannot claim that this book provides comprehensive answers for all the aspects of the research questions posed. For example, previous work suggests that the structures of inter-firm networks differ per industry (Rosenkopf and Schilling, 2007). The network structures will probably also vary depending on the purpose of the collaborative agreements (joint R&D, marketing, production, etc.). However, it goes beyond the purpose of this dissertation to analyze and compare all the different types of networks in all the different industries. Instead, we investigate two specific inter-firm networks, one from each of the two theoretical perspectives for these networks. Because such an approach has limitations that are specific to the analyses in the four main chapters, we address the question of how far we can generalize from our findings in the discussion sections at the end of each chapter.

In order to investigate the economic aspects of inter-firm networks, Chapters 2–4 focus on networks of R&D partnerships in the manufacturing industries. Chapter 2 presents a descriptive analysis of the basic structural properties and dynamics of these networks. We are very fortunate to have access to the Thomson SDC database, which allows us to explore the overarching network that spans the whole spectrum of manufacturing sectors as well as a large number of countries. The description in the chapter revolves around a re-examination of previously investigated research questions. Prior research has examined major patterns and trends in the number of strategic alliances and joint ventures between firms, but has omitted the structure and dynamics in the firm population itself (Duysters and Vanhaverbeke, 1996; Knoke et al., 2002; Hagedoorn, 2002). This is problematic, because variations in the numbers of firms per country, for example, produce a "natural" inequality in the network that is based on logical opportunities for partnerships.

We integrate data on the worldwide number of public companies and their R&D partnerships and confront prior hypotheses with this data and a set of methods that enables us to correct for patterns in the firm population. Chapter 2 aims at a general and comprehensive picture of the structure and dynamics of inter-firm networks. In this way, it provides a natural starting point for our following chapter, where we test one of the factors that might explain their formation.

Chapter 3 proceeds with an econometric test of existing economic theories to explain the structure of networks of R&D partnerships. Goyal and Joshi (2003, 2006) and Billand and Bravard (2004) present a number of game-theoretical models, in which competing firms form bilateral R&D alliances with each other in order to gain competitive advantage over their rivals. An interesting aspect of their models is that they predict network structures that share some important commonalities with the structures of the networks observed in Chapter 2. Using a panel of firms from several medium- and high-tech manufacturing industries, we investigate whether the formation of R&D partnerships adheres to scale effects, as the central mechanism underlying the formation of alliances in their models. Scale effects arise because the expected profitability of an alliance is positively related to the competitive position of a firm in the market. The analysis in this chapter provides some interesting insights into the role of strategic motives for inter-firm collaboration. In this way, it contributes to our examination of Research Question 1.

Chapter 4 builds on the game-theoretical model introduced in Goyal and Joshi (2003, 2006) and assesses the social desirability of the predicted network structures. In the model developed in this chapter, a set of firms compete in a market for differentiated products. Before the competition is resolved, every firm may form a bilateral R&D partnership with every other firm operating in the market. It is assumed that such a partnership generates a process innovation that enables the involved partners to reduce their costs of production. However, a partnership is also aligned with some costs of formation. By determining the structural properties of the total welfare-maximizing networks, the chapter develops an answer to Research Question 2. Moreover, by extending on Goyal and Joshi's (2003, 2006) characterization of the equilibrium networks, the chapter compares the structure of the welfare-maximizing network with the equilibrium network structures (Research Question 3). Motivated by our empirical support for Goyal and Joshi's model found in Chapters 2 and 3, the chapter concludes with some recommendations for policy programs to foster inter-firm R&D collaboration.

Chapter 5 of this thesis examines the role of inter-firm networks in the light of information asymmetries, mistrust, and embeddedness, where the focus is on an enquiry of Research Questions 4 and 5. The specific network being studied is the network of social relations between law firms and the acquiring companies in international mergers and acquisitions (M&A's). The chapter investigates empirically whether the network resources of a law firm increase its chances of being nominated as a legal counsel. Moreover, it is examined whether the firm's network resources also improve the quality of its legal services.

Two types of social networks are taken into consideration. First, some of the companies that are very active in the international merger market make repeated use of the same law firms as their merger counsels. These repeated interactions result in a network of advisor-client relations that provides valuable opportunities for the law firms embedded in them. Second, because international M&A's are complex business transactions, many law firms request the help of other law firms, which creates a network of co-advisor alliances between them. The empirical analysis in this chapter consists of two steps. In the first step, we investigate the role of embeddedness for the quality of the legal counsel from a law firm in an international M&A. Our measures of quality are the likelihood that the merger is completed and the required time to completion. In the second step, we test the role of embeddedness for the nomination of a law firm as a legal advisor.

The results of our analysis might uncover ambiguous effects of embeddedness. Suppose, for example, that embeddedness is the key criterion for the nomination of a merger counsel. Such a finding would be in line with the assertion that economic actors rely on their own experience and trusted informants to assess the trustworthiness and capabilities of a potential business partner (Granovetter, 1985). However, it is not so clear that an embedded law firm is able to provide the best legal advice. Instead, since international M&A's demand very specific, country-dependent legal expertise, a local expert law firm might be the better alternative for the successful and timely completion of the transaction. Hence, by relying on the network resources of his former legal counsel a client might select suboptimal counseling services.

Before we proceed with the presentation of the four main chapters, we should make a final remark about the setup of this dissertation. The following chapters were written as independent research papers. As a consequence, the terminology and notation may vary slightly between them. Moreover, some overlap, especially between the introductory sections of the chapters and this introduction, could not be avoided.

Chapter 2

The international network of research and development (R&D) partnerships: a descriptive analysis*

2.1 Motivation for a re-examination of macro-level trends and patterns

Networks of inter-firm research and development (R&D) partnerships have recently attracted great attention from researchers (Mytelka, 1991; Gulati, 1998; Nooteboom, 2004; Goyal, 2007) and policy makers (Caloghirou et al., 2004). This interest is spurred by the belief that inter-firm networks can play an important role in international technological development and economic growth. Two sources of network effects have been identified in the literature. First, there are the beneficial effects from the collaborative partnerships themselves. As compared to in-house projects, collaborative R&D avoids the duplication of research investments and enables the exploitation of nationally distinct stocks of know-how (Kogut, 1988; Hagedoorn et al., 2000).

On top of this, it has been argued that inter-firm networks can provide benefits that go beyond the effects of the relationships they consist of. At the heart of this idea are some studies suggesting that the network itself is

*This chapter is the result of a joint project with Michał Bojanowski and Rense Corten, both working at the Department of Sociology, Utrecht University.

a locus of knowledge production (Freeman, 1991; Powell et al., 1996; Ahuja, 2000; Schilling and Phelps, 2007). The studies point to various mechanisms through which the network facilitates information production and diffusion: first, know-how can be transmitted along chains of partnerships in the network from firm to firm. Second, information that "leaks" out of a company's R&D projects may be assimilated by the firms that are connected to it. Finally, firms can use the network to gather timely information about technological novelties and trends (Ahuja, 2000). The importance of the aforementioned network effects is that they imply the possibility that a few international partnerships link distinct knowledge pools in different parts of the world. Moreover, they point to the capability of the network as an effective device for transferring technological know-how to the lesser developed countries.

However, the presence of network effects also raises some questions about the structure of the global network of R&D partnerships. Is the network sufficiently connected to enable international know-how diffusion? Is there sufficient overlap between national or regional clusters in the network? Moreover, are collaborative activities sufficiently equally dispersed around the globe? In this chapter, we contribute to these questions by empirically investigating important macro-level properties of the inter-firm network . We examine the *density*, *concentration*, and *integration* of the network on a global scale and over the time period from 1989 to 2002.

When compared to prior work on these questions, the distinctive feature of the study in this chapter is that we isolate an important, but so far omitted, factor to explain the structure of the inter-firm network, namely the structure of the global firm population. To the best of our knowledge, all previous studies have formed their own view on the network based on an observation of the distribution of inter-firm R&D partnerships around the globe (Duysters and Hagedoorn, 1996; Knoke et al., 2002; Hagedoorn, 2002; Moskalev and Swensen, 2007). We argue that disregarding the numbers of firms per country and their changes over time will logically lead to a distorted picture of the network. The reason is that many properties of the worldwide distribution of R&D partnerships, such as the geographical concentration of partnerships or the fraction of international alliances, are influenced by the sizes of the national firm populations.

For example, prior research has found that the largest share of the worldwide number of R&D partnerships is between firms from the stronger economies in North America, Western Europe, and East Asia (Freeman and Hagedoorn, 1994). This finding has led to a rather pessimistic outlook for the future of the technological gap between developed and less developed countries. We argue, however, that it is natural to find more partnerships within the developed countries, because these countries also host the largest share of the worldwide number of firms. Similarly, it has been found that US companies form a lot of domestic partnerships when compared to other countries (Hagedoorn, 2002). This pattern has been explained by the favorable antitrust treatment of R&D joint ventures in the United States. However, given the size of the US economy, we would expect a large share of domestic partnerships, simply because the number of available domestic partners is much larger in the United States than any where else.

One could argue that these considerations alone do not make our exercise indispensable, because the firm population is just one explanatory variable of the network structure, amongst many others. Yet, as compared to other variables, the structure of the firm population is unique because it produces a "natural" inequality in the network based on logical *opportunities* for partnerships. In order to distinguish the effect of opportunities from other determinants of the network structure, we apply measures of network density, integration, and concentration taken from the social network literature that are corrected for the different sizes of the national firm populations.[1]

Our analysis reveals two sets of results. On the one hand, it confirms the robustness of some of the previous empirical findings. First, in line with Hagedoorn (2002), we find an unclear time trend in the total number of R&D partnerships over the 1990s. Second, we reconfirm the trend towards the formation of segregated national clusters in the global alliance network, as firms show a steadily declining interest in international partnerships (Duysters and Hagedoorn, 1996; Knoke et al., 2002). On the other hand, our analysis provides some novel insights: first of all, the network is less concentrated than firstly suggested by previous research. The dominance of US firms in the network is to a large extent explained by the pure size of the US economy. Japanese firms are comparably active collaborators when controlling for the smaller number of firms based in Japan. Second, we find that the inter-firm R&D alliance network is extremely sparse. Comparing the number of partnerships to the number of firms, our findings suggest that the typical firm is involved in a partnership about every thirty-five years. Moreover, the group of companies that is involved in a considerable number of alliances represents only a small fraction of the numbers of companies worldwide. Hence, an important contribution from our analysis is a rather different view on the global R&D partnership network than the one

[1] For an overview about the social network measures, see Wasserman and Faust (1994).

put forward in previous research. The sparseness of the network raises some serious doubts about the general importance of collaborative R&D for the firms themselves, but also about the role of the network as a spurring force behind a globalizing economy.

The remainder of this chapter is organized as follows. Section 2.2 reviews the state-of-the-art of what is known about the questions we will raise. Section 2.3 presents our methodology and Section 2.4 introduces the datasets on inter-firm partnerships and numbers of firms per country. Our results are presented in Section 2.5. Their discussion and the conclusion are delegated to Section 2.6.

2.2 Previous findings

Several previous studies have investigated trends and patterns in the distribution of inter-firm R&D partnerships around the globe. This research has attributed regional differences and temporal changes in the formation of new partnerships to economic, political, and technological developments. Freeman and Hagedoorn (1994) and Hagedoorn (2002), for example, point to the rapid growth of the information technology sector in the 1960s and the rise of the biotech sector in the 1970s as two important factors for the rise of worldwide collaborative activities. On the political side, supranational efforts towards an integration of the world economy, such as the Uruguay Round, have provided firms with new opportunities for international partnerships (Desai et al., 2004). Because the purpose of these studies is directly related to the aim of this chapter, the questions and findings are reviewed here.

Two often studied figures are the level and the time trend in the number of newly formed R&D partnerships (Hagedoorn, 1996, 2002; Knoke et al., 2002). A widely accepted hypothesis is that due to the liberalization of formerly protected markets, shortened product life cycles, and the increased uncertainty of R&D projects, collaborative research has become more important during the second half of the past century. Since the mid-1980s, R&D collaboration constitutes a key factor in the innovation strategy of a firm (Harrigan, 1988; Mytelka, 1991; Nooteboom, 1999). Because the propensity to collaborate also determines the density of the global alliance network, we investigate in accordance with this research:

Question 1 (Network density). *How dense is the global network of inter-firm R&D partnerships?*

Question 2 (Network density over time)**.** *Has the density of the global network of inter-firm R&D partnerships increased or decreased during the period 1989–2002?*

Several studies have confirmed the first hypothesis by showing that the number of newly formed R&D partnerships has drastically increased during the 70s up to the mid 1980s (Hagedoorn, 1996, 2002). However, for the period 1990–1998, which is also the period studied in this chapter, Hagedoorn and van Kranenburg (2003) have not found any such clear trend, but rather a cyclical time line. An explanation for this pattern comes from Gomes-Casseres (1988). He argues that such an "alliance cycle" can be explained by bandwagon effects. In order to succeed in the competition for scarce resources and to maintain a legitimate position in the market, a company is expected to adopt the best practices from other, successful firms. However, what is a best practice at certain times might be out of fashion at other times. Other research links the alliance cycle of the 1990s to the parallel wave of mergers and acquisitions (Desai et al., 2004).

Another commonly studied phenomenon is the extent to which collaborative activities are regionally concentrated (Freeman and Hagedoorn, 1994; Hagedoorn, 2002). The underlying motivation, both for the authors as well as for the study in this chapter, is the hope that firms from all countries can, and also do, take advantage from collaborative R&D. Accordingly, we investigate the question:

Question 3 (Network concentration)**.** *Are there national or regional differences in the proclivity of firms to form R&D partnerships?*

Freeman and Hagedoorn (1994) have found that firms from the stronger economies in North America, Western Europe, and East Asia are involved in the vast majority of all partnerships. The authors conclude that the less developed countries lack the necessary technological and organizational capabilities for the complex task of R&D partnering. Hagedoorn (2002) provides an alternative explanation and relates it to the fact that the high-tech sectors, such as the biotech industry or the information technology industry, are concentrated in the stronger economies, and the United States in particular. However, because it is well-known that the firms from R&D intensive sectors are more prone to coordinate their research activities, the observation of Freeman and Hagedoorn (1994) is nothing but a reflection of sectoral differences in the proclivity to form R&D partnerships.

Another frequently studied feature of collaborative activity is the extent of its internationalization (Duysters and Hagedoorn, 1996; Hagedoorn, 2002). International R&D partnerships are important, because they facilitate the combination of distinct national knowledge resources and can be an effective means of transferring know-how to the least developed parts of the world. In the literature, there are two opposing hypotheses concerning the trend towards international R&D partnerships over time. The still ongoing supranational efforts towards a liberalization of foreign ownership, as well as the progressing international division of labor, have split formerly integrated production processes into separate pieces scattered around the world. This suggests, on the one hand, that international collaboration has become more important over time (Duysters and Hagedoorn, 1996). On the other hand, Desai et al. (2004) put forward an alternative hypothesis and argue that international partnerships have formerly been used as a vehicle to circumvent barriers to foreign ownership. However, because the liberalization efforts have rendered these partnerships obsolete, firms replaced alliances by direct investments abroad. Hence, rather than increasing the importance of international partnerships, the authors expect the opposite effect:

Question 4 (Network integration over time)**.** *Has the global network of R&D partnerships become more or less integrated during the period 1989–2002?*

According to Hagedoorn (2002), the share of international partnerships has been steadily declining over the period 1980–1998. Moreover, he has observed a strongly declining trend for the United States. Knoke et al. (2002) have made a similar observation for the information technology sector, where in particular Japanese semiconductor firms have reduced their international partnerships during the 1990s. These findings support the views of Desai et al. (2004) and suggest that international alliances have been replaced by cross-border mergers and foreign direct investments. Hagedoorn (2002) has come up with an alternative explanation, which is closely related to the argument developed in this chapter. He argues that the share of international R&D partnerships has declined in the US, not so much because of changes in the international environment, but rather as a result of domestic developments. The 1980s and 1990s have witnessed a strong growth in the US biotech and information technology industries, aligned with the start-up of many new businesses. Hence, it is not so much a tendency to avoid foreign alliance partners, but rather the availability of interesting local partners that explains the diminishing importance of international collaboration in the United States.

The previous findings have led authors, like Hagedoorn (2002) and Freeman and Hagedoorn (1994), to the question about regional differences in internationalization. Their concern is that US and Japanese firms tend to segregate themselves from the rest of the global network, thereby reducing potential knowledge spillovers from these important economies. Furthermore, considering the overall low level of collaborative activity in the least-developed countries, it is important to know whether these countries are at least connected to firms from the regions North America, Western Europe, and East Asia:

Question 5 (Regional differences in network integration)**.** *Are there national or regional differences in the propensity with which firms form R&D partnerships with foreign partners?*

Hagedoorn (2002) has investigated the differences in internationalization between the developed economies, and Freeman and Hagedoorn (1994) examined the link between these economies and the least-developed countries. Their findings confirm a low propensity in choosing foreign alliance partners for US firms, but not for Japanese firms. Moreover, they show that almost all R&D partnerships involving firms from the least-developed countries have a partner from one of the stronger economies on board.

In the following sections, we reinvestigate the questions as stated above by using a novel set of measures and novel data. We complement data on inter-firm R&D partnerships by data on the numbers of firms around the globe and examine the resulting data structure using methods from the social network literature. By doing this, we are able to isolate an important, but so far omitted factor, to explain patterns and trends in worldwide collaborative activities, namely the structure of the global firm population.

2.3 Research methodology

Here, we present our measures of network density, concentration, and integration and compare them with the measures that have previously been used to examine the worldwide network of R&D partnerships. In order to investigate the overall importance of collaborative R&D and its trends (Questions 1 and 2), previous studies have counted the numbers of newly formed R&D partnerships per year (e.g., Hagedoorn, 1996, 2002). However, this measure can lead to a misleading conclusion, as we will demonstrate with the following example. Suppose we find that in a given year the number of newly formed partnerships has increased when compared to the previous year. There are two alternative interpretations for this observation:

1. The number of partnerships per firm has increased, which means that firms have been more actively creating them. Following this interpretation, we would have to conclude that R&D collaboration has become more important for firms over the two years.

2. Firms have been equally active in creating partnerships in the two years, but the number of firms has increased. According to this interpretation, there would be no reason to conclude that the importance of R&D collaboration has increased.

The example suggests that a measure of the importance of R&D collaboration has to be corrected for the number of active firms in a given year. Such a measure is the *average degree* (Wasserman and Faust, 1994). For a formal exposition of the average degree, denote the degree of firm i in year t by η_i^t, which measures the number of newly formed partnerships of the firm. Moreover, denote the set of firms in year t by N^t and the cardinality of this set by n^t. The average degree in the network is defined as:

$$\overline{\eta}^t = \frac{1}{n^t} \sum_{i \in N^t} \eta_i^t. \tag{2.1}$$

To address the question about the concentration of collaborative activities in certain countries or regions (Question 3), previous studies have calculated and compared the number of partnerships per country and region, respectively (Freeman and Hagedoorn, 1994; Duysters and Hagedoorn, 1996). Similar to the shortcoming of the previous measure of network density, the number of partnerships per country is not an appropriate measure for a comparison of national differences in propensities or barriers to collaboration, because it does not take into account the fact that larger countries are expected to have more partnerships. Therefore, we use the *regional average degree* as a measure of country-specific propensities and constraints to collaboration. Formally, let us denote the set of firms in country k and year t by N_k^t. The regional average degree is defined as:

$$\overline{\eta}_k^t = \frac{1}{n_k^t} \sum_{i \in N_k^t} \eta_i^t. \tag{2.2}$$

In the same manner, regional average degrees can be defined on the level of world regions by letting N_k^t denote the set of firms in region k.

Finally, in order to trace patterns and trends in the affinity towards foreign alliance partners, Freeman and Hagedoorn (1994) and Hagedoorn (2002) have calculated the shares of international alliances in the total number of newly formed partnerships (Questions 4 and 5). As already outlined in the work by Blau (1977) and more recently by Currarini et al. (2009), a problem with this measure is that it conceals differences in the opportunities for international partnerships stemming from differences in the numbers of available alliance partners. To illustrate this argument, say we observe that the firms from a certain country form relatively more domestic as compared to international partnerships. There might be two possible explanations:

1. The firms from this country have, for whatever reason, a *preference* for domestic partnerships; or
2. there are, as compared to the rest of the world, a lot of firms in this country and therefore a lot of *opportunities* for domestic partnerships.

While the researcher might be interested in the first effect, ignoring the second will lead likely to a wrong conclusion about the role of preferences. In order to isolate the preference-based tendency to form domestic partnerships, we calculate for each country a variant of the *inbreeding homophily* measure introduced by Coleman (1958). Formally, denote the share of domestic partnerships in the number of newly formed partnerships in country k and year t by s_k^t. We define the inbreeding homophily index of country k as:[2]

$$H_k^t = \frac{s_k^t - n_k^t/n^t}{1 - n_k^t/n^t}. \tag{2.3}$$

In order to study the global trends in network integration, we trace the development of the average of the national homophily measures. Moreover, for the comparison of homophily across world regions, let the term s_k^t measure the share of intra-regional partnerships in region k and let the fraction n_k^t/n^t be the number of firms in the region relative to the worldwide total.

[2]The measure (2.3) is a variant of Coleman's original measure, because Coleman (1958) defines the term s_k^t in terms of degrees in a network and not in terms of partnerships, as we do here. The reason for this deviation from the original definition is that we want to apply a homophily measure that is closely related to Hagedoorn's (2002) measure of internationalization, apart from the fact that ours allows to isolate the effects from alliance opportunities. In fact, the term s_k^t in the nominator of (2.3) corresponds to an uncorrected measure of homophily, which is directly related to Hagedoorn's share of international alliances, i_k^t, by $s_k^t = 1 - i_k^t$.

The inbreeding homophily measure has several desirable properties. Because firms from larger countries have more opportunities to source out interesting domestic partners, the measure is declining in the relative size of a country, n_k^t/n^t. The index value is zero, if the observed share of domestic partnerships equals the relative country size, $s_k^t = n_k^t/n^t$. In this case, the firms from the particular country are defined to exhibit no preference towards, or against, domestic partners. The observed share of domestic partnerships is then merely due to opportunities. In contrast, there is a maximal tendency to form domestic partnerships in a country if $s_k^t = 1$. Finally, if the share of domestic partnerships is smaller than the relative country size, $s_k^t < n_k^t/n^t$, a country is said to be heterophile.

2.4 Data

In the following, we present the data used for our study. Since our aim is to develop a complete picture of the worldwide network of R&D partnerships, the requirements on the scope and completeness of an appropriate set of data are relatively high. First of all, we need a sample of firms which is representative for the global population of firm. An adequate dataset has to contain the numbers of firms per country for a series of consecutive years. Moreover, we require a complete collection of all R&D partnerships between the firms in the sample. For every partnership, information should be available on the date of completion, the names of the participants as well as their countries of origin. For our study, we combine data from two sources which satisfy the above mentioned requirements. What follows is a detailed description of the sources and the applied sample selection procedure.

The first source of data is the Thomson Financial SDC Platinum database on inter-firm strategic alliances and joint ventures. The database gathers information on newly formed partnerships from press releases, specialized journal articles, and other business-oriented databases. While the first recorded joint ventures date back to the early 1960s, a comprehensive data collection service only started at the end of the 1980s. Next to the above mentioned partnership characteristics the database contains variables on the partnership purpose, the mode of governance (contract versus ownership), the participants' industry affiliations, and their public status.[3]

When compared to alternative data sources on R&D partnerships, the advantage of the Thomson SDC data is its global and cross-industry scope

[3] For more information, consult `http://www.thomson.com/content/financial/brand_overviews/SDC_Platinum`.

(Schilling, 2009).[4] A major limitation lies in the method of data collection. The appearance of a partnership in the database depends on the self-interest of firms and news services to publicize the announcement of a joint venture. Moreover, Thomson Financial gathers most of its information from English speaking news services and, thus, one can expect a reporting bias towards joint ventures between Anglo-Saxon companies. In order to address these problems, we confined our analysis to alliances and joint ventures where at least one *publicly held company* is involved. Because the activities of public companies are of interest to financial investors and the general public, we suspect that their partnerships are also likely to appear more consistently in the business news than the alliances between only private firms. As a partial indication for this conjecture, the fact is that in 80% of the R&D partnerships recorded in the Thomson SDC data at least one of the participants is a public company.

Another possible limitation lies in the fact that Thomson Financial itself might not have any particular interest in gathering a complete collection of all completed alliances. The reason is that the company's primary target group are financial investors who rather require more detailed information for a selective set of events. To make the extent of this problem visible, we have calculated the measures, which have been used in previous studies to describe the worldwide alliance network, for the Thomson SDC data as well and compared them with the findings from a study using the same measures but an alternative alliance dataset. The calculations and comparisons of the measures are presented one by one in Section 2.5. Our overall conclusion is that many of the previously found properties of the worldwide distribution of R&D partnerships can be replicated within the Thomson SDC data as well.

Our second data source complements the alliance data by providing information on the numbers of public companies per country and year. The numbers are retrieved from the World Development Indicators 2003 (WDI), which is part of the annual reports of the World Bank and records the numbers of domestic companies listed on the national stock markets.[5] The advantage of the WDI data for our purposes lies in the fact that it covers a large set of countries and an extensive period of time including the late

[4] Some important alternative data banks on inter-firm R&D partnerships are the databases from MERIT-CATI, CORE, NCRA-RJV, Recombinant Capital, and Bioscan. See Schilling (2009) for a recent detailed comparison.

[5] For more information, see `http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:21298138~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html`.

1980s and the 1990s, where the number of newly formed R&D partnerships reached its peak.

A major drawback is that the WDI data does not provide a complete picture of the total number of firms in a country, because it does not contain any information on private enterprises. Moreover, the reported numbers might not even be representative for the firm populations, because the proportion of firms that go public may vary from country to country. These two issues can render the interpretation of our findings difficult. However, given the lack of an alternative database, with the required comprehensive geographical and temporal scope, we think that the large number of countries and the extensive time period covered by the WDI data far outweigh these disadvantages.[6]

Another problem of the WDI data is that it does not contain a split of the numbers of public companies by industries. This can be problematic, because for an accurate picture of the network density, for example, one would want to filter out those companies from the network, where ex-ante considerations exclude the possibility of R&D partnerships. One might consider the financial service industry. Since the typical bank does not even have an R&D budget, it is unlikely that it will ever be involved in a research project or be considered as an alliance partner. However, as is outlined below, we apply a broad definition of an R&D partnership in this chapter, which also includes agreements involving a mere licensing of technologies, and, as is shown in Table 2.1, even the financial sector is involved in quite a lot of these agreements.

In order to obtain a complete picture of all R&D partnerships of the public companies in our sample, we confine our analysis to a subset of the available data. First, we select the largest possible number of countries and subsequent years from the WDI data, for which the database provides complete information on the numbers of public companies. This selection results in the period 1989–2002 and a total number of firms from 52 countries situated in different parts of the world. The countries within our study

[6]Some alternative data sources we considered were the Worldscope company profile database as well as the United Nations UNIDO data. The former suffers from the same problem as the WDI data that it records only publicly held companies. While the UNIDO data contains private business establishments as well, a major problem is its limited scope, as the numbers were collected for the first time in 1998. Moreover, the use of the UNIDO data would have raised a similar problem to the non-representativeness of the number of public companies, because the propensity to open a business establishment differs from country to country as well. Two examples are Poland and Italy, where the numbers of registered business establishments are comparable to the ones of the United States, because many employees work on a freelance basis.

Industry sector	Count of alliance participations	% of total
Agricultural, forestry, fishing	2	0
Mining and construction	177	1
Manufacturing	8,470	71
Transportation, communications, electricity services	605	5
Wholesale and retail trade	238	2
Finance, insurance, real estate	163	1
Personal and business services, computer software	2,333	19
Public administration	3	0
	11,991	100

Table 2.1: Industry affiliation of alliance participants.

comprise 27 nations classified by the Worldbank as high-income economies, 19 classified as middle-income economies, and 6 classified as low-income countries. The numbers of public companies are presented in Table A.1 in the Appendix. Second, based on the previous selection, we include only those alliances and joint ventures from the Thomson SDC data, where at least one public company is involved that has its headquarter in one of the 52 countries. However, the other alliance participants might well be based outside the selected countries and might also be privately held firms or governmental institutions.

Finally, we focus on those partnerships, where the purposes is joint R&D as indicated by the alliance activity description. This selection includes equity-based research joint ventures as well as the more loose forms of contract-based R&D agreements. As a result, we keep the information on 8,150 R&D completed partnerships between 3,555 alliance participants out of a total number of 31,671 public companies. The numbers of partnerships per year and country are summarized in Table A.2 in the Appendix. The industry affiliations of the alliance participants are presented in Table 2.1.

2.5 Results of a descriptive analysis

Figure 2.1 illustrates the network generated from our data. The figure shows the aggregated network consisting of all the partnerships formed between 1989 and 2002. In the following parts of this section, we reproduce the gradual construction of the network, investigating trends in the speed of construction and analyzing how the international ties in this network are related to the numbers of firms in the different regions.

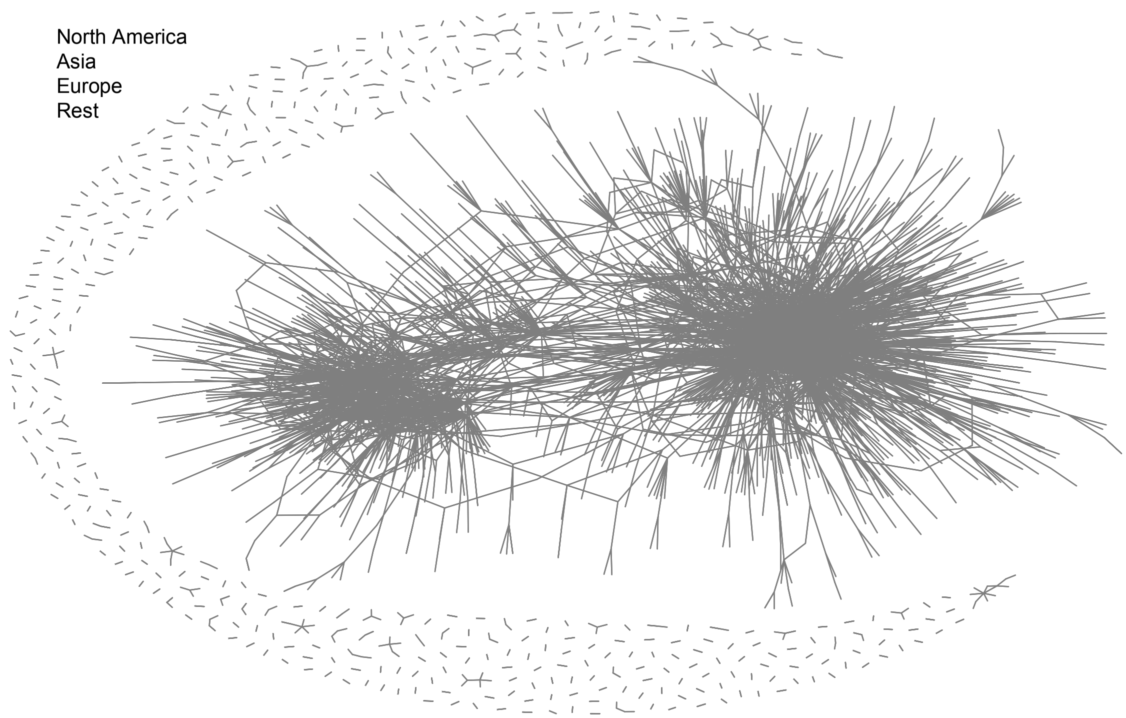


Figure 2.1: Global network of R&D partnerships, accumulated over 1989–2002.

NOTE. The figure illustrates the network of R&D partnerships between a number of public companies from 52 countries. The network is generated using the Fruchterman-Reingold alignment algorithm in the software package R. The nodes in the figure depict those firms from which at least one R&D partnership originated in the period 1989–2002. The nodes are colored according to their regional affiliation (Anglo-Saxon countries: United States, Canada, United Kingdom, Australia, New Zealand, and Israel; East Asia: Hong Kong, Japan, South Korea, and Singapore; Western Europe: the countries on the Western European continent).

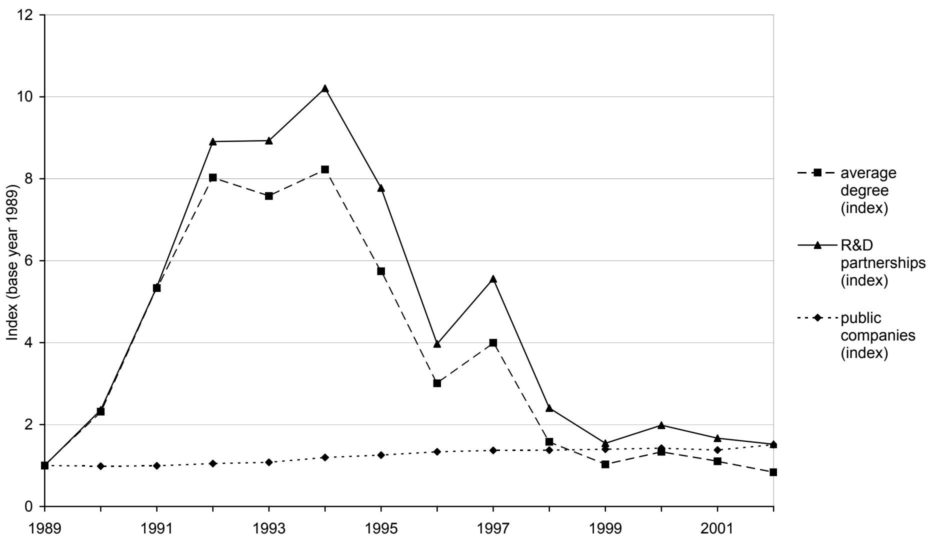
2.5.1 Network density

Here, we investigate the time-average density of the network which will serve as our answer to Question 1. Moreover, we examine the rate at which new partnerships have been added to the network over time (Question 2). In order to isolate the effect of the structure and the dynamics of the worldwide firm population, we examine both density measures, the average degree as well as the previously used number of newly formed R&D partnerships. Figure 2.2 summarizes our findings.

The figure shows the time lines for the average degree and the number of newly formed alliances using an index representation. Both measures indicate the same picture of a phase of expansion in the formation of new partnerships, peaking in the mid 1990s, followed by a significant contraction. Until 1994, the number of new partnerships rose sharply to a level ten times greater than in 1989, but declined thereafter to a level comparable to the original. Similarly, the average degree was more than eight times greater in 1994 than in 1989. Hence, the findings from both measures contradict the hypothesis that firms made increased use of collaborative research during the 1990s. Instead, they support Hagedoorn and van Kranenburg's (2003) observations of an alliance cycle.

Moreover, our analysis of the average degree provides some interesting insights into the overall extent to which firms are connected in the global alliance network. As suggested by the small table below the graph in Figure 2.2, the typical public company in our sample is only involved in a very small number of R&D partnerships. In fact, averaged over the period under study, the average degree amounts to just 0.028 suggesting that the typical firm signs a collaborative R&D agreement about every thirty-five years. In light of the findings of the literature on joint venture termination, according to which the average lifespan of a joint venture amounts to no more than seven years (Kogut, 1989; Park and Russo, 1996), we are left to conclude that the typical public company was not involved in any ongoing R&D partnership at all during the 1990s.

Because these findings seem to contradict the observations from previous studies, let us briefly discuss their relationship here. Earlier studies have reported some very actively collaborating firms in the high-tech sectors, in particular in the information technology and the biotech industries (Hagedoorn and Schakenraad, 1992; Duysters and Vanhaverbeke, 1996; Powell et al., 2005). How can the low average degree be reconciled with these observations? To investigate the issue, we have to take a closer look at the distribution of newly formed partnerships across the firms in our dataset.



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Average degree	.008	.018	.042	.063	.059	.064	.045	.024	.031	.012	.008	.010	.008	.007

Figure 2.2: Newly formed R&D partnerships and average degree over time.

The distribution is illustrated in Table 2.2. As the table shows, all R&D partnerships were concentrated around a small fraction of the total number of public companies during the period 1989–2002. In 1989, for example, the number of firms that announced at least one collaborative agreement was just 130. This number rose to 973 in 1994. However, as compared to the total number of public companies, both were very small numbers. In fact, in a typical year, a share of only 1% of the total number of firms announced any collaborative agreement at all. Some of these firms, notably a handful of well-known players from the IT-industry, have been involved in a considerable number of partnerships every year. Hence, a way to reconcile our observation of a low average degree with the findings from the previous literature is to recognize that the global network of R&D partnerships is very concentrated: while the vast amount of collaborative activity is due to a small number of firms from the high-tech sectors, there is a large, but previously overlooked, amount of firms that are not even involved in a single partnership.

Year	Public companies Number	Avg. degree	Alliance participants Number	Avg. degree	Examples of top collaborators
1989	25,575	.009	130	1.54	Sun Microsystems (14), Novell (6)
1990	25,148	.016	308	1.48	IBM (14), DuPont (7)
1991	25,403	.029	578	1.83	IBM (27), Hewlett-Packard (19)
1992	26,786	.040	811	2.07	IBM (51), Hewlett Packard (31)
1993	27,572	.037	831	1.97	IBM (44), Microsoft (21)
1994	30,593	.042	973	2.02	IBM (39), Hewlett Packard (37)
1995	32,072	.036	820	1.76	Microsoft (30), IBM (29)
1996	34,151	.025	535	1.50	Microsoft (16), IBM (14)
1997	35,008	.033	713	1.53	Microsoft (30), Hewlett-Packard (23)
1998	35,143	.021	334	1.31	Microsoft (5), Bayer (5)
1999	35,723	.017	238	1.21	SmithKline Beecham (4), Monsanto (4)
2000	36,399	.008	292	1.30	Hitachi (9), Panasonic (9)
2001	35,237	.006	248	1.23	Samsung (6), Panasonic (6)
2002	38,583	.004	208	1.21	Fujisawa Pharma (5), GlaxoSmithKline (5)

Table 2.2: Central firms, peripheral firms, and isolates in the global network of R&D partnerships.

2.5.2 Regional concentration of the network

In the previous subsection, we have seen that a small group of firms are responsible for a large fraction of the newly formed R&D partnerships. Here, we investigate whether the concentration of collaborative activity is also reflected on the level of countries and world regions (Question 3). Considering the important role that the inter-firm alliance network might have for the economic growth in the less developed parts of the world, the hope is that companies from all countries are equally involved in it.

Several previous studies have found that the majority of firms participating in R&D agreements are based in the world's strongest economic regions, the Anglo-Saxon countries, Western Europe, and East Asia (Freeman and Hagedoorn, 1994; Duysters and Hagedoorn, 1996; Knoke et al., 2002). Our findings summarized in Table 2.3 confirm this pattern, regardless of whether we look at the worldwide distribution of partnerships, as the previously used concentration measure, or the regional average degree. 99% of all the companies that participated in an alliance between 1989 and 2002 were based in the Anglo-Saxon countries, Western Europe, or East Asia. Also, the average degree of Western European firms, as the least active of these regions, was still more than ten times larger than the average degree in the developing countries.

However, our analysis of the average degree provides a rather differ-

	Number of R&D partnerships	% of total	Regional average degree
Regions			
Anglo-Saxon countries	482	73	0.052
East Asia	118	18	0.040
Western Europe	53	8	0.016
Developing countries	6	1	0.001
Countries			
United States	435	63	0.059
Japan	107	16	0.048
United Kingdom	30	4	0.017
Canada	29	4	0.025
Germany	18	3	0.035
France	12	2	0.021
Australia	8	1	0.007
South Korea	7	1	0.009
Rest of the world	40	6	0.003

Table 2.3: Regional distribution of R&D partnerships and regional average degrees.

ent picture regarding the distribution of collaborative activities between the world's strongest economies. Using the MERIT-CATI data, Hagedoorn (2002) finds that most R&D partnerships formed during the 1990s involve an Anglo-Saxon company. In particular, firms from the US played a dominant role in both the Anglo-Saxon part of the network as well as in the global alliance network as a whole. As Table 2.3 shows, this pattern is also reflected in our data. 73% of all newly formed R&D partnerships involved an Anglo-Saxon company. Moreover, US companies were, with a share of 63% of all newly formed partnerships, responsible for many of the collaborative activities during the 1990s.

Yet, even though the distribution of partnerships might suggest otherwise, the typical US firm is not a much more active collaborator than any other firm from the Anglo-Saxon countries, Western Europe, or East Asia. Consider, for example, the case of Japan. Comparing the numbers in columns one and three of Table 2.3 for Japan and the United States, it becomes clear that Japanese firms are much closer to US firms in terms of their collaborative activity, when comparing average degrees instead of numbers of partnerships. With an average degree of 0.059 in the United States and 0.048 in Japan, the typical US firm formed only 20% more partnerships than the typical Japanese firm. This suggests that only a minor part of the huge difference in the numbers of partnerships between the two countries is explained by differences in the propensities to collaboration. Instead, the most important factor seems to be that Japan has with, on average over time, only 2,330 public companies a relatively small firm population as compared to the 7,310 public companies in the United States.

Repeating the same exercise for the United States and any other country from the world's strongest' economic regions, one can see that much of the apparent dominance of US companies in the global alliance network is explained by the sheer size of the US economy.

2.5.3 International integration in the network

We now turn to a re-examination of Questions 4 and 5 concerning the extent to which the global network connects firms from different countries and regions. A highly integrated alliance network would be desirable, because such a network could facilitate the diffusion of know-how and technologies around the globe (Pearce, 1989; Freeman and Hagedoorn, 1994). In his study, Hagedoorn (2002) has come to a rather pessimistic conclusion about the worldwide trends in the integration of the network. Even though he has found that the share of international alliances in the total of newly formed partnerships was with a time average of 60% on a rather high level during the 1980s and 1990s, he has also observed a steadily declining trend. Hence, the network seems to fall apart into more nationally segregated clusters, because firms increasingly chose domestic instead of foreign alliance partners. However, as we argue in this chapter, the share of international alliances might conceal the "true" openness towards foreign alliance partners, because the measure contains the combined effects of preferences and opportunities for selecting international partnerships.

A measure that is corrected for opportunities is the homophily index (2.3). Figure 2.3 plots the worldwide average homophily during the period 1989–2002 and indicates its trend for the United States, the strong economies as well as the developing countries in our data. As can be seen from the development of the worldwide average, there was a slight but noticeable trend towards the formation of homophile clusters in the network. In fact, our findings suggest that the network was quite international in 1989, with an average homophily that did not reflect any preference towards or against international partnerships. However, the upwards trend shows that international alliances became less popular over time, with a worldwide average homophily of 0.26 at the end of the year 2002. Hence, Hagedoorn's (2002) pessimistic view on the worldwide trends in international collaboration seems to be robust with respect to controlling for the opportunities for finding foreign and domestic alliance partners.

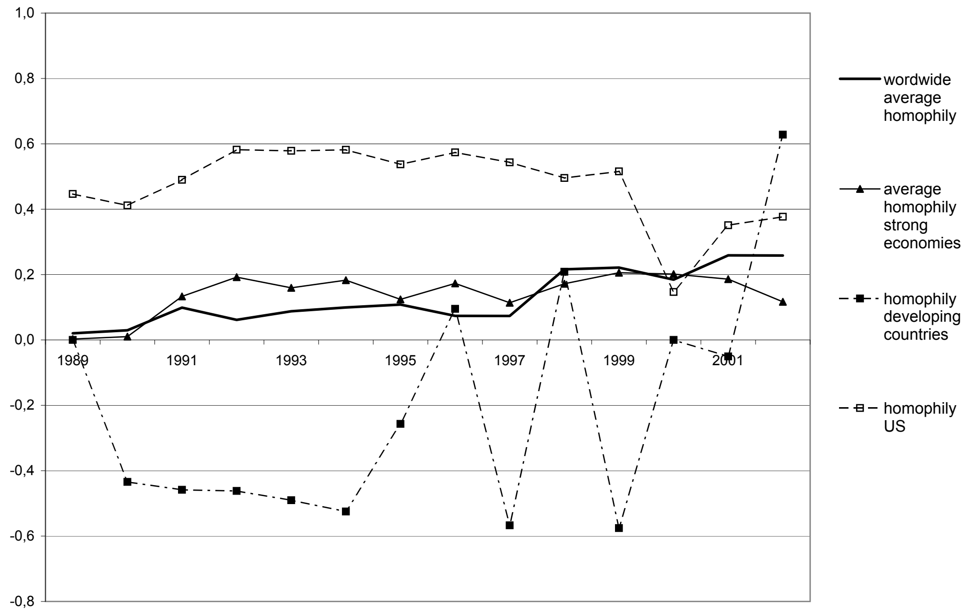


Figure 2.3: Regional and worldwide average homophily over time.

In the following, we investigate national and regional differences in homophily. Hagedoorn (2002) has observed major differences in homophily between the countries from the regions North America, East Asia, and Western Europe. While foreign alliance partners are rather welcome in most of these countries, US companies tend to form a segregated national cluster. In another study, Freeman and Hagedoorn (1994) have found that almost all R&D partnerships in the developing countries also involved a partner from one of the stronger economies. Our results, which are summarized in Table 2.4, confirm the finding for the developing countries, but shed new light on the homophily among US firms.

The first two columns of the table show the share of domestic partnerships, as the previously used homophily measure, as well as the homophily index (2.3), respectively. Since these measures are hardly comparable, the third column presents a hypothetical share of domestic partnership, s_k^*, that is based on the homophily index from column two. In particular, we rewrite the homophily index (2.3) as $s_k^* = (1-n_k/n)H_k + n_k/n$ and assume the numbers of firms to be identical across countries or regions. Hence, $n_k/n = 1/52$ for the country-level hypothetical shares and $n_k/n = 1/4$ for the regional-level hypothetical shares. Finally, we calculate s_k^* for a certain country or

	Share of domestic/ intra-regional R&D partnerships, s_k	Homophily index, H_k	Hypothetical share of domestic/intra-regional partnerships, $s_k^* = (1 - 1/n)H_k + 1/n$
Regions			
Anglo-Saxon countries	0.57	0.28	0.46
East Asia	0.26	0.15	0.36
Western Europe	0.12	-0.01	0.24
Developing countries	0.19	-0.24	0.07
Countries			
United States	0.59	0.47	0.48
Japan	0.27	0.21	0.22
Australia	0.27	0.25	0.26
Canada	0.18	0.14	0.16
United Kingdom	0.17	0.12	0.13
South Korea	0.17	0.15	0.16
Germany	0.14	0.12	0.14
France	0.13	0.11	0.13
Rest of the world	0.06	0.05	0.07

Table 2.4: Share of domestic R&D partnerships and regional homophily.

region by substituting the term H_k from column two in the table into the formula. Because the measure s_k^* is corrected for the sizes of the national firm populations and, therefore, for the opportunities of domestic partnerships, it reflects the share of domestic alliances that is only due to preference-based homophily.

All three measures in the table present the same picture that the public companies from the developing countries, despite their overall low level of collaborative activity, show a strong preference for partnerships with firms from the stronger economies. In particular, the index value of -0.24 clearly indicates a heterophily in this region.

Concerning the homophily in the United States, the share of 0.59 of domestic partnerships in the first column of Table 2.4 supports the observation by Hagedoorn (2002) that US firms, unlike firms from most other nations, tended to form quite a lot of domestic partnerships during the 1990s. However, the homophily measures in columns two and three show that, next to a preference-based homophily, at least part of the explanation lies in the fact that US firms had so many opportunities for domestic partnerships. Even though the United States was by far the most homophile nation with an index value of 0.47, a comparison between the first and the third column suggests that a considerable fraction of 0.11 of the share of domestic partnerships in column one is merely due to opportunities. An explanation might be that the US economy, with its strong position in many manufacturing industries, offers many more potential alliance partners than any other nation. Also, the latest trends in our data put the importance of international alliances for US firms in a rather optimistic light (see Figure 2.3). Although US companies tended to prefer domestic partners throughout most of the 1990s, the homophily index indicates a slight turnaround in the year 2000, when US firms became more open towards foreign alliance partners.

Hence, even though our analysis confirms the findings of previous studies that US firms tended to form a segregated national cluster, we also find that the size of the US economy conceals the country's true level of internationalization to a certain degree.

2.6 Summary and discussion

In this chapter, we have studied the structure and dynamics of the global network of inter-firm R&D partnerships over a period of fourteen years, from 1989 to 2002. While we have focussed on a reinvestigation of previously addressed research questions, the novelty of our study is that it relates patterns and changes in the network structure to geographical and temporal differences in the numbers of firms per country and region.

In order to set up this relationship, we complement data on strategic alliances and joint ventures by data on the number of publicly held companies around the globe. Moreover, we apply measures from the social network literature that allow us to control for patterns in the worldwide firm population. These steps are necessary, because the patterns produce a natural inequality in the network which is, unlike other political or technological barriers and stimuli to collaboration, merely based on the logical opportunities for partnerships.

Even though our data provides an incomplete picture of the global inter-firm R&D network, because (i) the Thomson SDC data does not contain all the R&D partnerships formed during 1989–2002 and (ii) we focus on the collaborative activities of publicly held companies from a sample of countries, our analysis is still able to reproduce many of the previously found empirical regularities. The most important among these are the "alliance cycle" of the 1990s (Hagedoorn, 2002; Hagedoorn and van Kranenburg, 2003), the concentration of collaborative activity in the developed economies (Freeman and Hagedoorn, 1994), and the trend towards a formation of segregated national clusters (Duysters and Hagedoorn, 1996; Hagedoorn, 2002). This suggests that many of the essential macro-level patterns of the network are retained in our data. However, our analysis also reveals a series of novel insights:

1. The global inter-firm R&D network is very sparse. Our findings show that the typical public company in our data initiates a collaborative agreement once every thirty-five years. Moreover, the share of companies that announces an alliance amounts to no more than 1% of the worldwide number of public companies.

2. The previously found dominant role of US firms and their centrality in the global R&D network is amplified to a significant extent by the size of the US economy. The average US firm is not a much more active collaborator than any other firm from the Anglo-Saxon countries, Western Europe or East Asia. What makes US firms so visible in the network is their sheer number.

3. The size of the US economy conceals the importance of international R&D partnerships for US firms to some extent. A significant share of the large number of partnerships within the United States can be explained by the fact that, as compared to other nations, there are so many US firms and, therefore, many opportunities for domestic alliances.

Particularly the first observation implies a rather different picture of the international R&D network than the ones proposed by previous research on this topic. Despite the fact that our data does not evince all collaborative R&D activities in the period 1989–2002, our finding of an extremely low number of newly formed partnerships raises some serious questions about the conclusions of at least two streams in the literature. First, there is the often made claim that R&D joint ventures were widely used strategies in the fierce competitive environment of the 1980s and the 1990s (Harrigan, 1988; Mytelka, 1991; Nooteboom, 1999). Our findings certainly cast some doubt about this assertion. Instead, they rather support a view which portrays R&D collaboration as some kind of “elite sports” which is exercised by the world’s largest firms from the high-tech industries, whereas the vast majority of firms are never engaged in any collaborative activity at all.

Second, our findings could have some important implications for the literature investigating the role of inter-firm alliance networks for knowledge diffusion (Ahuja, 2000; Hagedoorn et al., 2006; Schilling and Phelps, 2007). With an average of just 0.028 newly formed R&D partnerships per firm each year, the typical firm hardly formed any collaborative agreement at all during the fourteen years studied. Thus, even if prior research is correct and knowledge spills along chains of alliances in a network, the worldwide inter-firm network might be simply too sparse to assimilate these spillovers. This grim view on the network is reinforced by our finding that the 1990s witnessed a worldwide trend towards the formation of more segregated national clusters in the network, which further inhibits the important international knowledge flows.

To put this rather pessimistic view into perspective, let us point out that the collaborative agreements investigated in this chapter are not by far the only possible channel for inter-firm knowledge spillovers. In fact, a problem in our alliance dataset, the Thomson SDC Platinum data, is that it only contains information on publicly announced strategic alliances and joint ventures. Even though we select a firm population, where we expect that the Thomson SDC data provides a rather complete picture of the R&D partnerships of these firms, there might still be many more unrecorded agreements. As a first possible extension to our study, one could therefore try to link the different available data sources on alliances and joint ventures, most notably the data from MERIT-CATI, CORE, NCRA-RJV, Recombinant Capital, and Bioscan, to obtain a more complete picture of the global inter-firm network. Schilling's (2009) comparison of the different databases suggests that this could be a worthwhile step, since their overlap is very low.

Furthermore, there might be spillover channels other than the collaborative agreements between the firms. In fact, many of our observations are consistent with the perspective proposed in Desai et al. (2004). The authors argue that, due to the political initiatives in the 1980s and 1990s towards a liberalization of foreign ownership, firms have replaced international joint ventures by cross-border mergers and foreign direct investments as their preferred mode of foreign market access. Hence, our finding of a trend towards more segregation in the global alliance network could be nothing else than the reflection of this process of substitution. At the same time, there would be no reason for concern about the erosion of international spillovers. As another possible extension to our work, we therefore propose to investigate the network between firms also taking into account other inter-firm relations such as mergers and acquisitions. A recent study in this spirit is M'Chirgui (2007).

Finally, another valuable extension is a deeper examination of the fact that the vast amount of collaborative activities is concentrated around just a few firms in the network. The potential implications of this phenomenon for the production and diffusion of innovations through profit-driven organizations have stimulated various academic fields to advance theories on the question of why it arises (Powell et al., 1996; Barabási and Albert, 1999; Goyal and Joshi, 2003). An econometric test of these theories is presented in the following chapter of this dissertation.

Chapter 3

An econometric test of scale effects in the formation of R&D partnerships

3.1 Motivation

The descriptive analysis in the previous chapter has shown that the worldwide network of R&D partnerships is dominated by a small group of companies. These companies form a considerable number of new partnerships every year, while the majority of firms are never involved in any alliance at all. A similar pattern can also be found when considering the network structure in particular markets. Hagedoorn and Schakenraad (1992), for example, identify seven key players in the information and communication technology industries of the 1980s (AT&T, IBM, Siemens, Philips, Fujitsu, NEC, and Olivetti), who were involved in many of the collaborative partnerships in these industries. Moreover, for the global biotech and pharmaceutical industries of the 1990s, Powell et al. (2005) find that a group of 24 well-known players had each formed more than twenty strategic alliances, while the majority of firms each formed less than two.

According to a theoretical literature on inter-firm collaboration, the phenomenon is a natural consequence of scale advantages in the formation of R&D partnerships (Goyal and Joshi, 2003, 2006; Billand and Bravard, 2004). The underlying rationale is that the expected profitability of a joint R&D project is positively related to the competitive position of a firm in the market. This position, in turn, depends on the number of joint research projects of the firm, relative to the number of projects of the other firms operating in the same market. The incremental returns of an R&D partnership are, therefore, increasing in the number of prior partnerships of the firm. Another argument proposed in the literature is that an actively collaborating firm accumulates partnering experience, which enhances its learning capabilities and reduces the costs of engaging in new partnerships (Cohen and Levinthal, 1989).[1]

The arguments are backed up by empirical evidence on scale effects in in-house R&D projects (Henderson and Cockburn, 1996) and complementarities between the different research strategies of a firm (Colombo and Garrone, 1996; Cassiman and Veugelers, 2006). However, although there are several empirical studies published in the business and sociology literature (Powell et al., 1996, 2005; Hagedoorn et al., 2006), scale effects in the formation of collaborative R&D projects have not yet been tested in economics. Moreover, a shortcoming of the existing studies on the topic is that they have been limited to particular industries or have only inadequately corrected for heterogeneity in the characteristics of the firms. It is unclear, however, whether differences between firms in terms of their propensities to form R&D partnerships are not related to some unobserved time-fixed firm characteristics that influence their proclivity to collaborate. For example, the firms from some nations or industries might be more willing to collaboration in R&D than others (see, e.g., Figure 2.1 in Chapter 2). Furthermore, firms may differ in terms of their access to marketing and distribution channels or their geographical distance to industrial centers, all of which has an impact on the expected profitability of an R&D project (Cohen and Levin, 1989). According to this alternative explanation, the concentration of collaborative activities within an industry is much less related to scale effects, but rather to the statistical distribution of firm characteristics.

This chapter tests the presence of scale effects in the formation of R&D partnerships against the alternative of time-fixed firm characteristics in a panel data study. The data for our study is retrieved from the Thomson SDC database and comprises the R&D partnerships of companies from thirty-two different medium- and high-tech industries. Our testing strategy builds on

[1] There is a third rationale propagated in the statistical physics literature according to which the high concentration of collaborative activities occurs, because being an already active collaborator makes a firm an attractive alliance partner to others (Barabási and Albert, 1999; Krapivsky et al., 2000). The major difference between this argument and the ones proposed in the economics literature is that the latter build on the central position of a firm itself (*ego centrality*), whereas the statistical physics literature argues with the centrality of a potential alliance partner in the network (*alter centrality*). Their commonality is that both predict a proportional relationship between the current collaborative activities of a firm and its probability of forming partnerships in the future.

the idea that scale effects are reflected by a feedback from the current collaborative activities of a firm on its propensity to form R&D partnerships in the future. We present a rigorous econometric test of this feedback mechanism, employing fixed-effect correction methods for dynamic panel data. The findings from our estimations suggest that, even though individual heterogeneity does partially explain the concentration of collaborative R&D activities, scale effects seem to play a role within all of the industries being studied. In particular, the R&D partnerships formed today have a positive and significant effect on the likelihood that a firm enters another alliance within the upcoming two years.

The remainder of this chapter is organized as follows. Section 3.2 introduces and describes the data. Section 3.3 develops the econometric model and Section 3.4 presents the results. The findings are summarized and discussed in Section 3.5.

3.2 Description of the explanandum

The Thomson SDC database is one of the two available datasets on inter-firm R&D partnerships with a comprehensive coverage of the whole spectrum of industries and a large number of countries.[2] Next to partnerships with the purpose of joint R&D or technology exchange, the database contains information on other types of inter-firm agreements, such as licensing agreements or long-term procurement contracts. A major limitation within the data lies in the fact that the information is collected from announcements in press releases, journal articles, and comparable public sources. However, despite the potential reporting biases aligned with this collection procedure, the study of Schilling (2009) shows that the database produces a relatively clear picture of the joint efforts of companies.

For our test of scale effects in the formation of R&D partnerships, we extract all agreements from the Thomson SDC data, where (i) at least one company from the chemical, pharmaceutical, manufacturing, or software industry (SIC codes 2800–2891, 3011–3990, 7370–7377) is involved, (ii) the purpose is joint R&D, and (iii) which are completed between 1985 and 2005. SIC codes with less than a total of 100 R&D partnerships over the sample period or an average of less than two partnerships per firm are omitted in order to focus on markets with some considerable alliance activity. As a result, our sample comprises a total of 8,826 R&D partnerships between

[2]The alternative dataset is the CATI databank collected at the MERIT institute at the University of Maastricht.

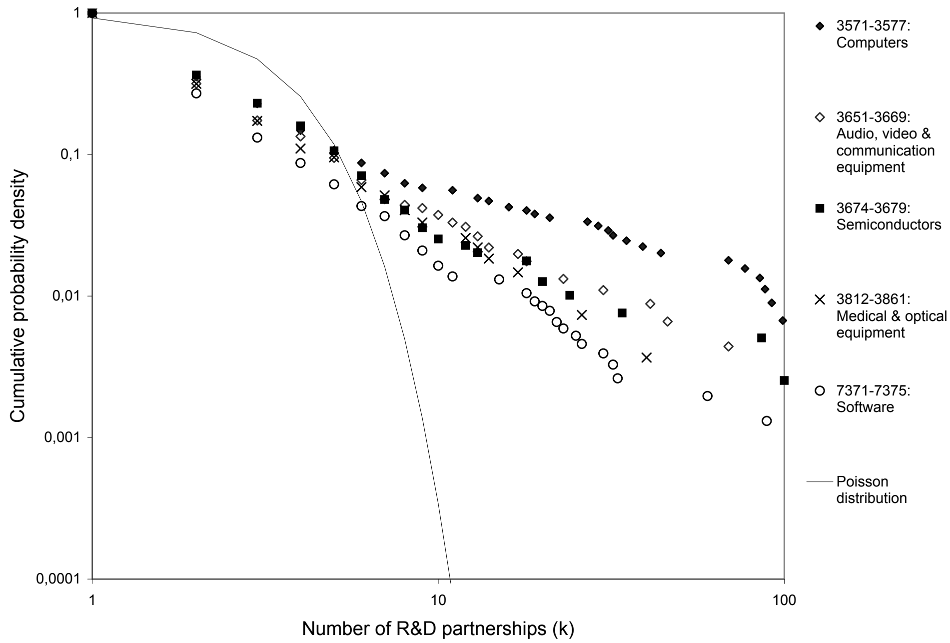
companies from 32 different SIC codes.

Because it is our aim to investigate between-firm differences on the level of specific product markets, the natural unit of analysis is the company division, which produces and sells a certain category of products. A division is identified in the Thomson SDC data by the names of the participants in an R&D partnership and its market affiliation is retrieved from the primary 4-digit SIC codes of the alliance participants. The definition of the unit of analysis and the method of information retrieval have two important implications. First, the R&D partnerships of two divisions of the same holding company are treated as being independent from each other. However, since there is no compelling reason why, for example, Philips Lighting should benefit from the R&D projects of its sister, Philips Semiconductors, the assumption of independent company divisions seems justifiable. Second, divisions without any alliance activity between 1985 and 2005 are omitted from the number of firms in a market. However, as our estimation methods correct for firm-specific fixed effects, these divisions would be deleted from the analysis anyway, because their lack of activity is perfectly identified by the fixed effects.

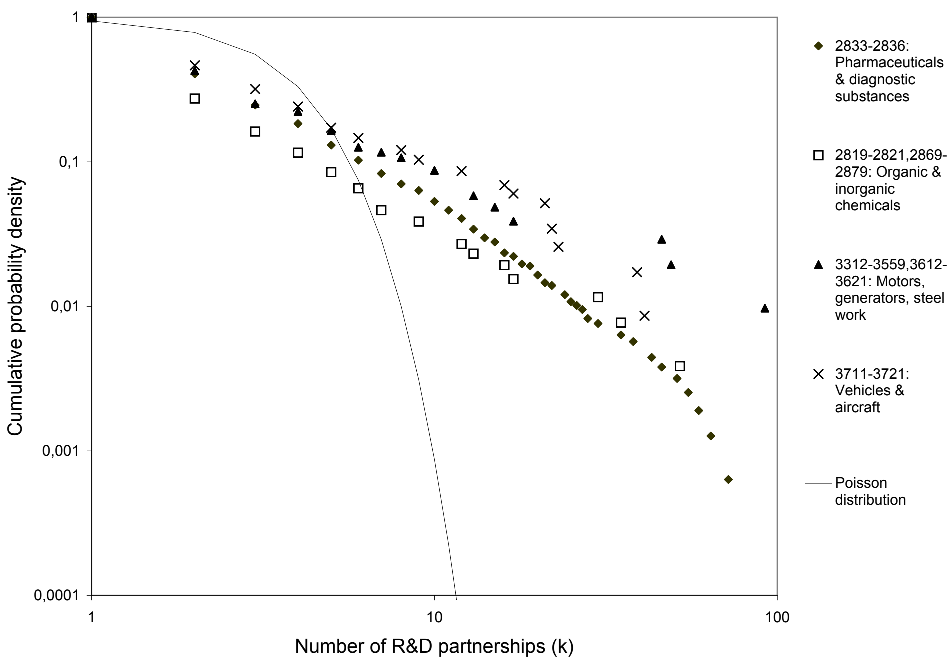
A comprehensive description of important macro-level patterns in the Thomson SDC data is presented in Chapter 2 of this dissertation.[3] One of the main findings in this chapter is that the overall network of R&D partnerships, which spans the different countries and industry sectors, is extremely sparse. Moreover, a closer look at the distribution of partnerships has shown that there are substantive differences throughout the firms in terms of their activity in the network.

Even though the sample in the current chapter is difficult to compare with the one of Chapter 2, the sparseness and the asymmetry of the collaboration network are reflected here as well. Figure 3.1 presents the intrasectoral distribution of R&D partnerships for the 32 markets under study on a log-log scale. The vertical axes in the sub-figures show the share of firms that have been involved in at least k R&D partnerships during the period 1985–2005. For comparison, the figures contain the distribution of partnerships that would occur, if the probability of a firm having k alliances follows a Poisson law. Both figures draw a consistent picture that a typical company of the chemical, pharmaceutical, manufacturing, or software

[3]Note that the sample of collaborative agreements in Chapter 2 differs in some respects from the one selected here. On the one hand, the current sample is narrower in that it is limited to firms from the chemical, pharmaceutical, manufacturing, and software sectors. On the other hand, the analysis in Chapter 2 is confined to only those R&D partnerships, where at least one publicly held company is involved.



(a) Distribution of the number of R&D partnerships per firm in seventeen electronics and software markets.



(b) Distribution of the number of R&D partnerships per firm in fifteen chemical, pharmaceutical, and manufacturing industries.

Figure 3.1: Distribution of R&D partnerships in thirty-two manufacturing industries.

industries is only involved in a few R&D partnerships. The average number of partnerships across the 5, 185 company divisions in our sample is just 2.7. Moreover, the figures show that, as compared to the Poisson distribution, there is a relative large fraction of firms within each market that has formed a high number of partnerships. Hence, the existing collaborative agreements are concentrated around a few central players.

In the following, we develop a dynamic model that relates these patterns to scale effects in the formation of R&D partnerships, on the one hand, and individual heterogeneity of the firms, on the other.

3.3 The econometric model

The purpose of this section is to provide a microeconomic foundation for a panel data model that integrates scale effects in the formation of R&D alliances and time-constant firm-specific characteristics to explain the between-firm differences in collaborative activities.

Several previous studies have theoretically investigated the incentives of rivaling firms to form joint R&D partnerships with each other (Goyal and Moraga-Gonzáles, 2001; Goyal and Joshi, 2003; Billand and Bravard, 2004; Deroïan and Gannon, 2006). These studies focus on the intensity of product market competition to explain the formation of alliances, but otherwise assume that the firms are identical in terms of the qualities and costs of their products. A partnership generates a process or product innovation that either reduces a firm's marginal costs of production or increases the quality of its existing products. An important prediction from these models is that the marginal returns to an R&D partnership, gross of research expenditures, increase in the stock of prior R&D partnerships of a firm. The reason is that the output of a joint research project, may it be a quality improvement or a cost reduction, is indivisible so that it can be applied to every unit of a firm's products. As a consequence, a partnership becomes more profitable the larger the market share of a firm is. Furthermore, because the market share increases in the stock of other R&D projects of a firm, the formation of R&D partnerships is subject to increasing returns or scale effects.

To formalize this argument, suppose that an R&D partnership aims at improving the product quality of the alliance partners. Because each of the collaborating firms can incorporate the expected invention into every single unit of its products, it is natural to assume that the invention induces an upwards shift of the demand intercept. Hence, denote by q_i the quantity of firm i's single product and by a_i the quality of this product, which is measured relative to the average quality in the market, the latter being normalized to zero. The inverse residual demand function of firm i shall be given by $P_i(a_i, q_i) = a_i + f_i(q_i)$, with $f_i(0) > 0$ and $f_i' < 0$. Let the marginal production costs be constant per unit of output and increasing in quality. Thus, $c_i(a_i)$ with $c_i > 0$, $0 \leq c_i' < 1$, and $c_i'' = 0$. In the following, we determine the first- and second-order effects of a marginal change in product quality, where it is assumed that this change precedes the sales of the firm's product on the market.

Maximizing the firm's profits, $\pi_i = (P_i(a_i, q_i) - c_i(a_i))q_i$, with respect to quantities leads to the standard first-order condition:

$$\begin{aligned} \frac{\partial \pi_i}{\partial q_i} = P_i(a_i, q_i^*) + \frac{\partial P_i}{\partial q_i} q_i^* - c_i(a_i) &= 0 \Leftrightarrow \\ a_i + f_i(q_i^*) + f_i' q_i^* - c_i(a_i) &= 0. \end{aligned} \tag{3.1}$$

Assume that a unique and positive profit-maximizing quantity, q_i^*, exists. Since $c_i' < 1$ it follows from the second line that the optimal quantity increases in the quality of the firm's product, $q_i^* = q_i^*(a_i)$ with $\partial q_i^* / \partial a_i > 0$. Accordingly, the first-order effect of an increase in product quality is given by:

$$\begin{aligned} \frac{\partial \pi_i}{\partial a_i}(a_i, q_i^*) &= \frac{\partial P_i}{\partial a_i} q_i^* + P_i(a_i, q_i^*) \frac{\partial q_i^*}{\partial a_i} - c_i(a_i) \frac{\partial q_i^*}{\partial a_i} - c_i' q_i^* \\ &= q_i^*(1 - c_i') + \frac{\partial q_i^*}{\partial a_i} \Big(a_i + f_i(q_i^*) + f_i' q_i^* - c_i(a_i) \Big) \\ &= q_i^*(1 - c_i'). \end{aligned} \tag{3.2}$$

While the first two equalities follow from the derivation of profits with respect to a_i and a rearrangement of the derivative, the third line is a consequence of condition (3.1). This shows that the marginal return to a product innovation, and consequentially also to an R&D partnership, is an increasing function of the unit output of a firm. Moreover, the second-order derivative of profits with respect to quality, which is proportional to $\partial q_i^* / \partial a_i > 0$, shows that the innovation also increases the firm's market share. Hence, any subsequent collaborative project to increase the product quality is aligned with even higher returns for the firm.

In order to adjust this simple model to the purpose of our study we introduce firm-level heterogeneity as well as a dynamic component. Let us, therefore, assume that the optimal quantity of firm i at time t is given by the linear function:

$$q_{i,t}^* = a_{i,t} + f_{i,t}(0) - c_i(a_{i,t}),$$

where $c_i(a_{i,t}) = \Gamma_i + \gamma a_{i,t}$, with $\Gamma_i > 0$ and $0 \leq \gamma < 1$. Moreover, let us separate the term $f_{i,t}(0) - \Gamma_i$ into a parameter capturing the size of the market in which firm i operates at time t and a time-constant individual firm-specific shift parameter, ρ_i. Thus, let us write $f_{i,t}(0) - \Gamma_i = \rho_i A_t$, with $\rho_i > 0$ and $A_t > 0$. The individual shifter shall reflect differences in the technological opportunities of the firms, or to be more precise, of the company divisions operating in a certain market. Examples are variations among firms in terms of their access to marketing and distribution channels or their geographical distance to industrial agglomerations and large cities (Cohen and Levin, 1989). As can be seen from equation (3.2), firms with better technological opportunities have a higher incentive to form R&D partnerships.

Furthermore, assume that the formation of partnerships and the realization of profits occur at discrete points in time. At each time point, a firm may form new agreements with every other firm. The number of collaborative projects initiated by firm i at time t is denoted by $k_{i,t}$. We assume that the costs of these projects accrue instantaneously and are given by $\beta(k_{i,t})^2$, with $\beta > 0$. In contrast, firm i benefits from the quality improvements at any $r \geq t$, where the benefit is discounted by a factor δ_{r-t}, with $0 \leq \delta_{r-t} \leq 1$. Specifically, let the product quality of firm i at time t be given by:

$$a_{i,t} = k_{i,t} + \sum_{s<t} \delta_{t-s} k_{i,s}.$$

Given its past partnerships, a firm proposes a number of new agreements in order to myopically maximize its profits. The optimal number of agreements of the firm is approximately determined by the first-order condition:[4]

$$\frac{\partial \pi_{i,t}}{\partial k_{i,t}} = \left(k^*_{i,t} + \sum_{s<t} \delta_{t-s} k_{i,s} \right) \left(1 - \gamma\right) + \rho_i A_t - 2\beta k^*_{i,t} \approx 0.$$

Given β is sufficiently large ($2\beta > 1 - \gamma$), an interior solution exists which is approximately:

$$k^*_{i,t} \approx \frac{1-\gamma}{2\beta + \gamma - 1} \sum_{s<t} \delta_{t-s} k_{i,s} + \frac{1}{2\beta + \gamma - 1} \rho_i A_t. \tag{3.3}$$

Hence, the model predicts a positive feedback from the number of alliances formed at $s < t$ on the firm's proclivity to form R&D partnerships

[4]Here, we implicitly assume that a collaborative project is initiated unilaterally and that the benefits and costs only flow to the firm that initiated it. A theoretical model with such an assumption is investigated in Billand and Bravard (2004).

in t. This feedback reflects the scale advantages in the operation of collaborative R&D projects. Moreover, as expected, equation (3.3) shows that the optimal number of partnerships increases in the firm-specific demand shifter.

We will use this equation to formulate our econometric model. Suppose, therefore, that $k_{i,t}$ is a discrete random count variable for any i, $i = 1, ..., N$, and t, $t = 1, ..., T$. Let us interpret the equilibrium prediction in equation (3.3) as a conditional expectation of the number of newly formed partnerships of firm i in year t:

$$E(k_{i,t}|(k_{i,s})_{s<t}, \rho_i, A_t) \quad = \quad \sum_{s<t} \phi_{t-s} k_{i,s} + \rho_i \exp[\varphi_0 + \varphi_1 I_t']. \qquad (3.4)$$

Our aim is to estimate the parameter vector, $\left[(\phi_{t-s})_{s<t},\, \varphi_0,\, \varphi_1 = (\varphi_{1,t})_{t=1,...,T}\right]$, where we hypothesize that $\phi_{t-s} > 0$ for any $s < t$.[5] While the $k_{i,s}$ can be measured from the Thomson SDC data, the market size effect is captured by the scalar product, $\varphi_1 I_t'$, where I_t represents a vector of year indicators, $I_t = \left[I_s | s = 1, ..., T\right]$, such that $I_s = 1$, if $s = t$, and $I_s = 0$ otherwise. Finally, ρ_i is treated as an unobserved firm-specific effect and we employ fixed-effect correction methods to control for this effect.

As compared to the estimation of ρ_i by the inclusion of measurable firm-specific covariates in equation (3.4), a major advantage of these correction methods is that they also control for the many firm characteristics that are not collected in the Thomson SDC data.[6] In this way, we are able to overcome a generic problem of any dynamic analysis that the presence of unobserved individual heterogeneity can cause serious estimation problems, because the unobserved time-fixed characteristics are necessarily correlated with the lagged dependent regressors (see, e.g., Cameron and Trivedin, 2005). Hence, the advantage of the fixed-effect methods is that they not only have lower informational requirements concerning firm-specific variables, but they also provide more precise parameter estimates.

However, because of the dynamic structure of model (3.4), we may not employ a standard fixed-effect correction method, since most methods are valid only when the explanatory variables are strictly exogenous (Hausman et al., 1984; Lancaster, 2002). Yet, due to the inclusion of the lagged dependent variables as regressors in model (3.4), this condition is clearly not met in our case. Instead, the regressors are predetermined by past shocks to

[5]The parameters are equivalent to $\phi_{t-s} \equiv \frac{1-\gamma}{2\beta+\gamma-1}\delta_{t-s}$, $\varphi_0 \equiv \ln(\frac{1}{2\beta+\gamma-1})$, and $\varphi_{1,t} \equiv \ln(A_t)$.

[6]In fact, the only firm-specific variables available in the Thomson SDC database are the sector and country affiliation of a firm.

the dependent variable, which renders the standard methods inappropriate, because they result in biased estimates when T is small as in our data.

Two estimation methods that are valid even for predetermined regressors are proposed by Chamberlain (1992) and Blundell et al. (2002). Chamberlain suggests to estimate the model parameters by means of the Generalized Method of Moments (GMM) after applying a suitable transformation to eliminate the unobserved effects from equation (3.4). In particular, he proposes to establish the following quasi-difference transformation of the original equation:

$$x_{i,t} = \left(k_{i,t} - \sum_{s<t} \phi_{t-s} k_{i,s}\right) \frac{\exp[\varphi_0 + \varphi_1 I'_{t-1}]}{\exp[\varphi_0 + \varphi_1 I'_t]} - \left(k_{i,t-1} - \sum_{s<t-1} \phi_{t-s} k_{i,s}\right).$$

Chamberlain uses this transformation to construct his quasi-difference GMM-estimator. Suppose that m lags of the dependent variable are included as regressors in equation (3.4). For a suitable vector of instruments, $z_{i,t}$, the following $(T-m)^2 - 1$ moment conditions hold:

$$E\big[x_{i,t} \,|\, z_{i,t}\big] = 0.$$

For example, if the I_t are strictly exogenous the maximal set of instruments is given by $z_{i,t} = \big((k_{i,s})_{s<t-1}, (I_t)_{t=1,..,T}\big)$. For $N \to \infty$, the moment conditions enable the consistent estimation of the parameters by means of the GMM-estimation technique (Hansen, 1982).

As Blundell et al. (2002) show in a simulation study, even the quasi-difference estimator suffers from a serious finite sample bias for small T. Therefore, the authors propose the use of an estimator based on the inclusion of a mean transformation of the dependent variable in equation (3.4). In order to eliminate the firm-specific fixed effect, the sample period is split into a pre- and an in-sample period. The mean value of the dependent variable over the pre-sample period, $\bar{k}_{ip} = (1/TP)\sum_{s=0}^{TP-1} k_{i,0-s}$, is included as a regressor in equation (3.4). The authors show that under weak requirements on the regressors, I_t and $(k_{i,s})_{s<t}$, the following moment conditions are satisfied:[7]

$$E_{TP\to\infty}\big[k_{i,t} - \sum_{s<t} \phi_{t-s} k_{i,s} - \rho_i \exp[\varphi_0^* + \varphi_1 I'_t + \varphi_2 \ln(\bar{k}_{ip})] \,|\, z_{i,t}\big] = 0,$$

[7] The requirement on the regressors is that the $k_{i,t}$ process is a stationary, independent identically distributed process with finite moments and its (long-run) mean is proportional to ρ_i (see Blundell et al., 2002, Corollary 2).

where φ_0^* is proportional to the original parameter φ_0 and $z_{i,t}$ is a suitable vector of instruments. For exogenous I_t, the maximal set of instruments is $z_{i,t} = \big(1, (k_{i,s})_{s<t-1}, (I_t)_{t=1,..,T}, \ln(\bar{k}_{ip})\big)$. The moment conditions justify the use of the Maximum Likelihood technique or the GMM technique for consistent estimation of the parameters, where $N \to \infty$ and $TP \to \infty$ is required for consistency. As Blundell et al. (2002) show in their simulation study, the advantage of such a pre-sample mean estimator is that it has good finite sample properties even for small T and TP. A disadvantage for our purposes is that only those firms can be included in the analysis that have formed at least one partnership throughout the pre-sample period. However, the drop out of firms can be minimized by increasing the length of the pre-sample.

3.4 Results from a generalized method of moments estimation

Here, we present our results based on three different estimators, (i) a baseline GMM-estimator, where the problem of firm heterogeneity is omitted, (ii) a quasi-difference GMM-estimator, and (iii) a pre-sample mean GMM-estimator. All estimations are done using the Gauss implementation by Windmeijer (2002). Even though the GMM-estimation technique is not necessary to obtain suitable baseline and pre-sample mean estimators, the technique has several advantages over a Maximum Likelihood (ML) estimation which make it more attractive for our purposes. First of all, the results in this section are based on the same estimation technique such that differences between the estimators are solely due to the means by which firm heterogeneity is treated. Second, GMM estimation enables tests of model (mis-)specification, when the parameter vector is overidentified. Finally, it should be mentioned that a just-identified GMM-estimator coincides with a ML-estimator such that the parameter estimates are identical (see, e.g., Blundell et al., 2002; Cameron and Trivedin, 2005, pp. 166). The findings from our GMM estimations are summarized in Table 3.1.

Throughout all our estimations, we confine the number of lagged dependent variables included as explanatory variables in model (3.4) to a maximum of six. The first column in the table presents the coefficients of the baseline estimator, where the sample moment conditions of this estimator are based on equation (3.4) with the single modification that ρ_i is assumed to be identical across all firms. Windmeijer's Gauss implementation could identify a suitable estimator only under the restriction to a lag length of four. As expected, the estimator attributes the differences between firms in

No. partnerships formed in year t	Level 1985–2005	Quasi-difference 1986–2005	Pre-sample 2004–2005
$k_{i,t-1}$	.445***	-.270	.405***
	(.023)	(3.665)	(.083)
$k_{i,t-2}$	.407***	-3.931	.234***
	(.005)	(6.127)	(.004)
$k_{i,t-3}$	.157*	-9.015	.036
	(.074)	(22.154)	(.024)
$k_{i,t-4}$	-.748***	-15.601	-.021
	(.049)	(39.292)	(.032)
$k_{i,t-5}$	–	-13.342	-.040
		(35.364)	(.156)
$k_{i,t-6}$	–	-12.867	-.116
		(30.730)	(.141)
$\ln(\bar{k}_{ip})$			1.558***
			(.302)
N	5,185	5,185	4,799
T	21	20	2
TP			19
OIR test	75.126***	0.030	0.292
(Degr. of freedom)	(13)	(2)	(2)

Table 3.1: Generalized method of moments estimation results.

NOTES: (1) * $p < .05$, ** $p < .01$, *** $p < .001$; (2) robust standard errors in parentheses below coefficients; (3) all regressions include year dummies (the level and the pre-sample model a constant in addition) not reported.

terms of their number of R&D partnerships, as indicated in Figure 3.1, to a positive feedback from the alliances formed in the past three years.

Nevertheless, the results from the quasi-difference estimator in column two suggest that these feedback effects are spurious only. None of the coefficients of the lagged number of partnerships remain positive and significant, when correcting for firm-specific time-fixed propensities to collaborate in R&D. However, the coefficients and standard errors reported in this column also indicate that we should be careful with our interpretation of the quasi-difference estimator, because they dramatically increase as compared to the values of column one.

The explosive behavior is, again, absent in the pre-sample mean estimator presented in the final column, which also shows that the positive feedback can be maintained even after correcting for individual heterogeneity. As the pre-sample period for this estimator, we use the nineteen years 1985–2003 and for the in-sample period the two years 2004–2005. Because it is necessary to exclude firms from the estimation that do not show any alliance activity during the pre-sample period, the number of independent observations drops slightly to 4,799 firms. As expected, the pre-sample mean estimator reports slightly lower coefficients for the first three lagged number of partnerships than the baseline model, but larger coefficients than the quasi-difference estimator. This observation is in line with the simulation study of Blundell et al. (2002), who find that the baseline (quasi-difference) estimator tends to systematically over-(under-)estimate the population coefficients within small samples. Moreover, the fact that the coefficients of the first two lags are positive and significant suggests that the formation of R&D partnerships is subject to scale effects. Raising the number of alliances of a firm in $t-1$ by one increases, ceteris paribus, the expected number of partnerships in t by .405.

The parameter vectors of all three models are overidentified by the fact that we measure the formation of alliances at multiple points in time. The maximal number of moment conditions available for the quasi-difference estimation, for example, are $(20-6)^2-1=195$. This enables us to perform overidentification restriction (OIR) tests for orthogonality of the instrument matrices (see, e.g., Cameron and Trivedin, 2005). The results of these tests, presented in the bottom lines of the table, reject the null-hypothesis of orthogonality for the baseline estimator, but not for the quasi-difference and the pre-sample mean estimator. This suggests that, as expected, the baseline model is underspecified, because it omits individual heterogeneity in the time-constant propensities of firms to form alliances.

In order to check the robustness of our findings, we estimated various alternative specifications of the pre-sample mean model, which are not reported in this dissertation. The tests showed that the feedback effect from the R&D partnerships formed in the past two years remains significant, regardless of whether alternative instrument matrices are chosen or less lags are included as explanatory variables in model (3.4). Moreover, we ran several further pre-sample mean estimations, one for each of the nine sector blocks of Figure 3.1, to allow for sector-specific coefficients of the lagged dependent variables. Not all estimation results were reasonable, because some sector blocks produce too few observations. The feedback from past alliances remained positive and significant for the remaining sectors. Depending on the precise sector block, the number of lagged dependent variables with a positive coefficient varies between one and two, where the most pronounced feedback effects prevails in the pharmaceutical and diagnostic substance sectors (SIC codes 2833–2836) and the weakest effects is observed for the software industries (SIC codes 7371–7375).

3.5 Conclusions

In the current chapter, we have presented an econometric test of recent theories to explain the huge variation among rivaling firms in terms of their numbers of R&D partnerships (Goyal and Joshi, 2003, 2006; Billand and Bravard, 2004). In particular, we have conducted a panel data analysis to test the presence of scale effects in the formation of R&D partnerships against the null-hypothesis of heterogeneity among firms in their time-constant propensities to collaborate. The heterogeneity taken into account in our tests comprises some easily observable firm characteristics, such as their sector and country affiliations, but also those characteristics that are difficult to measure, such as their precise geographical locations. In order to control for the latter effects, we employ two alternative fixed-effect corrections methods for dynamic panel data, the quasi-difference estimator and the pre-sample mean estimator (Chamberlain, 1992; Blundell et al., 2002).

Our findings largely support the presence of scale effects in the formation of R&D partnerships. In particular, our most reliable estimation, based on Blundell et al.'s (2002) pre-sample mean estimator, reveals a significant feedback from the current partnerships of a firm on its likelihood of forming further alliances within the coming two years. One of the open questions from our analysis is the exact source of the feedback. Next to the increasing-returns argument proposed by Goyal and Joshi (2003) and others, two alternative well-established explanations are the accumulation of partnering experience and preferential attachment (Powell et al., 1996; Barabási and Albert, 1999).

An isolation of the exact source of the scale effects would help to distinguish between these alternative theories and, thereby, contribute to theory development. A major problem for such a test is that all three theories predict a proportional relationship between the current collaborative activities of a firm and its probability of forming alliances in the future. Hence, it is impossible to distinguish between them on the grounds of the analytical setup and the data used in the current study. Future studies on this topic should, therefore, complement the basic alliance variables used in this study by additional firm-specific or alliance-specific variables. Moreover, the focus of the empirical analysis will probably have to shift from the firm to the partnership as the unit of analysis.

Chapter 4

Natural concentration in industrial R&D collaboration*

4.1 Motivation for a theoretical analysis

In the industrial organization literature on R&D collaboration, there is a long tradition of work focusing on the pros and cons of an industry-wide agreement as compared to independently operating research labs (e.g., d'Aspremont and Jacquemin, 1988; Leahy and Neary, 1997). Yet, as the previous two chapters have shown, this comparison is at odds with the empirical reality, because many markets are characterized by incomplete and highly concentrated collaboration networks. This observation naturally raises a number of questions. Can we explain the emergence of a concentrated network organization in a model of R&D collaboration between firms? Is concentration welfare-efficient? Finally, in the light of the favorable treatment of research joint ventures in the U.S. and in Europe, is there a policy lesson to learn from such an analysis? For example, should R&D collaboration be encouraged between the firms on the periphery of an industry or rather between the central players?

Despite the empirical evidence, issues like these have not been sufficiently addressed in the theoretical literature. Katz (1986) was the first to study a less than industry-wide collaborative agreement. More recent contributions come from Bloch (1995) and Yi (1998), who investigate the set of industry

*The study presented in this chapter has been published in the *RAND Journal of Economics*.

partitions into research coalitions, and Goyal and Moraga-Gonzáles (2001), Goyal and Joshi (2003), and Billand and Bravard (2004), who study *networks* of bilateral R&D alliances. A common finding is that less than industry-wide agreements are typical market structures in equilibrium. Of particular interest are the analyses presented by Goyal and Joshi (2003). The authors find highly asymmetric structures in equilibrium, where some firms are even completely excluded from any collaborative activity.

Goyal and Joshi (2003) investigate a game of network formation in a homogeneous-product oligopoly. In the first stage of the game, the firms can form *bilateral* collaborative links between each other, before in the second stage all firms, even the collaborators, compete in the product market. A collaborative tie leads to a reduction in marginal production costs for the firms involved. However, the firms have to incur some costs of link formation. The authors model this cost to be significant as compared to the returns from the unit-cost reduction. Yet, the cost is fixed and remains the same across all links.

This chapter investigates the socially efficient networks in the model of Goyal and Joshi (2003) and shows that asymmetric networks are typically efficient as well.[1] Our first result pertains to the architecture of the efficient network (Proposition 1). The efficient network may be the empty network, in which no firm collaborates, or the complete network with a collaborative agreement between any pair of firms. But if it is neither of these, the efficient network has a *dominant group* or an *inter-linked star* architecture, both of which exhibit a strong asymmetry between firms.[2]

Second, we examine the *density* and the *degree variance* in the efficient network. The results of this analysis show that social welfare in a network can be expressed as an additive function of the density and the degree variance in the network (Lemma 2). While the density captures the welfare contribution from the number of collaborative links, the degree variance depicts the contribution from their dispersion among the firms. Moreover, since welfare is positively associated with degree variance, our analysis implies that in an efficient network a given number of collaborative ties is maximally concentrated around a subset of the firms in a market (Proposi-

[1] The notions of efficiency investigated in this chapter are the consumer surplus and the total surplus. In fact, we analyze a more general model than the one presented in Goyal and Joshi (2003), since our model contains richer types of product market interaction. While the authors investigate a homogeneous-product Cournot oligopoly, we build on the market model by Singh and Vives (1984), which allows for price or quantity competition between firms as well as for differentiated products.

[2] The network structures are illustrated in Figure 4.1.

tion 2). Even though the exact values of the density and the degree variance depend on the characteristics of demand and the costs of forming links, our subsequent steps show that the characterization applies to a wide range of market settings. There exists a generic set of parameters that supports an efficient network with a highly unequal dispersion of links (Proposition 3).

The intuition underlying these findings is derived from a fundamental property of the demand for cost-reducing R&D investments. The seminal articles by Arrow (1962) and Dasgupta and Stiglitz (1980) already point to the *indivisibility* of research output and its implications for the market structure: an invention, for example a cost-reducing one, can be applied to every unit of a firm's product, regardless of its scale of production. The social returns from an R&D investment are therefore higher, the larger the firm's scales. This motivates some properties of tie formation in a network between oligopolistic firms. First, the social returns of creating a collaborative tie between two firms are higher, the larger the firms' market shares. Second, the reallocation of ties from a firm at the fringe of the market to a dominant market player is socially desirable. Furthermore, because a firm's market share improves in its stock of collaboration ties, the gradual construction of the network is subject to a self-reinforcing dynamic, which favors the formation of highly concentrated structures.

In a subsequent analysis, we compare the structure of the efficient network with the one of the strategically stable networks characterized in Goyal and Joshi (2003, 2006). The comparison shows that stable networks with a small or moderate density are typically inefficient. However, because of the complex structure of the efficient network in markets with a finite number of firms, our formal results pertain only to the limiting case of markets with a continuum of firms. In such a market, every stable network is inefficient that consists of less than half of the maximal attainable links (Propositions 4 and 5). As suggested by our previous findings, the reason for this failure in the network structure is that, even though the stable networks may be highly asymmetric, they still exhibit too little concentration.

Building on the last point, we develop some implications for the design of effective policy programs to foster R&D collaboration between firms. The major value of the analysis presented in this chapter is, however, its contribution to the existing studies on collaboration networks in oligopolistic markets, when the costs of link formation are significant. Goyal and Moraga-Gonzáles (2001) and Deroïan and Gannon (2006) provide a complete characterization of the strategically stable and the efficient structures in the set of *regular* networks, where all firms have an equal number of links. Moreover, Goyal and Joshi (2003, 2006) characterize the strategically stable structures among all (regular and irregular) networks and show that they are typically irregular. The current study identifies the *efficient* structures in the set of all networks.

Furthermore, the study in this chapter is one of the few to point out the social benefits from concentrating costly joint research activities around a small number of firms in a market.[3] An implication of our findings for the analyses in Bloch (1995) and Yi (1998) is that the exclusion of some firms from collaborating can be socially desirable. The authors point to the welfare losses from an asymmetric market structure in a model, where the costs of collaboration are insignificantly small and the industry-wide agreement is efficient. In contrast, we investigate the situation of large costs, for which the complete network is inefficient.

Finally, there is also a link between this chapter and the sociological literature on social networks. One of the focuses of this literature is to propose different network measures and to assert the suitability of each of these measures to different situations.[4] We provide a micro-economic foundation for the use of two simple measures in the study of inter-firm alliance networks: Lemma 2 suggests that the welfare-relevant properties of such a network are completely captured by its density and degree variance, where the last is one way to measure the centralization in a network (Snijders, 1981).

The remainder of the chapter is organized as follows. Section 4.2 introduces some network terminology, and Section 4.3 contains the description of the model. The efficient network is characterized in Section 4.4.1. Section 4.4.2 compares the efficient network with the structure of the strategically stable networks, and Section 4.5 provides some robustness checks of the main findings. Section 4.6 summarizes the results of the first part of this thesis.

[3] Another article with a similar message is Salant and Shaffer (1998). The authors investigate asymmetric investment profiles in the seminal model of an R&D joint venture by d'Aspremont and Jacquemin (1988). In the context of inter-firm networks, the analyses of some specific market settings in Goyal and Moraga-Gonzáles (2001) and Goyal and Joshi (2003) point in this direction as well. On the one hand, Goyal and Moraga-Gonzáles (2001) show for a Cournot-triopoly with significant costs of link formation that an asymmetric collaboration network can be efficient. Goyal and Joshi (2003), on the other hand, find for a Bertrand-oligopoly and insignificantly small linking costs that the efficient network has an inter-linked star architecture. Our analysis indicates that their findings carry over to more general market settings, where at the same time there are an arbitrary number of firms, differentiated products, and significant linking costs.

[4] See Wasserman and Faust (1994) for an overview of the measures used in social network analysis.

4.2 Formal definition of a network

Consider a set of initially identical firms, $N = \{1, 2, ..., n\}$, with $n > 2$. For any distinct $i, j \in N$, a pairwise relationship between the firms is depicted by a bilateral link ij, and a network $g = \{ij : i, j \in N, i \neq j\}$ is the complete collection of the links between firms. To denote network $g \cup \{ij\}$, which is obtained from g by adding link ij, write $g + ij$. Likewise, the network that is obtained from g by subtracting link ij is depicted by $g - ij$. Furthermore, denote by $N_i(g)$ the set of firms, with which firm i has a link in g; firm i's *degree* is defined as the cardinality of this set, $\eta_i(g) = |N_i(g)|$.

A network partitions the set of firms according to their degrees. Distinct $i, j \in N$ are members of the same group $h_l(g)$ of the degree partition $\{h_0(g), h_1(g), ..., h_m(g)\}$ if and only if $\eta_i(g) = \eta_j(g) = l$, where $0 \leq l \leq m$. Define the *degree distribution* of a network as the function that assigns to every nonnegative integer l the frequency weight $n_l(g) = |h_l(g)|/n$. Two important characteristics of the degree distribution are:

- the *density* $D(g) = \bar{\eta}(g)/(n-1)$, where $\bar{\eta}(g) = \sum_{i \in N} \eta_i(g)/n$ denotes the *average degree* and $0 \leq D(g) \leq 1$, and

- the normalized *degree variance* $C(g) = V(g)/\hat{V}(n)$, where the degree variance, $V(g) = \sum_{i \in N}(\eta_i(g) - \bar{\eta}(g))^2/n$, is normalized by its maximum given n firms, $\hat{V}(n)$, such that $0 \leq C(g) \leq 1$.[5]

The density measures the overall connectivity between the firms in a network, whereas the (normalized) degree variance is a measure of network concentration or network centralization, i.e. it captures the extent to which some firms are more central than others in the network (Snijders, 1981).

In a *regular* network, g^r, of density D every $i \in N$ has a degree of $\eta_i(g^r) = (n-1)D$. Hence, g^r does not exhibit any concentration, $C(g^r) = 0$. Otherwise, a network g is called *irregular* if and only if $C(g) > 0$. Two examples of regular networks are the *empty* network, g^e, where $\eta_i(g^e) = 0$ for all $i \in N$, and the *complete* network, g^c, with $\eta_i(g^c) = n - 1$.

Another characteristic of a network is its *architecture*. Two networks g and g' share the same architecture, if there exists a permutation of firms, P, such that $g' = \{P(i)P(j) | ij \in g\}$. Thus, network g' should be attainable from g by just relabeling the firms. An example of an irregular architecture, which is important in this chapter, is the *dominant group* architecture of

[5] Snijders (1981) determines the maximum degree variance, which is given by $\hat{V}(n) = \frac{(3n-2)^2(n-2)(3n+2)}{256n^2}$ for a network with n firms.

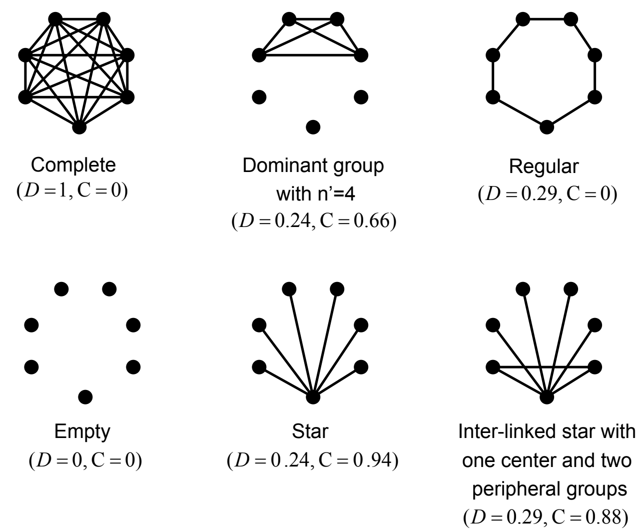


Figure 4.1: Some stylized network structures.

size n', $g^{n'}$, with $2 \leq n' \leq n-1$. The dominant group architecture is first introduced in Goyal and Joshi (2003) and consists of two groups of firms, $\{h_0, h_{n'-1}\}$; one in which every firm is linked to every other firm in that group (denoted by $h_{n'-1}$), and a second group consisting of isolated firms (denoted by h_0). The authors also introduce the class of *inter-linked star* architectures. An inter-linked star, g^x, induces a degree partition, where there are two or more groups of firms with a positive degree. The group of firms with the highest degree in g^x is denoted as the *center group*, $h_c = h_m(g^x)$. Every other firm with a positive degree belongs to the *periphery*, $h_p = \bigcup_{0<l<m} h_l(g^x)$. Moreover, each firm in the center group is linked to every firm with a link. Hence, let $i \in h_c$. If $\eta_j(g^x) \geq 1$, then $ij \in g^x$. A prominent example of an inter-linked star architecture is the *star*, g^s, which consists of two groups of firms, $\{h_1, h_c\}$, with $|h_c| = 1$. The defined networks are illustrated in Figure 4.1.

4.3 Setup of the theoretical model

In the following, we describe and investigate a generalized version of the two-stage model introduced in Goyal and Joshi (2003). In the first stage, a social planner forms a network of marginal cost-reducing links between firms, which requires the investment of a fixed cost per link. In the second stage, the firms compete in the product market. The model of the product market investigated in this chapter is more general than the one of Goyal and Joshi (2003). While the authors investigate a homogeneous-product Cournot oligopoly, we build on the market model by Singh and Vives (1984), which allows for price or quantity competition between firms as well as for differentiated products.

We first present the model and solve its second stage. The analysis of the welfare-efficient network follows in subsection 4.4.1. Some of the questionable assumptions underlying the model are highlighted in the text and discussed in Section 4.5. However, let us point out already here that none of these are essential and can all be relaxed without eroding the main results of the analysis in this chapter.

Market competition. In the second stage, each firm $i \in N$ sells a single, possibly differentiated, product to a continuum of homogeneous consumers, who each consume a *numeraire* good I in addition. Let q_i denote the quantity and p_i the price of good i. A representative consumer maximizes

$$U(I, q_1, ..., q_n) = I + \alpha \sum_{i \in N} q_i - \frac{1}{2} \sum_{i \in N} q_i^2 - \frac{\beta}{2} \sum_{i \in N} \sum_{j \neq i} q_i q_j \tag{4.1}$$

under the constraint $I \leq -\sum_{i \in N} p_i q_i$. The parameter α captures the total size of the market, whereas β, a real number from the interval $(0, 1]$, denotes the degree of substitutability between products. Thus, the analysis is restricted to markets where the collaborating firms are competitors in the product market. In particular, $\beta = 1$ depicts a market of perfectly substitutable goods, whereas $\beta \to 0$ represents the case of almost independent markets. From standard utility maximization, we arrive at a system of inverse demand functions $p_i = \alpha - q_i - \beta \sum_{j \neq i} q_j$, $i \in N$. A firm's profit, gross of linking costs, is given by $\pi_i = (p_i - c_i) q_i$.

Let the firms compete either in quantities or in prices, but let us disregard the case of perfect Bertrand competition, which means that under price competition we assume $\beta \in (0, 1)$. In either case, the Nash equilibrium quantities can be expressed in the form $\lambda q_i = \mu \alpha - \nu c_i + \xi \sum_{j \neq i} c_j$. Using subscript q and p to denote competition in quantities and prices respectively, the parameters are given by:

$$\lambda_q = 1, \qquad \mu_q = \frac{1}{2 + (n-1)\beta}, \qquad \nu_q = \frac{2 + (n-2)\beta}{(2 + (n-1)\beta)\,(2 - \beta)}$$

$$\xi_q = \frac{\beta}{(2 + (n-1)\beta)(2 - \beta)},$$

and

$$\lambda_p = \frac{(1-\beta)(1+(n-1)\beta)}{1+(n-2)\beta}, \qquad \mu_p = \frac{(1-\beta)}{2+(n-3)\beta}$$
$$\nu_p = \frac{2+(3n-6)\beta+(n^2-5n+5)\beta^2}{(2+(n-3)\beta)\,(2+(2n-3)\beta)}$$
$$\xi_p = \frac{(1+(n-2)\beta)\beta}{(2+(n-3)\beta)(2+(2n-3)\beta)}.$$

Prices and profits are in equilibrium $p_i = \lambda q_i + c_i$ and $\pi_i = \lambda q_i^2$, respectively. The following assumption ensures that, regardless of the precise network structure, no firm exits the product market:

Assumption 1. *No market exit: under any attainable profile of marginal production costs, induced by a network of collaborative ties, all firms produce positive quantities in equilibrium.*[6]

Links and cost reduction. In the first stage of the model, the social planner designs a collaboration network between firms. We interpret a link in this network as a bilateral R&D joint venture or a cross-licensing agreement, where the purpose is the joint development or the exchange of a process technology. Hence, links are formed in order to reduce the marginal production costs of the firms.

Throughout the chapter, we make the simplifying assumption that this cost reduction is exogenous. Thus, a network g directly induces a vector of marginal production costs, $c(g) = \{c_1(g), c_2(g), ..., c_n(g)\}$. This assumption is not uncommon in the literature on R&D collaboration and has been motivated by more detailed models of collaborative agreements (e.g., Bloch, 1995; Goyal and Joshi, 2003). Bloch (1995), for example, motivates exogeneity by a simple model of a joint venture between a firms, $a > 1$. The members of a venture can set up a joint research facility to which all of them have unrestricted access. Bloch assumes that, due to capital market imperfections, each firm can invest only a fixed amount r in the facility. Moreover, the output of the facility, $z(r)$, exhibits constant returns to scale and leads to a reduction of the members' marginal production costs. Hence, in a joint venture of size a, the members' costs are reduced by $az(r)$. Adapting this model to the case of bilateral agreements, it follows that each link leads to

[6]The precise condition depends on the mode of competition and the productivity of collaborative ties. This condition will be specified in footnote 8.

an exogenous cost reduction of $2z(r)$.[7] In addition, we make the following two assumptions regarding the R&D technology. Denote the linking costs of firm i in network g by $F_i(g)$. For any network g and $ij \in g$:

Assumption 2. *Constant link returns:* $c_i(g+ij)-c_i(g) = c_j(g+ij)-c_j(g) = -\gamma$ *and* $F_i(g+ij) - F_i(g) = F_j(g+ij) - F_j(g) = f/2$, *where* $\gamma > 0$ *and* $f > 0$*;*

Assumption 3. *No inadvertent spillovers:* $c_k(g+ij) - c_k(g) = 0$ *for any* $k \in N\backslash\{i,j\}$.

We therefore write more conveniently $F_i(g) = \frac{1}{2}f\eta_i(g)$ and $c_i(g) = \gamma_0 - \gamma\eta_i(g)$, where $\gamma_0 > (n-1)\gamma$. Both assumptions will be relaxed in Section 4.5.

Efficiency. It follows from the aforementioned that given a network g the net profits and consumer utility can be expressed as functions of the firms' degrees in g:[8]

$$\Pi_i(g) = \pi_i\big[\eta_i(g), \sum_{j\neq i}\eta_j(g)\big] - \frac{1}{2}f\eta_i(g) \quad \text{and} \quad U(g) = U\left[\big(\eta_i(g)\big)_{i\in N}\right]. \tag{4.2}$$

Networks are investigated in terms of both social welfare concepts, the consumer surplus (net of linking costs) and the total surplus. A network g^* is therefore defined *efficient*, if respectively $U(g^*) - \frac{1}{2}f\sum_{i\in N}\eta_i(g^*) \geq U(g) - \frac{1}{2}f\sum_{i\in N}\eta_i(g)$ or $U(g^*) + \sum_{i\in N}\Pi_i(g^*) \geq U(g) + \sum_{i\in N}\Pi_i(g)$ for all g. For expositional simplicity, we denote the total surplus and the consumer surplus in a network by $W(g)$ throughout the following sections, unless a distinction is necessary.

4.4 Results

4.4.1 Properties of the efficient network

In this section, we characterize the efficient network structure of the model. The difficulty with the analysis is that, even though we disregard knowledge

[7] In an accompanying paper to this chapter, we show that Bloch's assumption of a fixed investment can be relaxed, because in equilibrium the firms invest the maximum amount attainable from an imperfect capital market (Westbrock, 2008). More precisely, even if the joint investments of the members of a venture is a real number from the interval $[0, r]$, equilibrium investments are given by r.

[8] In order to satisfy Assumption 1, we need to assume that in the dominant group architecture g^{n-1}, where only firm i is isolated, $q_i(g^{n-1}) > 0$. This implies for quantity competition $\alpha - \gamma_0 > \frac{\gamma(n-1)(n-2)\beta}{2-\beta}$, and for price competition $\alpha - \gamma_0 > \frac{\gamma(1+(n-2)\beta)(n-1)(n-2)\beta}{2+(2n-5)\beta-(2n-3)\beta^2}$.

spillovers, the marginal social returns of any two collaborative links are interrelated by the fact that the collaborating firms are, also at the same time, competitors in the product market.

We show that this market-based interdependence between links has two faces: the social welfare function is *convex* as well as *submodular* with respect to collaborative links. We apply these properties to characterize the architecture of the efficient network. Subsequently, we express social welfare in a network as a function of two characteristics of its degree distribution, the density and the degree variance. The specific form of this functional dependence allows us to derive the important result that a concentration of collaborative ties is a typical feature of the efficient network. We conclude the section with an analysis of the dependence of the efficient network on the precise cost and demand parameters.

Network architecture. In a first step, we investigate the marginal social benefits of forming collaborative links between firms, taking an arbitrary network structure as being given. For this purpose, it is helpful to think of a collaborative tie ij as a cost-reducing investment by firms i and j. The marginal social benefits of this investment increase with the scale of production at the firms, prior to that link, because the output of the collaboration, i.e. a process innovation, can be applied to every unit of their products. However, in an oligopolistic market, the quantities of firms i and j are determined by all of their other collaborative ties as well as the links of all their competitors, making the returns dependent on the structure of the whole network. This market-based interdependence between collaboration links is demonstrated in two properties of link formation.

Lemma 1. *For any network g with $ij, ik, kl \notin g$, any $i, j \in N$ and $k, l \in N \backslash \{i, j\}$:*

(i) the total surplus and the consumer surplus are convex in links: if $\eta_j(g) \geq \eta_k(g) + 1$, $W(g + ij + ik) - W(g + ik) > W(g + ik) - W(g)$;

(ii) the total surplus (under price and quantity competition) and the consumer surplus under price competition are submodular in links: $W(g + ij + kl) - W(g + kl) < W(g + ij) - W(g)$.[9]

The proof of the lemma can be found in the Appendix. Convexity follows from the fact that firm i attains a larger market share in network $g + ik$ than

[9]The consumer surplus is submodular under quantity competition as well, requiring $\beta < (n-2)/(n-1)$.

in g. Hence, the subsequent process innovation aligned with the addition of link ij affects a larger output of firm i. However, convexity requires that firm i's subsequent partner, firm j, is at least as well connected in network $g + ik$ as firm i's previous partner, firm k, is and therefore produces at least the same quantity. Submodularity means that the social returns to a link ij deteriorate with the formation of a link between any other pair of firms. The reason is that firm i's and j's market shares are declining in the number of links of their rivals.[10]

The two properties allow for a marginal check of efficiency, which is in the same vein as the stability check introduced in Goyal and Joshi (2003, 2006). The idea is to check whether a given network is socially desirable or whether an additional collaboration tie can increase welfare. This results in a meaningful selection among the network architectures.

Proposition 1. *If the efficient network g^* is regular, then it must be either the empty network, g^e, or the complete network, g^c. If the efficient network g^* is irregular, it has either a dominant group architecture, $g^{n'}$, for some $2 \leq n' \leq n-1$, or an inter-linked star architecture, g^x.*

Proof. We first characterize the regular and efficient architectures. Suppose a regular network g that is neither empty nor complete. Thus, there exist distinct $i, j, k \in N$ such that $ij \in g$ and $ik \notin g$. For efficiency of g, it must hold for any $ij \in g$ that $W(g) - W(g - ij) \geq 0$. In network $g - ij$, however, $\eta_k(g - ij) = \eta_j(g - ij) + 1$ and therefore, from *convexity in links*, $W(g + ik) - W(g) > W(g) - W(g - ij)$. This implies a contradiction to network g having an efficient architecture. Hence, if the efficient network is regular it must either be the *empty* or the *complete* network.

Let us turn to a characterization of irregular architectures. First, suppose that an efficient and irregular network g^* induces a two-point degree partition, $\{h_0, h_m\}$, and suppose $|h_m| = 2$. Then we have a *dominant group* architecture. Assume next a network g that induces a degree partition, $\{h_0, h_m\}$, with $|h_m| > 2$, and in which for every $i \in h_m$, $\eta_i(g) < |h_m| - 1$. Hence, there exist distinct $i, j, k \in h_m$ with $ik \in g$ and $ij \notin g$. For g having an efficient architecture, it must be $W(g) - W(g - ik) \geq 0$. However, $\eta_j(g - ik) = \eta_k(g - ik) + 1$. Hence, *convexity in links* applies and therefore $W(g + ij) - W(g) > W(g) - W(g - ik)$. This implies a contradiction. Thus, if an efficient network g^* induces a two-point degree partition with

[10] Note that the central arguments behind convexity and submodularity are the constant unit-cost reductions of the collaborating firms and the resulting changes in market shares. Thus, Lemma 1 is also likely to apply in the context of a more general demand system than the linear one chosen for this study.

$|h_m| > 2$, then $\eta_i(g^*) = |h_m| - 1$ for every $i \in h_m$. This is a *dominant group* architecture.

Next, assume that a network g^* with an efficient architecture induces a degree partition, $\{h_{l_1}, h_{l_2}, ..., h_m\}$, with at least two groups of firms with a positive degree. We show that for every firm i with $\eta_i(g^*) > 0$ it must be $ij \in g^*$, if $j \in h_m$. Suppose not, then we have a network g that induces a degree partition with more than one group of positive degree, where there are distinct $i, j \in N$ such that $\eta_i(g) > 0$ and $j \in h_m$ but $ij \notin g$. Since $\eta_i(g) > 0$, there must exist a firm $k \in N$ with $ik \in g$. However, because $\eta_k(g - ik) \leq \eta_j(g - ik) - 1$, *convexity in links* applies and, therefore, $W(g + ij) - W(g) > W(g) - W(g - ik)$. This implies a contradiction. Hence, in an efficient network g^*, it must be for any $j \in h_m$ that $ij \in g^*$ for every firm i with $\eta_i(g^*) > 0$. This is an *inter-linked star*. □

The networks included in the set of efficient architectures are illustrated in Figure 4.1. The proof is solely based on the convexity of the social welfare function. Due to this property, a firm i with at least a single link in network g, say to a firm k, should be connected to every firm j with the highest degree in the network. The reason is that $\eta_j(g - ik) \geq \eta_k(g - ik) + 1$, so that Lemma 1 (i) can be applied. Hence, a commonality of all efficient network architectures is that there exists a group of firms (the center group), where each firm in this group has the highest degree and is connected to every other firm with a link.

An important class of architectures that is excluded by the proposition are the *regular networks*, which are non-empty and incomplete. The reason is that in a regular network the center group consists of every $i \in N$. Yet, only in the complete network are the firms completely connected to each other. From the class of *irregular networks*, any architecture is ruled out that consists of a center group and a periphery of firms, but where either the firms in the center are not completely connected with each other or where any one firm in the periphery is not linked to all the center firms. Hence, in an efficient architecture, the central firms are densely connected through a web of direct links and, in the case of an inter-linked star, indirect links via the peripheral firms.

Two remarks about Proposition 1 are worth noting: first, as suggested by our analysis below, the characterization of the result is tight in the sense that there is no architecture included in the set of efficient architectures that is not efficient for some parameters. Second, even though the proof of the result does not take advantage of the submodularity of the welfare function, this property crucially shapes the architecture of an efficient network. While convexity renders the formation of links between those firms efficient that are already involved in a lot of ties, submodularity dilutes the benefits of also linking the poorly connected firms. Hence, submodularity favors the selection of highly concentrated dominant group architectures or inter-linked star architectures, where collaborative activity is concentrated around a small group of firms.

Because the architectures differ considerably in terms of the size of that group and the degrees of the firms contained in it, it is still an open question which of these is desirable. Moreover, it is still not clear whether some cost and demand parameters exist for which a dominant group or an inter-linked star architecture can actually be supported as a welfare-maximizing network. These issues are investigated below.

Degree distribution. Here, we determine the properties of the degree distribution in a socially efficient inter-firm network. Because it is assumed that the marginal production costs only depend on the number of collaborative ties of a firm, it is clear that any two networks with the same degree distribution also produce the same total surplus. The analysis of the relationship between the degree distribution and social welfare can, therefore, provide further insights into the structure of an efficient network.

Generally, the welfare in any network g can be decomposed into two additive terms:

$$W(g) - W(g^e) = \left[W(g^r) - W(g^e)\right] \; + \; \left[W(g) - W(g^r)\right].$$

Choosing the regular network g^r such that $D(g^r) = D(g)$, the first summand contains the contribution to welfare from the pure density in a network, since $\eta_i(g') = \eta_j(g')$ for any $i, j \in N$ and $g' \in \{g^e, g^r\}$. The welfare effects from the dispersion of collaboration ties among the firms are, therefore, completely captured by the second summand. The following result shows that, due to the linear demand system in our model, we can go a step further and measure the dispersion effect by another simple statistic of the degree distribution.

Lemma 2. *The total surplus and the consumer surplus in network g can be written as functions of the density and the normalized degree variance. In particular, $W(g) = Y\left[D(g), C(g)\right]$ with:*

$$\begin{aligned} Y\left[D(g), C(g)\right] \quad &= \quad Y\left[0,0\right] + \left(\phi_1 + \phi_2 D(g) - \frac{n(n-1)}{2} f\right) D(g) \\ &\quad + \phi_3 C(g) \end{aligned} \tag{4.3}$$

where $Y\left[0,0\right] > 0$, $\phi_1 > 0$, $\phi_2 > 0$, and $\phi_3 \geq 0$.

The lemma states that the welfare-relevant properties of a network are completely captured by its density and its (normalized) degree variance. The proof and the precise specification of the parameters are given in the Appendix. As is shown in equation (4.3), the contribution to welfare from the network density can be positive or negative depending on whether or not the linking costs exceed the social returns to a marginal cost reduction. The density enters the welfare function quadratically ($\phi_2 > 0$), because every additional collaborative tie increases the effective market size, thereby generating a larger accessible surplus for firms and consumers. Moreover, since ϕ_3 is typically strictly larger than zero, it follows that, having fixed the density, social welfare increases with the concentration of links in a network.

Proposition 2. *Suppose that either the measure of welfare is the total surplus or $\beta \in (0,1)$. An efficient network g^* is maximally concentrated among the networks with the same density: if $D(g^*) = D$ for any $0 < D < 1$, then $C(g^*) = \max\{C(g)|D(g) = D\}$.*

The implications for the structure of an efficient network can be illustrated with the help of Figure 4.1. The proposition implies that the interlinked star network in the figure attains a higher welfare than the ring, but also that the star is more efficient than the dominant group. This suggests that, from an efficiency point of view, it is desirable to maximally concentrate a given number of cost-reducing links around the smallest number of firms possible.

This result is surprising for several reasons. The first thing to note is that the proposition applies to a wide range of market settings and is independent of whether welfare is measured in terms of consumer surplus or total surplus. In fact, there is only one case contained in our model, in which social welfare does not increase in link concentration.[11] Second, it is interesting to notice that the proposition opts for a corner solution, where the only constraint to concentration is the maximum degree that a group of firms can attain in a network of a given density. Such a solution may not be so surprising for a market, where products are homogeneous and prices are set by a social planner, because the concentration of collaborative ties enables the planner to reduce the production costs at his most efficient plant. However, since the firms in our model are free to raise their prices above unit production

[11] As shown in the Appendix, it is $\phi_3 = 0$ if and only if firms compete a la Cournot with homogeneous products and welfare is measured in terms of consumer surplus. That the distribution of marginal production costs is irrelevant in this case is well known in the literature, because the aggregate market output only depends on the sum of the firms' costs (see, e.g., Bergstrom and Varian, 1985).

costs, concentration is aligned with the exertion of market power. In this light, Proposition 2 suggests that, if it is for the purpose of concentrating some cost-reducing collaborative ties, concentration in the product market is a tolerable side effect.[12]

The first part of the explanation is that the concentration in a network can be altered by rearranging some of its links, which is a linking cost-neutral transformation of the network structure. Hence, the result is solely based on the effects of concentration on the distribution of marginal production costs and, in turn, on gross industry profits and consumer surplus. Not surprisingly, the concentration of links has a positive impact on industry profits, because the overall level of market power increases. More interesting to note is that consumers benefit from concentration as well, which is a particularly surprising finding considering that the firms sell differentiated products in our model.

An intuition can be gained from the following: consider a regular and incomplete network, g^r, where the unit production costs are given by $c_i = c_j$ and prices by $p_i = p_j$ for any $i, j \in N$. A consumer with utility function (4.1) splits his total consumption into equal parts. Suppose now that link ij is removed and firm i is connected to another firm k instead. In this way, concentration in the network increases and, given that the products of the firms are differentiated, p_j increases and p_k declines. Under quantity competition, for example,

$$dp_j = \gamma(1 - \nu_q - \xi_q) = \frac{1-\beta}{2-\beta} = -dp_k > 0\,,$$

for any $\beta \in (0, 1)$. In the more concentrated network, the consumer can still afford the original bundle of goods, because prices have changed at the same absolute rate. However, he can save costs and still obtain the same utility by shifting some of his consumption from product j to k. Hence, increasing network concentration yields cost savings for the consumer. Moreover, because the demand for good k has increased, a subsequent price reduction of p_k, compensated by a price increase of another product, is even more favorable than the previous one. Thus, any subsequent increase in network concentration leads to further cost savings, where the rate of savings is rising with every link rewired. This shows that, even in a market with differentiated products, it can be desirable to maximally concentrate a given number of collaboration ties around a small group of firms.

[12] In fact, it can be shown for our model that, within the class of networks with a fixed density, the normalized degree variance is proportional to the *Herfindahl* index of product market concentration.

Efficient networks and linking costs. In the following, we characterize the structure of the efficient network in a comparative static analysis, where we focus on the role of linking costs. First, a general result for industries with an arbitrary number of firms is provided. Since a characterization of the precise network structure is complicated in this case, we revert to an analysis of the range of linking costs for which the efficient network exhibits at least some concentration. A detailed characterization is provided later in the section, where we assume some specific numbers of firms.

The following is our general result for markets with $n > 2$.

Proposition 3. *Suppose the firms sell sufficiently close substitutes ($\beta > \tilde{\beta}$). Suppose, moreover, that the measure of welfare is the total surplus (under price or quantity competition) or the consumer surplus under price competition. There exist f_1 and f_2, with $0 < f_1 < f_2$, such that in the efficient network, $C(g^*) > 0$ if and only if $f \in (f_1, f_2)$.*[13]

Proof. The proof is in two steps. First, the claimed cost interval is characterized assuming it is non-empty. Then, the existence of such a cost interval is proven. With respect to the first step, suppose there exists at least one f' such that $C(g^*) > 0$. We show that f' is bounded to be finite and positive. Finiteness follows from noting that, regardless of the precise specification of the other model parameters, there always exists a sufficiently large f'', $f'' \neq f'$, such that the efficient network is empty. Denote the smallest of these costs by f_2. Because welfare is monotonically declining in linking costs, $g^* = g^e$ for any $f'' > f_2$. Hence, since $C(g^e) = 0$, we obtain $C(g^*) > 0$ only if $f' < f_2$. Applying a similar argument to a small (possibly negative) f'' and the complete network, g^c, we get $C(g^*) > 0$ only if $f' > f_1$. In the Appendix, we show that the efficient network is complete, if the costs of link formation are zero (Lemma 4). Thus, $f_1 > 0$. To complete the characterization, note that $C(g^*) = 0$ if and only if $g^* \in \{g^e, g^c\}$, which follows from Proposition 1. Hence, suppose an f' exists such that $C(g^*) > 0$, then $C(g^*) > 0$ for any $f' \in (f_1, f_2)$.

We now show that an interval (f_1, f_2) exists in a general class of market settings, only requiring that the products of the firms are sufficiently close substitutes. To do so, we prove that there are some f_3 and f_4, with $f_3 < f_4$, such that for $f \in (f_3, f_4)$ a star network, g^s, satisfies $W(g^s) > W(g^c)$ and $W(g^s) > W(g^e)$. Existence follows immediately, since $W(g^*) \geq W(g^s)$. Hence, $g^* \notin \{g^e, g^c\}$ for any $f \in (f_3, f_4)$.

[13] A concentrated network can also maximize the consumer surplus under quantity competition (see Example 2 below). This, however, requires $\tilde{\beta} < \beta < \hat{\beta}$.

In the star, it is $D(g^s) = 2/n$ and $C(g^s) = (n-1)(n-2)^2/(n^2\hat{V}(n))$. Substituting this into welfare function (4.3), one can write $W(g^s) > W(g^c)$ and $W(g^s) > W(g^e)$ equivalently as

$$(n-1)\big(\frac{n}{2}-1\big)f \quad > \quad \big(1-\frac{2}{n}\big)\phi_1 + \big(1-\frac{4}{n^2}\big)\phi_2 - \frac{(n-1)(n-2)^2}{n^2\hat{V}(n)}\phi_3$$

and

$$(n-1)f < \frac{2}{n}\phi_1 + \frac{4}{n^2}\phi_2 + \frac{(n-1)(n-2)^2}{n^2\hat{V}(n)}\phi_3.$$

Denote the right-hand side of the first inequality by $(n-1)\big(\frac{n}{2}-1\big)f_3$ and the right-hand of the second inequality by $(n-1)f_4$. Then, $f_3 < f_4$ if and only if

$$(n-2)\frac{\phi_3}{\hat{V}(n)} - \frac{2}{n-1}\phi_2 > 0\,,$$

where the parameters ϕ_2 and ϕ_3 are defined in the proof of Lemma 2. Now, suppose welfare is measured in terms of total surplus and competition is in quantities. The inequality becomes

$$\frac{n(n-1)\,(n-2)\,(3-\beta)}{(2-\beta)^2}\gamma^2 - \frac{2n(n-1)^2\,(3+\beta n-\beta)}{(2+\beta n-\beta)^2}\gamma^2 > 0.$$

It can easily be seen that the term on the left-hand side is negative for $\beta = 0$ and positive for $\beta = 1$ and, moreover, that the term is monotonically increasing for any $\beta \in (0,1]$. Hence, there exists a $\tilde{\beta}$ in the interior of $(0,1]$ such that the inequality is satisfied, if and only if $\beta > \tilde{\beta}$. Under price competition and the consumer welfare measure, the inequality can be equivalently written as

$$\frac{n\,(n-1)\,(n-2)\,(1+\beta n-2\beta)^2}{(2+2\beta n-3\beta)^2}\gamma^2$$
$$-\,(1-\beta)\,\frac{2n(n-1)^2\,(1+\beta n-2\beta)^2}{(1+\beta n-\beta)\,(2+\beta n-3\beta)^2}\gamma^2 > 0.$$

The left-hand side is negative for $\beta = 0$ and has a positive limit for $\beta \to 1$. Moreover, the term has a single negative local extremum β^* in the interior of $(0,1)$. Hence, there exists a $\tilde{\beta}$, with $\tilde{\beta} \in (0,1)$, such that the inequality is satisfied if and only if $\beta > \tilde{\beta}$. In the same manner, it can be shown that the inequality is satisfied for price competition and the total surplus as well. Again, β must be sufficiently large. On the other hand, for quantity competition and the consumer surplus measure we additionally require $\beta < 1$.

Thus, we have obtained an interval (f_3, f_4) such that for $f \in (f_3, f_4)$ the star welfare-dominates the empty and the complete network in a market with close substitutes. □

In the proof, we exploit the fact that a particular concentrated network, namely the star, dominates the empty and the complete network in terms of welfare, if linking costs are on an intermediate level and the firms sell sufficiently similar products. The result confirms the findings of Goyal and Joshi (2003), who show that the efficient network is the complete network, when the costs of linking are small. Moreover, it is in line with the intuition that the efficient network is empty for large linking costs. However, the main insight is that for intermediate linking costs the efficient network is characterized by a concentration of collaborative ties.

The following examples fill the gaps in Proposition 3 by adding three further insights: first of all, the proposition is not clear about the precise structure of the efficient network for intermediate linking costs. The examples provide a detailed characterization. Second, it is yet not clear whether a concentrated network might be efficient for small β as well. In the first example, concentration is not desirable, when firms sell weak substitutes $(\beta \leq \tilde{\beta})$. In light of the discussion following Proposition 1, this is not very surprising. The reason is that the welfare function needs to be sufficiently submodular in order to obtain a concentrated efficient architecture. Yet, the strength of submodularity increases with the intensity of product market competition. Finally, the proposition does not comprise the case of the consumer surplus-maximizing network under quantity competition. The second example shows that the efficient network may be concentrated even in this case.[14]

Example 1. *Suppose that* $n = 3$ *and moreover that the firms compete in prices and welfare is measured in terms of total surplus. Let* $\beta \leq 0.62$. *Then,*

[14]We only briefly summarize the examples here. More details on their derivation can be found in the Appendix.

$g^* = g^c$, *if* $f \leq f_2$, *and* $g^* = g^e$ *otherwise. Moreover, let* $\beta > 0.62$. *Then:*[15]

$$\big(g^*, D(g^*)\,,\, C(g^*)\big) \;=\; \begin{cases} \big(g^c\,,1\,,0\big) & \textit{if } 0 \leq f \leq f_1\,, \\ \big(g^s\,,2/3\,,\,1\big) & \textit{if } f_1 \leq f \leq f_2\,, \\ \big(g^{n'},1/3\,,\,1\big) & \textit{if } f_2 \leq f \leq f_3\,, \\ \big(g^e\,,0\,,0\big) & \textit{if } f_3 \leq f\,. \end{cases}$$

The following example characterizes the efficient network in the limit case of a market with a continuum of firms. For this purpose, let us depict the effective market size in a large market by a parameter A, where $A > 1$, and the costs of link formation by ρ. We obtain the following network characterization.

Example 2. *Suppose that* $n \to \infty$ *and moreover that the firms compete in quantities and the welfare measure is the consumer surplus. Let* $\beta = 0.5$, $\gamma = 1$, *and* $A = 2$. *Then:*[16] $(g^*, D(g^*)\,, C(g^*)) \approx$

$$\begin{cases} \big(g^c\,,1\,,\,0\big) & \textit{if } 0 \leq \rho \leq 2.4\,, \\ \big(g^{n'}, 5.6 - 1.9\rho\,,\, 1 - 20(\rho - 2.7)^2\big) & \textit{if } 2.4 \leq \rho \leq 2.7\,, \\ \big(g^x, 10.1 - 3.5\rho\,,\, 1 - 20(\rho - 2.7)^2\big) & \textit{if } 2.7 \leq \rho \leq 2.9\,, \\ \big(g^e\,,0\,,\,0\big) & \textit{if } 2.9 \leq \rho\,. \end{cases}$$

Thus, both examples suggest that the efficient network has a highly concentrated structure, if linking costs are on intermediate levels.

To summarize the section, we have seen that an efficient network of cost-reducing ties is characterized by a concentrated network structure in a wide range of market settings. In particular, concentration is efficient, when linking costs are on an intermediate level and competition in the product market is sufficiently intense. Despite the fact that concentrated networks facilitate the exertion of market power, the reason for their efficiency is that they enable cost-efficient production of the market output.

4.4.2 Match of stable and efficient networks

In this section, we try to relate the previous findings to the structures of inter-firm alliance networks in the real world. At first sight, our findings put

[15] The critical cost levels are given by $f_1 = \frac{(3-\beta)(1+\beta)(3\alpha-3\gamma_0+\gamma)\gamma}{6(1+2\beta)} + \frac{(3+5\beta)(1+\beta)\gamma^2}{3(2+3\beta)^2(1-\beta)}$, $f_2 = \frac{(3-\beta)(1+\beta)(\alpha-\gamma_0+\gamma)\gamma}{2(1+2\beta)}$, and $f_3 = \frac{(3-\beta)(1+\beta)(3\alpha-3\gamma_0+5\gamma)\gamma}{6(1+2\beta)} - \frac{(3+5\beta)(1+\beta)\gamma^2}{3(2+3\beta)^2(1-\beta)}$.

[16] The parameter specification is not necessary to obtain some closed-form expressions for the density and degree variance in the efficient network, but the unspecified versions are too lengthy to be presented here.

the observed, highly concentrated structures of several high-tech industries in a rather positive light. However, since our analysis suggests that concentration should be maximal for a given number of links, it still might be that the observed networks are not concentrated enough. Moreover, because the efficient network can be empty or complete, they might be too dense or too sparse.

In order to shed some light on this issue, this section compares the structure of the efficient network with the equilibrium predictions of the model. The latter have been exhaustively characterized in Goyal and Joshi (2003, 2006), who investigate two different equilibrium concepts: network stability and network stability against transfers. In the following, we compare the efficient structures with each of these. Because a comparison is difficult for markets with a finite number of firms, the section contains only formal statements for the limit case of a market with a continuum of firms ($n \to \infty$). The relevance of the results is discussed at the end of the section. However, let us point out here that due to the focus on markets with differentiated products and asymmetric costs the analysis of the limit case does not constitute a breach of our fundamental premise of strategically interacting firms.

Match with stable networks. Goyal and Joshi (2003) define a stable network as a network, where any firm that is linked to another has no incentive to sever the link, and any two firms that are not linked should have no incentive to establish a collaboration link. Moreover, no firm should have an incentive to delete all its links (Goyal and Joshi, 2003, p.73). It turns out that this stability concept is very appealing in our context, because it sufficiently restricts the set of equilibrium networks and enables a general characterization of their efficiency. The following statement is a corollary of Proposition 3.1 in Goyal and Joshi (2006) and an immediate implication of the fact that a firm's profit function, as given in (4.2), satisfies their requirements of convexity with respect to links and market-wide externalities.

Lemma 3. *Suppose a large industry ($n \to \infty$). A stable network exists and is empty, complete or has a dominant group architecture.*

Note that each of the three architectures are also contained in the characterization of the efficient networks in Proposition 1. In particular, one should note that in a dominant group architecture, all collaborative ties are concentrated around a subset of the firms. This gives room for the possibility that the individual considerations of firms lead to the formation of an efficient network structure. However, as Figure 4.1 illustrates for a market with seven firms, a dominant group, g^4, with four firms in the center does not attain the same high degree variance as a star network of the same density. Thus, as an implication of Proposition 2, architecture g^4 is inefficient because welfare can be increased by rearranging some of its links. Furthermore, in some unreported analyses, we constructed networks that have the same density as some dominant group of size $n' \geq 4$, but attain a larger degree variance. Even though all these networks had an inter-linked star architecture in common, it was hard to derive a general construction rule that can be applied to arbitrary n and n'.

In contrast, for a market with a continuum of firms, we can take advantage of the fact that the maximum variance in a network of given density can be approximated by a simple expression. Formally, let $\hat{C}(D,n)$ depict the maximum (normalized) degree variance, $\hat{C}(D,n) = \max\{C(g)|D(g) = D, n = n'\}$. As we derive in the Appendix, it is:

$$\lim_{n\to\infty} \hat{C}(D,n) = \frac{256}{27} \max\left\{D^{\frac{3}{2}}(1-\sqrt{D})\,,\,(1-D)^{\frac{3}{2}}(1-\sqrt{1-D})\right\}.$$

Comparing the expression with the variance in a dominant group architecture (which is the first expression in the brackets) enables a welfare assessment of stable networks.

Proposition 4. *Suppose a large industry ($n \to \infty$). Suppose moreover that either the measure of welfare is the total surplus or $\beta \in (0,1)$. Every stable network of density $0 < D(g) < 0.5$ is inefficient.*

Proof. The proof follows from Lemmas 2 and 3 in combination with Figure 4.2, which plots the normalized degree variances of a dominant group architecture $g^{n'}$ (depicted by the dashed line) and a maximum-variance network as functions of density. □

The result states that any dominant group architecture consisting of less than half of the maximal attainable links is inefficient. The reason is highlighted in Figure 4.2 which shows that, for each of these networks, there exists a network of the same density that attains a larger degree variance and is, therefore, more efficient. Hence, social welfare can be increased in a dominant group architecture by rewiring some of the ties of the group of connected firms. Which collaborative ties should replace the links of the connected firms? Proposition 1 provides the answer. From the proposition, it follows that a sparse maximum-variance network must have an inter-linked star architecture. This suggests that the rewired ties should connect a subset

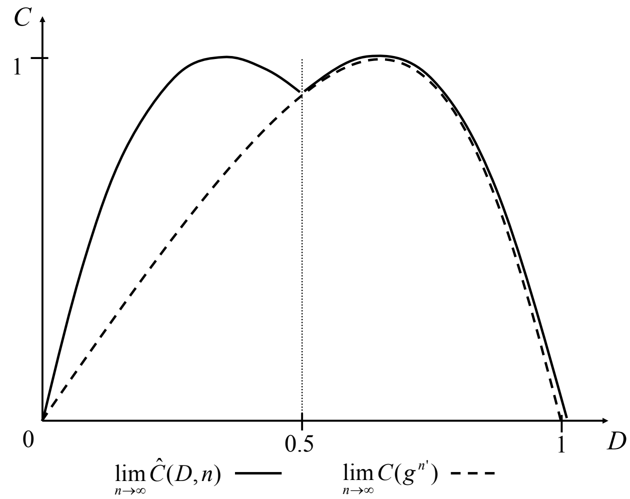


Figure 4.2: Predicted network concentration as a function of density.

of the group of connected firms with some of the firms that are isolated in a dominant group architecture.

Despite the clear assertion concerning the sub-optimality of the sparse stable networks, Proposition 4 leaves open the question of whether the efficient network is indeed more concentrated or whether it is denser or sparser. Moreover, the proposition does not allow for a welfare assessment of the dense dominant groups, because these architectures already attain maximal degree variance. Can a dense dominant group be stable and efficient at the same time? It turns out that the answers to both issues depend on the precise cost and demand parameters and, as is shown in an accompanying paper to this chapter, particularly on the degree of product substitutability (Westbrock, 2008). For low degree of substitutability (small β), every sparse and stable dominant group architecture consists of too few links, whereas every sparse dominant group is too dense when products are close substitutes. Finally, for intermediate levels of β, a sparse dominant group can be of proper density, but it is certainly less concentrated. Even though the variation of β produces comparable tensions between the efficient network and the dense and stable networks, the important difference is that for any $0 < \beta < 1$ there exists a dense and stable dominant group architecture that is efficient at the same time.

Match with transfer-stable networks. Let us turn to a comparison between the efficient networks and the stable networks, when transfer payments between firms are permitted. Motivated by the analysis in Goyal and Joshi (2003), we suspect that transfers might mitigate the discrepancy outlined above. As the authors conclude, dominant group architectures are stable without transfers, because the isolated firms are reluctant to form some collaboration links with the connected firms. Hence, transfers might enable the latter to sustain some additional links with the isolated firms and, therefore, increase concentration in equilibrium. In fact, the authors show that transfer-stable networks may have highly concentrated inter-linked star architectures.

In the following analysis, we apply their criterion of stability against transfers (Goyal and Joshi, 2003, p.77). Denote by $t_i = \{t_i^1, t_i^2, ..., t_i^n\}$ the transfers offered by firm i to other firms, where $t_i^j \geq 0$ for all $j \in N$ with $ij \in g$, and $t_i^k = 0$ for $k \in N$ with $ik \notin g$. Moreover, denote by g_{-i} the network that is obtained from g by deleting all the links of firm i. Goyal and Joshi (2003) define network g as stable against transfers, if

$$\begin{aligned} &(i) \text{ for all } ij \in g: \; \pi_i(g) + \pi_j(g) - f \geq \pi_i(g - ij) + \pi_j(g - ij) \\ &(ii) \text{ for all } ij \notin g: \; \pi_i(g) + \pi_j(g) + f \geq \pi_i(g + ij) + \pi_j(g + ij) \\ &(iii) \text{there exist transfers } t_i,\, i \in \{1, 2, ..., n\}, \text{ such that} \\ &\qquad \pi_i(g) + \sum_{j \in N_i(g)} \left(t_j^i - t_i^j\right) - \frac{1}{2} f \eta_i(g) \geq \pi_i(g_{-i})\,. \end{aligned} \quad (4.4)$$

In order to obtain a suitable stability criterion for a network between a continuum of firms, let the transfer payments and the linking costs in condition (4.4) be proportional to the number of firms in the industry. Hence, let us specify $f = n\rho$ and $t_i^j = n\tau_i^j$, with $\tau_i^j \geq 0$, for any $i, j \in N$. Moreover, depict the effective market size by a parameter A, where $A = (\alpha - \gamma_0)/\sigma$ and σ denotes the minimum market size as defined in footnote 8. Finally, multiply the inequalities in condition (4.4) by $1/n$. The limit of the obtained condition is necessary and sufficient for the stability of network g. Moreover, the Appendix shows that both sides of the inequalities have finite limit values as n grows large.

The following result investigates the stability of an efficient network with respect to a profile τ_i, $i \in \{1, 2, ..., n\}$, linking cost ρ, and market size A.

Proposition 5. *Suppose a large industry ($n \to \infty$). Every transfer-stable network of density $0 < D(g) < 0.5$ is inefficient.*

Proof. Suppose to the contrary a network g^*, with $0 < D(g^*) < 0.5$, which is efficient. As shown in the Appendix, network g^* has an inter-linked star architecture that induces a degree partition, $\{h_p, h_c\}$. Moreover, the peripheral group, h_p, comprises a share of $\sqrt{1-D}$ of the total number of firms and for each $i \in h_p$, $ik \in g^*$ if and only if $k \in h_c$. In the following, we prove that g^* is not stable against transfers, when firms compete in prices. (The proof for quantity competition follows in the same way and is therefore omitted.)

For stability of g^*, any two $k, l \in h_c$ should sustain their link $kl \in g^*$,

$$\lim_{n\to\infty} 2\frac{\pi_k(g^*) - \pi_k(g^* - kl)}{n} = \gamma^2 \frac{A + 1 - D}{1-\beta} \geq \rho\,, \tag{4.5}$$

such as any $i \in h_p$ and $k \in h_c$ should sustain $ik \in g^*$,

$$\begin{aligned}&\lim_{n\to\infty} \frac{\pi_i(g^*) - \pi_i(g^* - ik)}{n} + \frac{\pi_k(g^*) - \pi_k(g^* - ik)}{n} \\ &= \gamma^2 \frac{A + 1 - D - \frac{1}{2}\sqrt{1-D}}{1-\beta} \geq \rho\,,\end{aligned} \tag{4.6}$$

and for any two $i, j \in h_p$ with $ij \notin g^*$,

$$\lim_{n\to\infty} 2\frac{\pi_i(g^* + ij) - \pi_i(g^*)}{n} = \gamma^2 \frac{A - 1 + D + \sqrt{1-D}}{1-\beta} \leq \rho\,. \tag{4.7}$$

Details on the derivation of the limit values can be found in the Appendix. It can be readily seen that inequality (4.6) implies (4.5), which is a consequence of the convexity of profits in links. Hence, the cost interval is bounded by (4.6) and (4.7).

Moreover, stability of g^* requires some profile of transfers such that every $i \in N$ maintains its links. It is natural to focus on transfer profiles, which only depend on the position of a firm in g^*. Hence, for any $k, l \in h_c$: $\tau_k^l - \tau_l^k = 0$. Moreover, the net flows from the firms in the center to the peripheral firms are identical across all links. Thus, for any $i \in h_p$ and $k \in h_c$: $\tau_k^i - \tau_i^k = \tau$. Stability of g^* requires that a $\tau \in R$ exists such that any peripheral firm does not delete all of its $n(1 - \sqrt{1-D})$ links,

$$\begin{aligned}&\lim_{n\to\infty} \frac{\pi_i(g^*) - \pi_i(g^*_{-i})}{n^2(1-\sqrt{1-D})} + \tau \\ &= \gamma^2 \frac{2A + 1 - 2D - \sqrt{1-D}}{4(1-\beta)} + \tau \geq \rho\,.\end{aligned} \tag{4.8}$$

Furthermore, any firm in the center should not delete all of its $n-1$ links,

$$\begin{aligned}&\lim_{n\to\infty} \frac{\pi_k(g^*) - \pi_k(g^*_{-k})}{n(n-1)} - \lim_{n\to\infty} \frac{n\sqrt{1-D}}{n-1}\tau \\ &= \gamma^2 \frac{2A + 1 + 2D}{4(1-\beta)} - \tau\sqrt{1-D} \geq \rho\,.\end{aligned} \tag{4.9}$$

On the one hand, by comparison of (4.7) and (4.8) it follows that an appropriate τ must be positive, which means that the center firms sponsor links to the periphery. In fact,

$$\tau \geq \gamma^2 \frac{2A - 5 + 6D + 5\sqrt{(1-D)}}{4(1-\beta)}\,. \tag{4.10}$$

On the other hand, τ is bounded from above by (4.9). It can be easily verified that for any $A > 1$ and $0 < D < 0.5$, there does not exist any τ satisfying inequalities (4.7), (4.9), and (4.10) simultaneously. Thus, the inter-linked star architecture is not stable against transfers. □

The result shows that, in contrast to our expectations, transfers are not sufficient to sustain the desired network structure. The reason is that in an inter-linked star architecture there are a periphery of firms that supply the central firms with some additional cost-reducing ties. However, as shown in the proof, there does not exist any transfer payment which satisfies the incentive compatibility constraint of a central firm to sponsor such a tie, encouraging at the same time a peripheral firm to propose it.

We conclude this section by observing that our attempt to reconcile strategically stable and efficient networks results in an overall negative picture. Even though a stable network might be efficient, if it is sufficiently dense, our analysis of the sparse networks shows that the desired, highly concentrated inter-linked star architectures are not incentive compatible. The importance of the analysis in this section rests on the fact that sparse alliance networks between a large number of firms are a typical phenomenon in many high-tech industries. The network in the biotech and pharmaceutical industry of the 1990s, for example, consisted of about 1,400 companies and had a density of just 0.002.[17] Similarly, Duysters and Vanhaverbeke (1996) report a total of 72 chip producers and a density of 0.07 for the DRAM industry of the 1980s. Finally, our descriptive analysis of the inter-industry network in Chapter 2 has shown that the typical company in this network forms an R&D partnership about every thirty-five years. These observations suggest that the networks characterized in Propositions 4 and 5 are of high empirical relevance.

4.5 Robustness checks

So far, we have disregarded some of the issues that might violate the favorable assessment of highly concentrated networks. Here, we briefly discuss

[17] The figures are calculated on base of Figure 3 in Powell et al. (2005).

the relationship of each of these issues to our results on the structure of the efficient network.

Market exit. According to Assumption 1, no firm is forced out of the market by occupying only a peripheral position in the network and thereby having a comparative cost disadvantage. However, market exit of a peripheral firm can be detrimental, because (1) competition in the product market is reduced, and (2) the central firms lose a valuable collaboration partner.

In the Appendix, we provide an example in which the benefits of a concentrated network outweigh both of these concerns. The underlying intuition is that, even in the model of Section 4.3, the cost disadvantage for a peripheral firm may be so strong that it only sells an insignificant small quantity in the market. Hence, from a welfare perspective it is only a marginal loss, if this firm exits the market altogether. Moreover, not every lost collaboration tie is necessarily detrimental. On the contrary, Goyal and Moraga-Gonzáles (2001) show that competing firms might have an incentive to form excessively many ties in order to seize their rivals' market shares.

Convex linking costs. The model in this dissertation is simple as compared to other studies on R&D collaboration by assuming linear demands and costs (e.g., Katz, 1986; Leahy and Neary, 1997). Yet, a concave demand schedule or convex costs might erode the favorable assessment of highly concentrated networks. Here, we will briefly discuss the robustness of Propositions 1 and 2 with respect to the simplest modification in this direction: convex linking costs. Let us therefore violate Assumption 2 by assuming $F_i(g) = \frac{1}{2} f \eta_i(g)^2$, instead. Then, if:

$$W(g + ij + ik) - W(g + ik) - f\eta_j(g) - f > W(g + ik) - W(g) - f\eta_k(g)$$

is satisfied for any g with $\eta_j(g) \geq \eta_k(g) + 1$, Lemma 1 applies. Moreover, the cost term in welfare function (4.3) is replaced by $\frac{n}{2} f\big((n-1)^2 D(g)^2 + V(g)\big)$. Hence, as long as f is sufficiently small as compared to the social benefits from concentration, both Propositions 1 and 2 carry over to a model with convex linking costs. Otherwise, if $\frac{n}{2}\hat{V}(n)f > \phi_3$, a network with an equal dispersion of links is more desirable.

Spillovers. The focus of a large body of the literature on research collaboration is the effect of knowledge spillovers to the whole industry (e.g., d'Aspremont and Jacquemin, 1988) or via the links in a network (Goyal and Moraga-Gonzáles, 2001). A central finding is that the efficient market structure of collaborative agreements depends on the nature and the size of these spillovers. However, Assumption 3 excludes spillovers from the model in this chapter. A modification in this direction is the following. Suppose a firm's marginal production cost in network g is given by:

$$c_i(g) \quad = \quad \gamma_0 - \gamma\Big[(1-\theta)\eta_i(g) + (\theta - \vartheta)\sum_{j \in N_i(g)} \eta_j(g) + \vartheta \sum_{k \in N} \eta_k(g)\Big],$$

where $0 < \vartheta \leq \theta < 1$. Hence, costs are additionally reduced by the collaborative links of firm i's neighbors at a rate θ and by the links of all other firms in the network at a rate ϑ. For a market with Cournot competition and homogeneous products, we have checked the robustness of Propositions 1 and 2 with respect to a modification towards industry-wide spillovers ($\theta = \vartheta$). The analysis is presented in the Appendix. It turns out that both results carry over, if the rate of spillover is sufficiently small. In contrast, our attempt to generalize the results to situations with network-dependent spillovers ($\theta > \vartheta$) has not been very fruitful. The reason is that, in this case, the social benefits to a single link, or to a whole network structure, depend on richer network properties than the ones required in Lemmas 1 and 2.

4.6 Summary of the first three chapters

In his seminal article, Arrow (1962) has pointed to the imperfections aligned with the demand and the production of information, and to the consequences for the market structure in innovating industries. Our findings from Chapter 2 of this thesis suggest that the imperfections are also reflected in the structure of the worldwide network of R&D partnerships. The network is very sparse and highly asymmetric with a small group of firms being involved in the majority of partnerships. In Chapter 3, we have tested the role of scale advantages in the formation of R&D partnerships to explain this phenomenon. The results of our tests have been largely supportive and have confirmed the presence of scale advantages. According to Arrow (1962), scale advantages arise because of a fundamental property of the demand for information. Due to an indivisibility in the application of research output to the products or processes of a firm, the expected returns to an R&D project increase in the firm's market share. However, because the market share, in turn, depends on the novelty of the existing products and processes of the firm, the incentive for forming further R&D partnerships increases in the firm's stock of prior partnerships.

The current chapter has investigated the implications of the indivisibility for the structure of the welfare-efficient R&D collaboration network. For this purpose, we extend on the analysis of a game-theoretical model introduced by Goyal and Joshi (2003). The authors have shown that increasing returns, or scale advantages, in the formation of bilateral collaborative ties are sufficient to obtain highly asymmetric dominant group or inter-linked star architectures in equilibrium. A first important result from our analysis is that a welfare-efficient network in their model typically has a dominant group or an inter-linked star architecture as well. Second, we find that it is welfare-optimal to maximally concentrate all collaborative activities around a subset of the firms in a network. Hence, in the light of Goyal and Joshi's characterization of the strategically stable networks, our analysis suggests that concentration is a natural characteristic of a collaboration network between firms.

The current chapter also provides a comparison of the stable and the efficient networks, where the focus is on the question of whether an efficient structure can be supported in equilibrium. Our findings are unambiguous and negative for the networks of low or moderate density: no sufficiently sparse network that is efficient, is strategically stable at the same time. The reason for this failure in the network structure lies in the individual considerations of the firms. A sparse efficient network has an inter-linked star architecture, which consists of collaborative ties between the firms in the center and the periphery of the network. Yet, our analysis shows that the peripheral firms are reluctant to sustain these links.

The previous three chapters might have some interesting implications for the design of policy programs to foster collaborative activity, like the EU Framework Programmes on R&D. A general implication is that policy makers should take into account the structural properties of the network of ongoing R&D partnerships between firms. In particular, our findings from Chapter 2 suggest that a program that tries to trigger international knowledge spillovers through the links in the network would be of rather limited reach, because the existing network is highly concentrated and connects only a small group of companies from the world's leading economies. Instead, our results from Chapter 3 and the current chapter indicate that it is more sensible to promote scale advantages by expanding the number of R&D partnerships of the group of active collaborators. In particular, as the comparison between the stable and the efficient networks in this chapter implies, this should be achieved by encouraging collaborative projects between these firms and the smaller enterprises at the periphery of the network.

As a caveat to our normative conclusions, let us remark that our empirical findings from Chapters 2 and 3 are not definite evidence in favor of the model presented here. One of the reasons is that it is not clear in which respect the worldwide network of R&D partnerships resembles the theoretical predictions from Goyal and Joshi (2003), when comparing the precise structural properties of the networks. The authors show that an equilibrium network can have a similar sparseness and a similar degree of concentration as the empirical network. However, it is unclear whether the latter has the predicted dominant group or inter-linked star architecture. And even though one might be tempted to compare the empirical network illustrated in Figure 2.1 with the stylized networks from Figure 4.1, the comparison is not feasible for at least two reasons. First, the equilibrium predictions are about the structure of a collaboration network within a particular market, whereas Figure 2.1 shows a cross-industry network. Furthermore, the game-theoretical model in the current chapter predicts static networks, in which no firm has an incentive to form or terminate an alliance. However, the structure of the network observed in Chapter 2 is constantly changing. Hence, further empirical work is necessary to test the predictive power of the model concerning the precise architecture of an inter-firm network.

Another reason for why our policy prescriptions should be treated with caution is that the findings from our econometric tests in Chapter 3 also do not provide definite evidence for the theory presented here. Even though we find support for the presence of scale effects in the formation of collaborative agreements, it is unclear whether the explanation lies in the indivisibility of research output or whether the scale effects result from a different source.

Finally, we should also mention the restrictive assumptions underlying the analysis of the welfare-optimal network in the current chapter. We have confined our analysis to a model where the collaborative ties between firms bear an incremental innovation, which means that a link aims at improving the existing products of a firm. However, collaborative ties may also enable drastic innovations that replace older generations of products. It is a completely open issue whether our benevolent view of asymmetric network structures also holds in such a context. Another issue, which has only briefly been addressed in this chapter, is the welfare assessment of asymmetric networks under market exit and network-dependent spillovers.

Chapter 5

The dark side of network embeddedness: an empirical analysis*

5.1 Introduction

A central research question in the new economic sociology is how social networks affect economic activity and outcomes on markets (Powell, 1990). Two well-established hypotheses are that social networks provide unique mechanisms for the governance of market relations and convey valuable information about promising business opportunities. In this way, they constitute an important success factor for the actors embedded in them (Powell and Smith-Doerr, 1994; Podolny and Page, 1998).

However, as Granovetter (1985) already pointed out in his seminal article, there are also potential dark sides to network embeddedness that might impede the logic of the market mechanism. An important dark side is that the sharing of norms and information between embedded actors, and the absence of information sharing between non-embedded actors, might make an actor neglect some non-embedded but valuable business partners. Markets are good in ensuring that every product and resource is used by the actors who value them most. Yet, if the market participants only take into consideration the partners who are recommended to them by their trusted informants, they are likely to omit some better matching partners outside

*This chapter is the result of a joint project with Utz Weitzel, who is affiliated with the Utrecht University School of Economics and the Max Planck Institute of Economics, Jena, Germany.

their personal network.

In this chapter, we provide empirical evidence for such an adverse effect of network embeddedness from the market for legal services in international mergers and acquisitions (M&A's). We examine the means by which the social ties of law firms affect the quality of their legal counsel in the "closing" phase of cross-border mergers.[1] The analysis consists of two steps. In a first step, we investigate whether the network resources of law firms facilitate the likelihood of completion and reduce the completion time of the merger transactions of their clients. Motivated by sizable literature on the role of business consultant networks, we take several distinct elements of embeddedness into account that have an expected beneficial effect. In a second step, we test the role of law firms' network resources for their likelihood of being nominated as a legal counsel. Again, we argue in line with several previous studies that embeddedness increases the chances of nomination.

In both steps of our analysis, we find evidence for favorable effects when compared to a non-embedded law firm. However, the picture looks different when embeddedness is compared to another important resource of a law firm, namely its specific field of legal expertise. Due to high entry barriers for foreign lawyers, many law firms have specialized their services on mergers involving clients from their home country. This focus matters, because firms with the proper "local expertise" provide better counsel than firms without this expertise.

Our comparison with the effects of embeddedness confirms this. Not only has the proper local expertise a positive effect on the quality of legal counsel, but it is even more significant than embeddedness. In contrast, we find that embeddedness is more relevant for the nomination of a law firm as a legal counsel. Our analyses also show that the nomination decision is associated with an interesting dilemma. Because well-embedded law firms are not typically endowed with the proper local expertise required for a successful merger completion, clients have to balance a higher level of trust and familiarity with their counsel against more tailored expertise. Hence, altogether, our findings support the idea that - from the viewpoint of the service quality supplied in the market - embeddedness distorts the nomination in a suboptimal way.

The recognition of situations under which network embeddedness hinders, rather than supports, the pursuit of economic interest is an important

[1] Although technically inaccurate, it is common practice within the literature to use the terms "merger", "acquisition", "takeover" and "M&A" synonymously. Following this practice, we use the term "merger" to refer to all sorts of processes that (partially) combine the ownership of two or more firms.

and recently frequently studied topic (Portes and Sensenbrenner, 1993; Uzzi, 1996, 1997; Gulati and Westphal, 1999; Mizruchi and Stearns, 2001; Burt, 2005; van Witteloostuijn and van Wegberg, 2006; Lazzarini et al., 2008). In particular, Mizruchi and Stearns (2001) provide evidence from an intra-organizational network in a commercial bank. The authors show that relationship managers tend to refer to close colleagues for advice on financial transactions they consider as risky or complex. Yet, the referral to distant colleagues, with whom they are only weakly connected, is favorable in terms of their chances of closing the transaction. The paradox is similar to the one developed here: bankers seem to favor a trustful relationship instead of deal completion efficiency. The new aspect of our study is that it sketches an adverse effect of network embeddedness on the level of a market. Moreover, network embeddedness is not detrimental for all actors in our case. Our results show that law firms who are densely connected to clients and other law firms increase their chances of being nominated as legal counsel. However, by constraining the use of valuable local expertise, embeddedness results in market transactions of inferior quality.

The remainder of the chapter is organized as follows. Section 5.2 begins with an introduction into the role of law firms in the merger process. Subsequently, it presents a series of testable hypotheses that serves for our empirical testing of the outlined adverse effect of embeddedness. Section 5.3 introduces the data and the methodology. The results of our tests are presented in Section 5.4 and discussed in Section 5.5.

5.2 Theory and Hypothesis

5.2.1 The role of legal counseling in mergers

In order to fully appreciate the value of network embeddedness and local expertise in the market for merger counseling, we first lay out the function of the legal advisor in a merger.

Figure 5.1 shows a stylized version of a merger process.[2] The negotiations before the merger announcement are dominated by business-related questions, such as the price for the target, the type of the transaction (acquisition of assets or statutory merger), or the method of payment. Although the legal counsel might be involved in the drafting of the preliminary merger

[2]As the vast majority of mergers in our sample are not hostile (99% of the M&A's in our data) we focus on so-called friendly mergers, where the management teams of the acquirer and the target jointly draft a (preliminary) merger agreement, before they publicly announce their intention to merge.

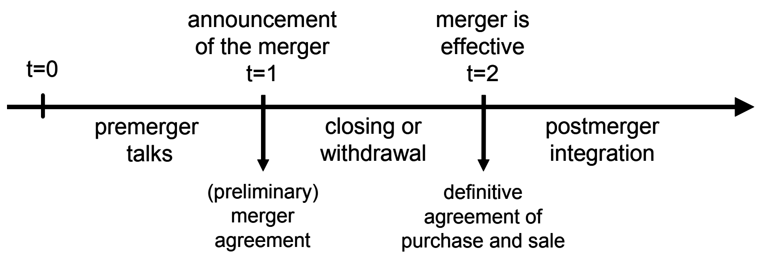


Figure 5.1: Stylized process of a friendly merger.

agreement, their primary duty begins after this agreement is signed and announced (DePamphilis, 2008; Sudarsanam, 2003, Chapter 19). In this "closing" phase, the counsel is responsible for (i) obtaining all necessary shareholder, regulatory, and third-party consents, and (ii) the structuring, drafting, and completion of the definitive agreement of purchase and sale. The definitive merger agreement is the cornerstone of the closing documents. It specifies all the rights and obligations of the parties that apply before and after the merger is effective. Only if this definitive agreement is signed and approved is the merger legally effective. Otherwise, the bid of the potential acquirer is officially withdrawn and the merger agreement terminated.

Mergers in general (domestic and cross-border) are complex by the fact that a large number of stakeholder groups are involved in them, such as managers, shareholders, banks, employees, customers, and regulatory authorities (Boone and Mulherin, 2005; DePamphilis, 2008). Accordingly, several segments in the definitive agreement require particular legal expertise to structure the diverse interests of the different parties.

For example, the legal advisor has to ensure that the transaction is in full compliance with the laws and regulations of every country where the firms involved are listed or incorporated. Moreover, in many countries, the mergers of public firms also need the approval of the acquirer and/or the target company's shareholders. Any non-compliance or disapproval can delay or prevent the definitive merger agreement. Hence, the role of the legal advisor can be seen as the one of a "transaction cost engineer" (Gilson, 1984), who reduce the costs of bargaining and contracting. Thereby, he can have a major impulse on the likelihood that an agreement is reached and determine the time and cost required for the closing of the transaction.

5.2.2 Local expertise, legal service quality, and advisor selection

Here, we outline the role of the specific field of expertise of a law firm in the laws from a certain national legal framework. We argue that a firm's country-specific expertise is an important determinant for the quality of its counseling services and influences its prospects of being appointed as a legal counsel.

Over the past two decades, the market for legal services in international mergers underwent some major structural changes. During the 1990s, the large number and high deal volume of mergers between British and American companies stagnated and even fell behind the number and volume in other parts of the world. Continental European as well as East Asian mergers played a much more important role in the market in recent years (Black, 2000; OECD, 2001).

Despite these developments, most law firms still focused their operations on mergers involving a client from their home countries. Surprisingly, this pattern holds not only for the small law firms, but also for the very large firms. Even though some of them have expanded their overseas' presence in order to satisfy the needs of the emerging international clientele, the industry seem to have resisted the dynamics on the demand side to a great extent. As is shown in Table 5.1 in the fourth column, the value of the advised mergers with a domestic client exceeds for all but two of the top 10 law firms, namely the UK-based firms Freshfields Bruckhaus and Clifford Chance, half of their total advised deal value during the period 1994–2006. For the firms below the top 10, the value of the mergers with a domestic client even amounted to 86% of the total deal value of their advised mergers.

Among other explanations, a central reason is that the entry of foreign lawyers is deterred by national regulations in all countries around the world. Foreign lawyers have only very limited rights to advise or represent a domestic client, which are only typically granted for matters that do not touch upon national laws (Kilimnik, 1984). While such impediments may be bypassed in other fields of business either by the acquisition of a domestic firm or by the setting up of an overseas' office, the right to acquire or manage a domestic law firm is impeded, or even excluded, for foreigners in many jurisdictions (Warf, 2001).

An important implication is that there are substantive differences between law firms from different countries with respect to the legal expertise they can contribute to the international mergers of their clients. Ensuring the legal compliance of a merger is quite a difficult task. One element of the

Law firm (1)	Deal value of advised M&A's (in bil. $US) (2)	Number of M&A's (3)	Country with highest M&A experience (% of deal value) (4)	Co-advised M&A's % deal value (% of number) (5)
1. Sullivan & Cromwell (US)	1,540	442	US (60)	91 (67)
2. Freshfields Bruckhaus Deringer (UK)	1,328	635	UK (35)	83 (48)
3. Linklaters (UK)	1,243	732	UK (76)	95 (70)
4. Shearman & Sterling (US)	1,154	446	US (57)	91 (54)
5. Clifford Chance (UK)	1,094	672	UK (27)	90 (51)
6. Cleary Gottlieb Steen and Hamilton (US)	1,000	342	US (52)	90 (61)
7. Skadden Arps Slate Meagher & Flom (US)	909	450	US (76)	89 (89)
8. Simpson Thacher and Bartlett (US)	879	255	US (78)	93 (73)
9. Slaughter & May (UK)	723	336	UK (52)	87 (55)
10. Davis Polk and Wardwell (US)	600	215	US (67)	91 (71)
Average of top 10	1,047	453	(58)	90 (64)
Average of rest (898 firms)	21	18	(86)	90 (56)

Table 5.1: Top 10 law firms in the market for cross-border merger advice.

SOURCE: Thomson Financials SDC M&A database. NOTES: (1) law firms are ranked in terms of the $US-value of their advised cross-border M&A's; (2) in case of M&A's with multiple advisors, we follow the convention to assign the total deal value to each advisor; (3) to calculate a firm's deal values by country, also domestic M&A's are included. In case of a cross-border M&A, half of the deal value is considered for the acquirer's country and the other half for the target's country.

complexity stems from the fact that mergers touch upon many laws, such as tax laws, antitrust laws, and labor laws, all of which have an influence on the correct format of the definite merger agreement (Gilson and Black, 1996). In cross-border mergers, the complexity of the task is amplified by the fact that the definitive agreement needs to comply fully with the laws and regulations of every country where the involved buyer and supplier are listed or incorporated. And, even in an age of supranational efforts to harmonize legal requirements, the differences between the legal frameworks are still substantive. In fact, as the latest report by the leading US law firm White & Case suggests, the complexity of the legal side of cross-border mergers might even have increased over the past two decades. The report concludes that the number of distinct antitrust and merger review procedures around the world has been steadily growing. While just 6 such procedures were in place in the early 1990s, 115 different procedures have been counted in 2008 (White and Case, 2009).

One part of the explanation is the increasing complexity of the financial and organizational tasks aligned with a merger, which has increased the number of laws and regulations a transaction touches upon (Sudarsanam, 2003). But also the increasing adoption of complex takeover regulations takes a significant toll, which makes it difficult for lawyers to transfer relevant counseling experience and expertise to a foreign legal environment. Consequently, the country-specific field of expertise of a law firm is an important determinant for its counseling qualities:

Hypothesis 1. *The better the expertise of a law firm in the laws and regulations of the countries of the buyer and the seller in a cross-border merger, the higher the expected quality of the firm's counseling services in the transaction.*

In this light, it is only a small step to argue that the specific local expertise of a law firm is also a decisive criterion for a client to appoint a legal counsel. A law firm with the proper local expertise can improve the client's bargaining position vis-à-vis its contract partner, reduce the suspicion and regulatory resistance to a merger, and justify the use of expensive legal services. Building on these arguments, we expect that law firms with an appropriate local expertise are more likely to be selected as a legal counsel:

Hypothesis 2. *A law firm is more likely to be selected as a legal advisor, the better its expertise in the laws and regulations of the countries of the buyer and the seller in a cross-border merger.*

5.2.3 Embeddedness, legal service quality, and advisor selection

Above, we have argued that the country-specific expertise of a law firm determines the quality of its legal counsel and the prospects for an advisory appointment. Here, we reason that the embeddedness in the network of market relations is another important resource for a law firm.

The social embeddedness of firms in networks of market relations has already been investigated in various different professional service industries (Baker, 1990; Stuart and Sorenson, 2001; Uzzi and Lancaster, 2004). A first important type of relation in the international legal service market is the advisor-client tie. As in other professional service industries, these ties range from a one-time advisory contract to the sole-source relationship between a large corporation and its “house” counsel.

The other type of market relation is the co-advisor alliance, which is a formal collaborative agreement between two or more law firms to jointly advise the acquiring or the target company for the process of a merger. Since cross-border mergers require expertise in various different legal frameworks, which hardly any firm can deliver on its own, law firms make extensive use of these alliances. As Table 5.1 shows (in column five), the ten leading firms collaborated with other law firms in 64% of their mergers during 1994–2006. The value of their co-advised mergers even amounted to 90% of their total transaction value. Many law firms have institutionalized their relationships with foreign partners in the form of long-term strategic alliances. A prominent example is the UK law firm Linklaters and its joint venture, the Linklaters & Alliance. Between 1998 and the year of termination of the joint venture in 2002, Linklaters advised in 288 cross-border M&A’s, together with four other European law firms. The Linklaters & Alliance is no exceptional case. As Figure 5.2 shows, all of the leading law firms are embedded in a network of long-term alliances with domestic and international partners.

In line with prior studies on the social embeddedness of professional service firms, three different aspects of network embeddedness seem to be crucial in the international legal service market: repeated interactions, network centrality, and links with prestigious business partners.

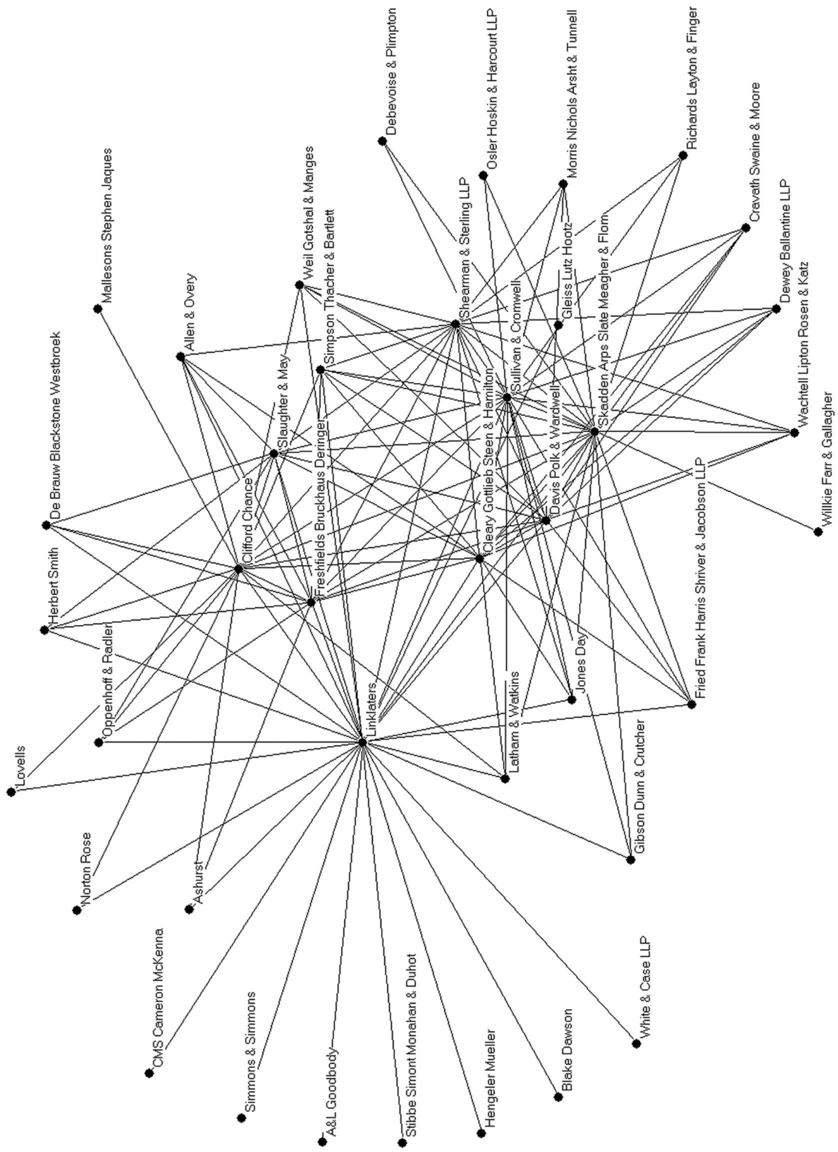


Figure 5.2: Alliance network of the top 10 law firms, 1994–2006.

SOURCE: Thomson Financials SDC M&A database. NOTES: An edge between two law firms indicates the presence of, on average, at least one co-advised M&A per year in the sample period.

Repeated advisor-client ties can help improve the quality of the legal services of a law firm in various different ways. First, the presence of prior advisor-client ties provides unique opportunities for the governance of follow-up relationships between a law firm and its client. Without any prior market contact, a client can only refer to public sources to gather information about a law firm's quality. Repeated interactions, however, enable the client to learn about the firm's capabilities and trustworthiness from own experience. This facilitates the formation of trustful market relations between them in the future (Gulati, 1995a; Buskens and Raub, 2002; Uzzi and Lancaster, 2004). Furthermore, even though an advisory contract attaches a law firm, in a first instance, only at formal organizational level to a client, multiple informal and personal relationships may emerge across their organizational boundaries. These relationships can enlarge the firms' horizons beyond the logic of their business and enable the reciprocation of favors in an interpersonal context (Granovetter, 1985; Walker et al., 1997). Both learning and an interpersonal context may serve as mechanisms to promote transaction-specific investments and the sharing of private information.

In a similar way, repeated prior interactions between two law firms facilitates cooperation and coordination in their roles as co-advisors. Similar to the hazards of alliances in other contexts, a lawyer cannot always observe and verify the input of his co-counsels (Kogut, 1989; Corwin and Schultz, 2005). Moreover, even though the law firms collaborate in the ongoing transaction, they compete for future client deals at the same time. Hence, a lawyer faces the latent risk that one of his co-advisors free rides on his efforts or takes over the client in a subsequent deal (Ljungqvist et al., 2007).

Taken together, all this suggests that prior ties between a legal advisor and its client as well as prior alliances between the members of a co-advisor team enhance the quality of the counseling services in a merger:

Hypothesis 3. *(a) The more prior advisor-client ties the legal advisor in a cross-border M&A has with his client, and (b) the more prior co-advisor alliances the advisor has with his co-advisors, the higher the expected quality of his counseling services in the transaction.*

A client does also benefit from the prior relations of his counsel with other law firms and clients outside the merger he is currently involved in. In line with the role of the market ties of professional service firms in other industries (Stuart and Sorenson, 2001; Rooks et al., 2006; Hochberg et al., 2007), valuable information can flow along these relations, such as insider information about the client's contract partner, experience with similar transactions, or estimates about the attitude of competition authorities. Hence, by referring to third-party views and external knowledge bases, the legal advisor can increase its pool of expertise:

Hypothesis 4. *(a) The larger the number of clients with whom the legal advisor in a cross-border M&A shares a prior advisor-client relation, and (b) the larger the number of law firms with whom the advisor shares a prior co-advisor alliance, the higher the expected quality of his counseling services in the transaction.*

Yet, as legal scholars argue, a lawyer can contribute more to a business transaction than just his legal and contractual expertise. And it is this additional function that explains why, in particular, the ties to prestigious law firms and reputable clients are important. There is a general suspicion about whether the managers of a company always act in their shareholders' interests (Jensen and Meckling, 1976; Eisenhardt, 1989). Because law firms have an interest in the continuity of their business, which rests fundamentally on how they are perceived by investors and other stakeholders, and because they have insight into sensitive company documents, they can "rent" their reputation to a transaction as a bond that the management's actions and disclosures are accurate (Gilson and Mnookin, 1985; Coffee, 2003). According to this argument, the presence of a reputable law firm, on its own, can have beneficial effects by reducing the suspicion and resistance of shareholders and regulatory authorities to a merger.

But where does the reputation of a law firm come from? As the studies of Podolny (1993, 1994) and Sandefur (2001) suggest, the reputation of an organization has many facets. On the one hand, Podolny's (1994) work on the status roles of investment bankers has shown that part of the banks' perceived roles is whether they collaborate with other banks of similar standings. Accordingly, the selection of an alliance partner influences how an organization is perceived itself. On the other hand, Sandefur (2001) finds that status in the legal service market derives from the affiliation of law firms with prestigious clients. Hence, these studies suggest that a law firm's relations with clients and other law firms bias its reputation into the direction of the reputation of those to whom the firm is tied. Considering the beneficial effect of reputation, this in turn implies:

Hypothesis 5. *(a) The more the legal advisor in a cross-border M&A is affiliated with prestigious clients and (b) the more the advisor is affiliated with prestigious law firms, the higher the expected quality of his counseling services.*

In light of the previous arguments, there are good reasons to expect that repeated interactions and network positions are important determinants for the nomination of a counsel as well. Collecting information about the competencies and reliability of a potential counsel is a costly and time consuming task (van de Ven, 1976; Stinchcombe, 1990). Still, this information is relevant since the nomination of a counsel can critically determine the success of a planned transaction. Similar to the role of network embeddedness in other industries, repeated interactions are a means to create trust between law firms and their clients (Gulati, 1995b). A law firm's centrality in the overall network of these relations determines the firm's access to information about potential future mergers and shapes its visibility in the market (Gulati and Gargiulo, 1999; Powell et al., 1996, 2005). Furthermore, the possibility that an organization's status spills over to those that are attached to it, makes it attractive to link to a prestigious lawyer (Goode, 1978; Blau, 1989). Taken together, this suggests:

Hypothesis 6. *A law firm is more likely to be selected as a legal advisor for a cross-border M&A, (a) the more prior relations the firm has with the client and the other legal advisors involved in the merger; and (b) the more relations the firm shares with other clients and other law firms; and (c) the more the firm is affiliated with prestigious clients and law firms.*

To summarize, the network embeddedness framework suggests that repeated market ties, and the position of a law firm in the network of these ties, are associated with a higher quality of its legal counsel and a higher likelihood for being appointed as a merger counsel.

However, in the light of the dynamics in the international legal service market towards a demand for merger advice on a large number of nationally distinct legal frameworks, there are possible hazards aligned with embeddedness. A particular hazard is that the organizational and private bonds underlying the long-term relations between law firms and their clients, and the static nature of their network positions, might deter the flexible access to valuable local expertise. Clients and law firms who refer to their previous business partners can effectively diminish the uncertainty associated with the partner selection problem, but they are also likely to omit some valuable alternatives outside their personal network. Hence, despite the potential beneficial effects of a law firm's network resources, the social network in the international legal service market might lead to a suboptimal provision of legal counsel in cross-border mergers.

The forces at work behind this adverse effect of network embeddedness are the same shared norms and agreed-upon expectations that maintain and stabilize an embedded partnership. Their dark side is that they can create powerful pressures of conformity and reciprocity, that limit an actor's freedom of choice (Portes and Sensenbrenner, 1993).

The risk of such an "overembeddedness" scenario is high, if our data supports the following two conjectures. On the one hand, the location-specific legal expertise of a law firm should be more strongly related to the quality of its services than all its different network resources taken together. Considering the significant national differences in the legal and regulatory frameworks, this might indeed be a reasonable conjecture. A trustful relationship might indeed not compensate for a deficit in the proper local expertise. On the other hand, repeated interactions and the network position of a law firm should be more influential for its selection as a legal advisor in a cross-border merger than the firm's country-specific legal expertise. In fact, several previous studies have argued that social ties may canalize the flow of information between actors (Gulati and Gargiulo, 1999) and create powerful norms of reciprocity (Portes and Sensenbrenner, 1993). Yet, due to a lack of adequate theoretical arguments we do not formulate separate hypotheses on these conjectures.

5.3 Data and methodology

5.3.1 Sample

In the following, we present the data and the methodology used for our formal test of the outlined "overembeddedness" scenario. We retrieve the data for our study from the Thomson Financials SDC M&A database. The database collects information on every merger announced to the Security and Exchange Commission in the United States and comparable stock exchange supervisory agencies in other countries, including a list of the names of the legal advisors to the acquirer and the target. We download 30,845 M&A's announced between 1994 and 2006 with at least one legal advisor on board and a deal value greater than $US 10 million. The sample comprises domestic and international mergers from all countries around the world. In a subsequent step, we confine the sample to a set of 5,661 mergers: next to focusing on cross-border M&A's, we select only those mergers, which are between companies in the non-financial and non-legal service industries and where the acquirer and the target come from a country in one of the regions North America, Western Europe, or East Asia.

The names of the legal advisors in the large sample of mergers are used to construct the networks of advisor-client and co-advisor relations as well as law firms' country-specific expertise variables. Specifically, we determine the state of a law firm's social relations and its expertise at the point of time of a particular merger using all the transactions of the firm within the four years preceding the year of the merger. We also consider mergers in the legal service industry. In order to correct for the transition of social relations and experience from one law firm to another, we add the four-year history of the target firm to the history of the acquiring firm at the date of merger completion.

By doing this, our procedure creates for each law firm an annually updated four-year memory of relations and experience. Such a moving time window has been frequently applied in previous studies (Podolny, 1994; Gulati and Gargiulo, 1999; Jensen, 2003). In the context of the legal service market, it is motivated by the high turnover of personnel, both within the law firms as well as their clients' organizations (Heinz et al., 2001). A negative effect of this turnover is that it limits a law firm's possibilities to maintain long-term relationships with its clients based on personal ties between their personnel. Moreover, a resigning lawyer takes valuable case-specific experience with him or her.

5.3.2 Dependent variables

In order to test Hypotheses 1, 3, 4, and 5, we investigate the effects of the law firms' network resources and local expertise variables on the quality of their counsel in the 5,661 cross-border M&A's. Our unit of analysis is the legal advisor-merger dyad. This means that each merger contributes an observation for every legal advisor working on it.

Specifically, we focus on the service quality of the counsels to the acquiring companies in these mergers. The reason is that we suspect that the tasks of the acquirer and the target counsel are often diametrically opposed to each other. While the former are typically appointed in order to increase the chances of deal completion, the counsel to the target company might work against completion and try to prolong the takeover process in the hope that the acquirer reconsiders and withdraws the bid. We choose the acquirer advisors for our analysis, because the role of the target advisor strongly depends on the type of M&A. In a hostile takeover, the target counsel typically seeks to minimize the chances of deal completion. In a friendly merger, however, the advisor is not expected to prolong or prevent the consummation of a deal.

As explained in Section 5.2.1, the acquirer counsel adds value to a merger by ensuring the legal and regulatory compliance and by structuring the process of the transaction. An appropriate dependent variable should either measure these activities directly or exhibit a direct causal relationship with them. In the relatively young empirical literature on the role of business lawyers, two types of measures have been used to quantify the performance of the legal advisor in a merger. Value-oriented performance measures focus on the financial returns to a merger. However, the few existing studies using such measures have so far provided conflicting results (Subramanian, 2007; Krishnan and Laux, 2008). Clear effects of the presence and quality of a counsel have only been found for directly output-oriented performance measures. Here, some studies have successfully related the counsel's presence and quality to the occurrence of specific provisions in the acquisition agreement (Coates, 2001; Gilson and Schwartz, 2005). Others have gone a step further and associated presence and quality with output measures that relate to the merger process (Subramanian, 2007; Krishnan and Laux, 2008).

These studies rest on the idea that a lawful and well-structured merger process increases the chances for completing the transaction. As Gilson (1984) argues, the legal advisor is a "transaction cost engineer", who reduces the costs of bargaining and contracting in a merger and, thereby, increases the chance that an agreement is reached between the parties. Furthermore, good legal counsel will also expedite the closing of a merger, for instance, by reducing the time that the merger is reviewed by the authorities or by expediting the legal due diligence. Because of the negative effects on the attitude of stakeholders and the hold-ups in investments, a short closing time is critical for the success of the transaction (Buono et al., 1985; Angwin, 2004).

This suggests that the time to completion and the likelihood of completion are two adequate measures for the service quality of an acquirer counsel. We retrieve these variables from the Thomson SDC database.[3] We code a cross-border M&A as completed, if its status in the Thomson SDC as of January 15th, 2009, indicates it as such. Only 15 mergers with an unknown status are deleted from the analysis. All remaining cases, including mergers with a pending status for more than two years, are coded as incomplete.

[3]One might argue that for the purpose of studying the service quality of professional service firms a potential problem of this data is that it does not contain information on planned mergers that are never publicly announced. However, as explained in Section 5.2.1, in contrast to investment bankers and management consultants, who are primarily appointed for their advice on the financial and business matters of the transaction, the main task of the legal counsel is to implement the legal and contractual side of a merger after the deal has been announced.

For the time to completion variable, we calculate the difference between the date of unconditional completion and the date of announcement for every completed merger.

For our tests of Hypotheses 2 and 6, we examine the likelihood that a given law firm is chosen as legal counsel in one of the 5,661 cross-border M&A's. The dependent variable in this analysis is the acquiring company's selection of a law firm as its legal counsel. In line with previous studies, we code the dependent variable as a dichotomous variable, which is equal to one if a law firm in the risk set of potential counsels is actually chosen as a legal advisor, and zero otherwise (Gulati and Gargiulo, 1999; Stuart and Sorenson, 2001).

Generally defined, the risk set consists of all firms that could potentially be chosen as an advisor for a particular merger. For our study, we take the middle way between the inclusion of all firms in the risk set that have ever been active as an advisor throughout 1994–2006, such as Podolny (1994) does, and the restriction to a small (random) sample of firms (e.g., Stuart and Sorenson, 2001). We compose the risk set for a particular merger of all law firms that have been counseling in at least one merger in the year of merger announcement (1998: 367 firms, 1999: 448, 2000: 406, 2001: 429, 2002: 360, 2003: 381, 2004: 387, 2005: 414, 2006: 454). While this set of firms proves to be small enough to make a statistical analysis computationally tractable, it provides at the same time a reasonably good representation of the set of firms, from which one could expect participation. By choosing such a broad risk set, we can alleviate estimation biases inherent in the sampling approaches to the generation of the risk set (Manski and Lerman, 1977; King and Zeng, 2001).

5.3.3 Estimation procedures

For the advisor performance analyses (testing Hypotheses 1, 3, 4, and 5), we use the following estimation methods. First, we estimate the likelihood of merger completion applying a logit model for cross-sectional data. However, a potential problem of a standard model of this kind is that it does not take into account that a law firm may enter the cross-section several times. This can result in a systematic underestimation of the standard errors for law firm attributes that do not change from merger to merger, such as our embeddedness and expertise variables (Mizruchi and Stearns, 2001; Rogers, 1993). In order to correct for this non-independence across observations, we apply the correction method proposed by White (1980) and Rogers (1993) and report robust standard errors adjusted for clustered observations. Specifically, we cluster all advisor-merger dyads involving the same law firm. The robust logit model is estimated using the commands implemented in STATA 10.

Second, even though the time to merger completion is, at least in principle, a continuous random variable, there are two distinctive features that render a standard OLS regression infeasible. On the one hand, the time to completion is logically bounded to be greater than zero. On the other hand, as a matter of empirical fact, many mergers are - conditional upon completion - executed within the first week after their announcement (28% in our data), while closing periods of more than a year are exceptional in our data (10%). Both issues suggest that the fitting of a normally distributed regression model leads to serious specification errors.

Models that deal with these peculiarities of the data are the models for duration data (Allison, 1984; Greene, 2002). These are models for the length of time spent in a given state before a transition to another state takes place, such as the time passed between the announcement and the execution of a merger. Their commonality is that duration models build on a hazard function, instead of estimating the unconditional probability of a state change at a certain point in time directly. The hazard function captures the conditional probability of a state change for merger i at time t conditional on no change having occurred for any $T < t$.

For our study, we use the Weibull specification of this function (Cameron and Trivedin, 2005):

$$\lambda_i(t) = \gamma_i \times \alpha t^{\alpha-1}.$$

The first factor γ_i captures law firm-specific differences affecting the hazard function. We specify it as an exponential function of our law firm covariates of interest. The second factor depicts the baseline hazard rate of a merger that is, in contrast to the first factor, the same across law firms, but varies in the length of the closing period of a merger. The parameter α is a coefficient that determines the nature of this time dependence. It allows for the possibility that the hazard of completion increases or decreases during the closing period.[4] This feature of the Weibull model is useful for our purpose, because due to the lack of proper theoretical or empirical arguments we cannot rule out a duration dependence of the hazard rate. Rewriting the hazard function to the unconditional time to completion, the Weibull model can be estimated using standard Maximum Likelihood (ML) techniques.

[4]If $\alpha = 1$ the hazard function is constant over time and, hence, the Weibull model reduces to the simpler exponential model. In contrast, when $\alpha > 1$ ($\alpha < 1$) the baseline hazard is increasing (decreasing) in time, implying that the longer the closing period the more (less) likely a merger is executed at an additional instant of time.

Because the same problem as for the likelihood of completion arises that a standard ML-estimator underestimates the standard errors for law firm attributes, we again correct for potential non-independence of observations involving the same legal advisor. Moreover, we also take right-censoring into account caused by incomplete mergers. In the context of a duration analysis, it is natural to interpret an incomplete merger as a commenced spell where the execution cannot be observed, because of a latent competing risk that has caused a premature withdrawal. Assuming the time to withdrawal W_i to be a random variable, which is statistically independent from the time to completion T_i, merger i reports a time to completion T_i, if the merger ends in completion before the withdrawal time. Otherwise, the merger ends in a withdrawal at time W_i. Following this interpretation, an incomplete merger can be treated as a randomly right-censored spell, for which appropriate correction methods are readily available (Kalbfleisch and Prentice, 2002; Cameron and Trivedin, 2005). Practically, the time to withdrawal is retrievable only for the withdrawn mergers from the Thomson SDC data, but not for pending deals. Hence, we only use the withdrawn mergers to correct for censored data.

We estimate the advisor selection (testing Hypotheses 2 and 6) using a binominal logit model. As in the performance analysis, a major concern with such a model is the assumption of the non-independence of observations (Lincoln, 1984; Mizruchi, 1989). To deal with this issue, we calculate robust standard errors adjusted for clustered observations of the same law firm.

5.3.4 Independent variables

The following embeddedness variables are central to all our analyses. First of all, we define the *advisor-client relation* between a law firm and the acquiring company in a cross-border merger as the number of previous advisor-client ties between the two firms within the four years preceding the merger. The variable measures the presence as well as the strength of their social relation. However, because mergers are rare events for many clients, the presence of any prior tie at all is already likely to distinguish between law firm-client dyads with and without a shared social context. Hence, we also include a binary variable in our regressions indicating the presence of at least one prior advisor-client tie (coded one) or the absence of any such relation (coded zero).

Second, to determine the number and intensity of a law firm's *co-advisor relations* with the other legal advisors involved in a merger, we calculate in a first step the total number of previous co-advisor ties of the law firm with these advisors. In a second step, the total is divided by the number of advisors involved in the merger (subtracting one if the law firm is a legal advisor itself). Hence, the co-advisor relations variable measures the average strength of the relations between the law firms. Again, we include an additional variable distinguishing between law firms with and without any prior relations to the legal advisors. Both variables are undefined in the case of a cross-border merger with only a single advisor. To prevent a bias from excluding these cases, we set the corresponding variables to zero, but control for this arbitrary specification by adding the binary variable *single advisor* in all our regressions that indicates mergers with a single advisor.

Third, to measure the number of clients and other law firms, with whom a law firm has previously shared a market tie, we compute the sum of the degrees of a law firm in the advisor-client network and the co-advisor network. Practically, we use the binary variables indicating the presence/absence of a prior tie between a law firm and a client/other law firm. The *degree* of a law firm is determined as the sum of the entries in the binary variables. Our motivation for choosing a firm's degree in the total network is that personal and business attachments to both groups, clients and other law firms, can provide access to valuable information sources. We are not aware of any theory to distinguish between the two sources. To check this assumption, we also include two separate degree measures in our analyses (unreported). The two measures turn out to be highly correlated and their effects are similar.

Fourth, for the same reason of a lack of an appropriate theory to distinguish between the affiliation to prestigious clients and prestigious law firms, we construct the variable *affiliation with prestigious partners* (law firms and clients). A peculiarity of these affiliations is that they can bias the status of a law firm in both directions. Ties to high-status actors enhance the prestige with which one is viewed, while ties to lower-status actors detract from it (Faulkner, 1983; Podolny, 1993). Consequently, we construct an affiliation measure that takes this peculiarity into account. In a first step, we determine a measure of status for every law firm and every acquiring company active on the market. Following Sherer and Lee (2002), we use the affiliation of a law firm to the top 50 most profitable firms as our status indicator. Since profit data is not available for all firms in our data, we proxy profitability by the $US value of the mergers where a law firm has provided advice in the four years preceding a given year. This is a viable proxy, because law firms price their services at hourly rates which increase in the value and complexity of the underlying transaction (Uzzi and Lancaster, 2004). Furthermore, "there is a greater trend towards some form of success fee to relate lawyer's input to the value added" (Sudarsanam, 2003, p. 473). Such contingency fees also increase in the value of the transaction, supporting our proxy. Analogously to the legal advisors, we construct a client status measure based on the affiliation to the top 50 most active companies in the merger market. Again, we measure activity in terms of the total merger values of this client in the previous four years. To check the reasonability of the status measures, we compared the lists of top firms over time (unreported). In line with the expectation of status persistence, we find that the affiliation of firms to the top brackets is similar from year to year.

In a subsequent step, we count for each law firm the number of prior market relations with a law firm/client from the top 50 bracket. These numbers are related to the firm's total number of prior relations to obtain the desired affiliation measure. Our measure depicts the percentage share of relations that a law firm shares with a high status actor. A high (low) value indicates a law firm that exclusively interacts with prestigious (low-status) actors, controlling for the firm's number of interactions. Accordingly, we expect the firm's status to experience an upwards (downwards) bias (Goode, 1978).

Lastly, in order to operationalize the merger-specific local expertise of a law firm we construct two separate variables, *acquirer-country expertise* and *target-country expertise*. Each measures the experience of a law firm with previous mergers from the same countries as the buyer and the seller in the current transaction. Even though experience might be seen as being only a "behavioral measure" of legal expertise (Uzzi and Lancaster, 2004), which consists much more of the quality of legal training and the excellence of the lawyers working for a firm, there are at least two good reasons for using experience variables. First, because market pressure and client feedback should reward expert law firms with future advisory appointments, experience is a viable proxy for legal expertise (Lazega, 2001). Second, an advantage of an experience variable over alternative expertise measures, such as the law school grades of the lawyers working for a firm, is that it represents an even richer measure of expertise, because it also captures the expertise of a firm gained through its actual practice of the law.

The acquirer-country expertise and the target-country expertise of a law firm are calculated as percentage shares of the firm's total advisory experience.[5] Hence, the variables capture the notion of a horizontal differentiation

[5]Moreover, we consider the participation of a law firm in a merger for its experience with the laws and regulations in the nation of the acquirer as well as for its experience

between the law firms (Hotelling, 1929): while a firm with a good expertise in the laws of a certain country can provide more tailored services in a merger touching upon the legal framework of that country, other firms perform better in other transactions. For each of the two variables, a value of a hundred percentage points (zero percentage points) reflects a high (low) specialization in the legal matters of the particular country, controlling for the absolute size of a law firm and the overall quality of its staff.

We store the latter in the variable *general expertise*, which reflects the vertical differentiation between law firms in terms of the universally agreed-upon quality of their services. A law firm's general expertise is measured as the number of mergers advised by that firm in the previous four years. A disadvantage of using such a count variable is that an advisory appointment in a single mega-merger is assumed to create less legal expertise than a number of average sized mergers. The advantage is that the measure is not inflated by some few very large transactions. As a robustness check, we also estimated our models using the total $US value of a law firm's prior transactions (unreported). The results are qualitatively similar to those reported in this dissertation.

5.3.5 Control variables

Several further control variables are used to rule out alternative explanations for the success of a merger and the selection of a legal counsel. First, we include the law firm status measure as introduced above in all our analyses in order to avoid the measurement of spurious effects in the affiliation with prestigious partners. The problem is that part of a law firm's status is made up of its reputation as an enabler of successful transactions. This reputation has positive effects on the firm's ability to complete future transactions and helps to attract clients (Gilson and Mnookin, 1985). However, because of the self-reinforcing effect of status that prestigious actors attract prestigious partners, the inclusion of the status variable is necessary to rule out a potential endogeneity of the affiliation variable. The binary variable *prestigious law firm* is coded one if a law firm belongs to the group of top 50 firms in a given year.

Second, we include the count variable *number of advisors* in the legal advisor performance analysis, which measures the actual number of acquirer counsels in a cross-border merger. The variable corrects for possible negative

with the target's nation, irrespectively of whether the firm is an acquirer counsel or a target counsel in the particular merger. This reflects the idea that, as part of his job, a lawyer gains experience in the legal matters of both nations involved.

performance effects, which arise from coordination problems in larger teams but which are unrelated to the characteristics of the individual advisors.[6]

Third, we include a group of variables focusing on the characteristics of the acquiring companies. The variable *acquirer experience* measures, similar to the law firm expertise variable, the number of prior merger engagements of an acquirer. In the legal advisor performance analysis, the variable captures differences in merger outcomes that are due to the legal and bargaining competencies of the client himself. The binary variable *public acquirer* indicates an acquiring company which trades its shares on a public stock market. The measure corrects for the fact that mergers by shareholder-owned companies are more complex and bear potential conflicts of interest between owners and management. This implies negative effects on the probability and speed of closing, independent of advisor quality. In the legal advisor selection analysis, the values of both these control variables are identical for all law firms that are potential counselors for a particular merger. Therefore, they only create an association with the number of advisors. The variables are still important, however, because they capture the possibility that, for example, more experienced clients demand less law firm assistance.

The fourth group of control variables pertains to the characteristics of the merger transaction. An inclusion of these variables is necessary, because many of the financial and business-related characteristics of a deal are not under the control of the legal advisor. In line with the previous literature on the role of professional service firms in mergers, we include the *log deal value*, measuring the natural logarithm of the \$US transaction value, the *number of bidders*, counting the number of competing bids for the target, the binary variable *public target*, indicating a shareholder-owned target, the variable *stock payment*, measuring the percentage share of stock payments by the acquirer, the binary variable *hostile bid*, indicating the attitude of the acquirer towards the target's management, and finally the binary variable *tender offer*, which reflects a merger where the acquirer asks the target's shareholders to sell their shares directly, if necessary without separate approval by the target management or a shareholders meeting (McLaughin, 1990; Kesner et al., 1994; Servaes and Zenner, 1996). All these characteristics have either an impact on the complexity of managing the transaction or indicate the degree to which one can expect opposition from third parties.

[6] In the legal advisor selection analysis, the value of this variable is identical for all law firm-merger dyads in the same risk set. It therefore cannot account for differences between individual dyads. Instead, it only records the number of ones in a risk set and, hence, the number of advisors selected. To foreclose this tautology, the number of advisors is omitted.

Moreover, we also included the binary variable *target advisor present* that indicates the presence of a counsel to the target. In the legal advisor selection analysis, all these merger characteristics can only account - similar to the client variables - for differences in the number of advisors appointed.

Finally, we include year fixed effects. In the advisor performance analysis, they correct for the fact that mergers typically cluster over time (see, e.g., Martynova and Renneboog, 2008). Given that more law firms are included in the risk set in later years, the probability of each individual firm becoming a merger counsel should, by definition, decrease over time. We therefore also include year dummies in the selection analysis.

The means, standard deviations, and pairwise correlations of the variables are presented in Tables C.1 and C.2 in the Appendix. The first table shows the descriptive statistics for the legal advisor performance analysis. The second table reports the respective values for the selection analysis. The tables show that multicollinearity may be a problem with some of the variables. To address this problem, we calculate the variance inflation factors for all variables to examine the extent to which multicollinearity has an impact on the precision of the coefficient estimates (Fox, 1991). In the advisor selection models two variables, degree and general law firm expertise, have an inflation factor above the recommended level of 10 (Kennedy, 1998). We therefore include these two variables separately in the estimation of the selection models and verify the robustness of the remaining coefficients with regard to a replacement by the other.

5.4 Results

5.4.1 Legal advisor performance

Table 5.2 presents our findings concerning Hypotheses 1, 3, 4, and 5. The baseline Models 1 and 4 regress the likelihood of merger completion and the time to completion on an array of control variables measuring the client and merger characteristics. The results of these two models provide a congruent picture. Also, the effects of most variables are in the expected directions. In particular, mergers with a large number of competing bidders, a public target, a larger fraction of stock payments, and a hostile attitude towards the target's management have a lower likelihood of completion and, conditional upon completion, require more time.[7]

[7]Note that also in the duration models a favorable effect is indicated by a positive coefficient, because the dependent variable is the hazard rate of completion.

	Logistic regression with robust std. errors: Likelihood of completion			Duration model with Weibull survival distribution and robust std. errors: Time to completion		
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Adv.-client rel.			.003			.002
(strength)			(.008)			(.002)
Co-advisor rel.			-.002***			.001***
(strength)			(.001)			(.001)
Adv.-client rel.			.209			-.007
(presence)			(.133)			(.027)
Co-advisor rel.			.045			.020
(presence)			(.183)			(.040)
Degree			.001			-.001
			(.001)			(.001)
Affiliation with			-.009			-.002
prest. partners			(.005)			(.001)
Target-country		.004**	.003*		.002***	.002***
expertise		(.001)	(.001)		(.001)	(.001)
Acquirer-country		.004*	.003		.001**	.002**
expertise		(.002)	(.002)		(.001)	(.001)
General exp.		-.001	-.001		.001*	.001
		(.001)	(.001)		(.001)	(.001)
Prestigious		.120	.443		-.044	.063
law firm		(.107)	(.245)		(.031)	(.068)
Single advisor		-.508***	-.519***		.016	.030
		(.117)	(.140)		(.031)	(.037)
Number of		-.033	-.026		-.007	-.012*
advisors		(.026)	(.026)		(.007)	(.006)
Acquirer	.001	.001	.001	.001**	.001**	.001**
experience	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
Public acquirer	.039	-.009	-.011	.020	.015	.014
	(.109)	(.109)	(.108)	(.030)	(.029)	(.029)
Target advisor	.845***	.741***	.705***	-.068	-.080*	-.079*
present	(.105)	(.109)	(.104)	(.036)	(.034)	(.034)
Deal value	.121***	.104***	.077*	-.203***	-.191***	-.187***
	(.030)	(.031)	(.031)	(.008)	(.009)	(.009)
Number of	-2.471***	-2.504***	-2.547***	-.463***	-.469***	-.470***
bidders	(.174)	(.178)	(.188)	(.057)	(.057)	(.057)
Public target	-.649***	-.685***	-.687***	-.334**	-.355***	-.356***
	(.115)	(.117)	(.116)	(.032)	(.031)	(.031)
Stock payment	-.005***	-.006***	-.006***	-.003***	-.003***	-.002***
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
Hostile bid	-2.69***	-2.645***	-2.734***	-.434***	-.442***	-.444***
	(.221)	(.227)	(.240)	(.088)	(.089)	(.089)
Tender offer	.692***	.684***	.707***	.121***	.138***	.134***
	(.144)	(.146)	(.149)	(.032)	(.033)	(.033)
Log(α)				-.261***	-.258***	-.256***
				(.021)	(.021)	(.021)
Announ. mergers	5,661	5,661	5,661	5,661	5,661	5,661
Adv.-merg. dyads	9,604	9,604	9,604	9,604	9,604	9,604
Chi square	624.4***	698.1***	1071.0***	1689.5***	1955.3***	3272.8***

Table 5.2: Results of the legal advisor performance analysis.

NOTES: (1) * $p < .05$, ** $p < .01$, *** $p < .001$; (2) standard errors (in parentheses) are adjusted for heteroscedasticity and correlation within advisor; (3) all models include year dummies (not reported); (4) Models 4–6 are corrected for right-censoring caused by incomplete mergers.

It is also not surprising to find that tender offers are more likely to be completed and in shorter time. These transactions bypass much of the closing procedure through the direct acquisition of target shares from their owners. Furthermore, in line with intuition, Model 4 shows that bigger mergers in terms of their $US-value require more time. In contrast, the positive effect of deal value on completion likelihood in Model 1 is somewhat unexpected. As an explanation, DePamphilis (2008, p. 208) notes that "the size of the transaction is not a good indicator of complexity. Small transactions in terms of revenue or purchase price can be horrifically complicated where multiple parties are involved, significant off-balance sheet liabilities exist, or multiple levels of regulatory approval are required." However, since many of the characteristics of the legal advisor are correlated with deal value (see Table C.1 in the Appendix), we retain the deal value in the following models to correct for unobserved factors that lie outside the control of the advisor.

Concerning the characteristics of the acquiring company and the advisors on the target's side, Model 1 shows that the presence of a target advisor is positively related to the likelihood of completion. Considering the fact that 99% of the transactions in our sample are friendly mergers, this finding reflects the effect of a target counsel who is collaborating with the advisors from the acquirer's side. Moreover, the expected positive effect of an experienced acquirer is reflected in a reduced completion time. Finally, the negative coefficient of the time-dependence parameter, Log(α), in Model 4 implies that the longer a merger remains incomplete, the less likely a timely completion becomes.

Models 2 and 5 introduce the characteristics of the merger counsel that are unrelated to his network resources. As predicted by Hypothesis 1, merger performance increases significantly in the local expertise of the acquirer counsel, both in terms of the likelihood of completion as well as in terms of the required time. Thus, both models confirm the importance of local expertise for the quality of legal counsel. The use of two expertise variables based on the total value instead of the number of mergers, as an alternative local expertise measure, yields similar results (unreported).

Interestingly, the models also show that the geographical focus of law firms, and hence their horizontal differentiability, has a more distinguishing effect on their service qualities than the vertical dimensions of law firm quality. Apart from a slightly significant effect from general expertise on completion time, there is no further effect of overall law firm quality or status. This finding further supports the importance of location-specific expertise in the international legal service market. It suggests that even the top law firms in a country can hardly transfer their competencies and expertise to another legal environment.

Models 3 and 6 assess the role of network embeddedness for the quality of a law firm's services and compare it with the effects from local expertise. All embeddedness variables are introduced simultaneously in the models.[8] The results provide, at best, weak support for our Hypotheses 3–5. Neither the degree, nor the affiliation with prestigious partners, is associated with any effect on the likelihood or the time to completion. The presence of an advisor-client tie has, at best, a marginally significant effect on the completion likelihood ($p = .115$). The only embeddedness variable with a significant effect is the strength of the co-advisor relations. However, the direction of the effect is ambiguous. Model 6 shows that every additional co-advisor alliance is associated with a signification reduction in the expected completion time. Yet, Model 3 suggests that the chances of an eventual completion decline at the same time.

For a further comparison, we calculated the sizes of the opposing effects. Holding all other variables at their means and increasing the strength of co-advisor relations by one standard deviation reduces the time to completion by 5.3 days (about 5% of the mean completion time). At the same time, the completion likelihood drops by 1.3 percent (1% of the mean completion likelihood). Considering the relatively stronger effect on completion time, this could be seen as weak evidence in favor of Hypothesis 3(b). However, a definite qualification of the opposing effects requires further information about how clients weigh the costs and benefits of a less likely versus a more timely completion.

The central finding from Models 3 and 6 is that they clearly support our conjecture that local expertise is more important for the service quality of a legal advisor than all its network resources taken together. For a formal test of this conjecture, it suffices to verify that target-country expertise, as the more effective of the two expertise variables, is more beneficial for the expected completion time than the strength of the co-advisor relations. A Wald-test on the equality of the weighted coefficients of the two variables (weighted by the standard deviations of the variables), reveals a significant difference ($p = .049$) in favor of target-country expertise. Moreover, the difference is economically meaningful. Increasing the strength of co-advisor relations by one standard deviation reduces the time to completion by 5.3

[8]We also investigate several models, where the advisor characteristics are introduced one after the other (unreported). The sizes and directions of the coefficients are similar to the one presented in Models 2, 3, 5, and 6.

days, which amounts to only about 60% of the corresponding effect of an increase in local expertise of 9.0 days (9% of the mean completion time).

5.4.2 Legal advisor selection

Above, we have seen that the network resources of a law firm have ambiguous effects on the successful and timely completion of the mergers advised by that firm. Before we proceed to our analysis of the effects of network embeddedness on the likelihood that a particular law firm is nominated as a legal counsel, we first study the distribution of network resources and local expertise variables among all law firms that are potential candidate advisors. Network embeddedness is likely aligned with detrimental effects for the quality of the legal services offered in the international legal service market, if a well-embedded law firm is not typically endowed with the proper local expertise required for a successful merger completion. The reason is that, in this case, clients face a choice dilemma in their nomination decision, where they have to balance a higher level familiarity with their trusted counsel against the know-how of a deal-specific expert firm.

Table 5.3 investigates the selection problem facing a typical acquiring company by looking at the correlation between network resources and local expertise in the set of law firms "at risk" of becoming a counsel.[9] The findings presented in the table fully support the presence of a choice dilemma for the acquirer. In the set of potential legal counsels, both local expertise measures are negatively correlated with each of the network embeddedness variables. Moreover, there is a positive correlation amongst the different dimensions of embeddedness. For example, while the presence of an advisor-client relation is positively correlated with the presence of co-advisor ties (correlation = .14, $p < 0.001$), the variable is negatively related to a firm's target-country expertise (correlation = $-.07$, $p < 0.001$).

Our findings on the role of network embeddedness and local expertise for the selection of a legal advisor are presented in Table 5.4. The baseline Model 7 regresses the presence of a one in the binary variable, legal advisor, on the same array of control variables that is also used in Table 5.2. Here, the variables account merely for differences in the number of appointed merger advisors, but do not explain which particular characteristics make some law

[9] The table is basically an excerpt from the larger correlation Table C.2 in the Appendix. The difference is that Table 5.3 presents pairwise correlations for a subset of the law firm-merger dyads in Table C.2. The single purpose for looking at this subset of firms is that the correlations in Table C.2 are inflated by some potential counsels that are neither endowed with network resources nor with local expertise.

	Variables	1	2	3	4	5	6	7
1.	Advisor-client relations (strength)							
2.	Co-advisor relations (strength)	.06						
3.	Advisor-client relations (presence)	.52	.06					
4.	Co-advisor relations (presence)	.13	.18	.14				
5.	Degree	.18	.13	.16	.34			
6.	Affiliation with prestigious partners	.07	.07	.09	.24	.56		
7.	Target-country expertise	-.04	-.01	-.07	-.04	-.10	-.16	
8.	Acquirer-country expertise	-.01	-.01	-.02	-.04	-.11	-.18	-.37

* A cell reports the pairwise correlation within a subset of all potential legal advisors, where each law firm in this subset has an above-average value in at least one of the eight variables (N=1,502,449 law firm-merger dyads).
** All correlations are significant at the 0.1%-level.

Table 5.3: Correlation of attributes in the risk set of potential legal advisors.

firms more attractive than others. Not surprisingly, many measures of the merger characteristics are insignificant and the fit of the model, as measured by the chi-square statistics, increases significantly after introducing the law firm characteristics in Models 8 and 9.

Based on Model 7, we first introduce all independent variables in Model 8 that are unrelated to the network resources of a law firm, and then include the embeddedness variables in Model 9.[10] The results of Model 8 confirm Hypothesis 2 by showing that a law firm is more likely to be selected as a counsel, the higher the firm's transaction-specific expertise in the laws and regulations of the countries of the buyer and the seller in the particular merger. In the light of the value of legal expertise for the successful completion of a merger, these observations are not surprising. Interestingly, the model also shows that general expertise and law firm prestige are important criteria in the selection decision, despite their weak effects on merger completion.

Model 9 investigates the role of a law firm's network resources for the likelihood of being appointed as a merger counsel and compares the effects with those of the local expertise variables. The model strongly confirms every sub-proposition in Hypothesis 6.[11] Law firms are more likely to be nominated, the more prior relations they have with the client and the other co-advisors, the higher their degree, and the more they are affiliated with

[10] We also investigate several models, where the law firm characteristics are introduced one after the other (unreported). The sizes and directions of the coefficients are similar to the one presented in Models 8 and 9.

[11] An unreported test shows that the coefficients of all remaining variables remain unchanged, when degree instead of general expertise is removed from Model 9.

	Logistic regression with robust standard errors: Selection of a legal advisor		
Variables	Model 7	Model 8	Model 9
Advisor-client relations (strength)			.0350*** (.0063)
Co-advisor relations (strength)			.0098* (.0041)
Advisor-client relations (presence)			2.3845*** (.1191)
Co-advisor relations (presence)			.9842*** (.1112)
Degree			.0032*** (.0006)
Affiliation with prestigious partners			.0219*** (.0050)
Target-country exp.		.0163*** (.0013)	.0169*** (.0012)
Acquirer-country exp.		.0112*** (.0011)	.0094*** (.0010)
General expertise		.0020*** (.0004)	—
Prestigious law firm		1.8818*** (.1871)	-.0925 (.2856)
Single advisor		-1.0026*** (.0856)	-.5259*** (.0613)
Acquirer experience	.0003*** (.0001)	.0001 (.0001)	-.0036*** (.0002)
Public acquirer	.0433 (.0454)	-.0936* (.0438)	.0146 (.0386)
Target advisor present	.1551*** (.0457)	-.0949* (.0438)	-.0885* (.0451)
Deal value	.1474*** (.0210)	.0721** (.0231)	.0033 (.0230)
Number of bidders	-.0182 (.0487)	.0332 (.0510)	.1205* (.0546)
Public target	.0391 (.0509)	-.05757 (.0473)	-.0797 (.0471)
Stock payment	.0010 (.0006)	.0004 (.0006)	.0022*** (.0006)
Hostile bid	.0202 (.0793)	.2063* (.0841)	.2641* (.0933)
Tender offer	.1723** (.0560)	.1215* (.0486)	.1178* (.0515)
Announced mergers	5,661	5,661	5,661
Law firm-merger dyads at risk	2,322,144	2,322,144	2,322,144
Law firm-merger dyads selected	9,604	9,604	9,604
Chi square	287.22***	2219.07***	5782.70***

Table 5.4: Results of the legal advisor selection analysis.

NOTES: (1) * $p < .05$, ** $p < .01$, *** $p < .001$; (2) standard errors (in parentheses) are adjusted for heteroscedasticity and correlation within advisor; (3) all models include year dummies (not reported).

prestigious partners. All this is in line with the argument that social relations and the networks of these relations convey valuable information to the actors' embedded in them about the skills and trustworthiness of potential business partners (Granovetter, 1985; Gulati, 1995b).

More importantly, however, Model 9 also supports our overembeddedness conjecture. Despite the absence of any clear effect on merger completion, all of the network-dependent variables have a positive effect on a law firm's likelihood to be selected as a legal counsel. Moreover, some of the embeddedness variables have a stronger, individual or group-level, effect than any one of the local expertise measures. In particular, a Wald-test on the equality of the coefficients for the presence of an advisor-client tie and target-country expertise shows that the former is significantly larger ($p < .001$), even when the latter is weighted by the range of the expertise variable of 100. Similar tests with the other embeddedness variables in Model 9 do not reject the null hypothesis that either one of them has a stronger individual effect on advisor selection than target-country experience. The fact, however, that all embeddedness measures are positively correlated with each other suggests that it is legitimate to look at their combined effects. Indeed, a Wald test on the combined effect of a one-standard deviation increase in degree and affiliation with prestigious partners versus a one-standard deviation increase in target-country expertise shows that the combined effect of the two embeddedness variables is significantly larger ($p < .07$).

Hence, taken together, our results support the idea that the information conveyed through the social network in the international legal service market interferes with the efficient matching of merger transactions and the appropriate transaction-specific legal expertise.

5.5 Discussion and conclusion

This chapter examines the existence of detrimental effects from social network embeddedness on actions and outcomes in the international market for legal services. Our first set of arguments focuses on the role of network embeddedness and local expertise, as two important dimensions of a law firm, on the quality of their legal counsel in cross-border M&A's. It suggests that both are associated with a higher likelihood and speed of completion of a merger. The results of our analyses show that, while local expertise is clearly beneficial for the service quality of a law firm, this only partially applies to network embeddedness (Table 5.2). Local expertise is not only associated with a higher completion likelihood, but it also reduces the completion time more significantly.

The second set of arguments focuses on the effects of the same two law firm dimensions on the likelihood that a firm is nominated as legal counsel in a cross-border merger. Again, there are various theoretical arguments in favor of their relevance, which are fully supported by our results (Table 5.4). However, a comparison of the relative importance of the two dimensions provides a more detailed picture. Despite their weaker association with service quality, a law firm's network resources have a stronger effect on the likelihood of an appointment than the firm's local expertise.

Our findings suggest that clients seek legal advisors, with whom they have previously worked together, who are well-connected to other clients and law firms, and who are affiliated with prestigious business partners. Moreover, law firms seem to recommend their former co-advisors to their clientele. All this supports the assertion of much sociological and organizational analysis that economic actors use their own experience and trusted informants in situations of high uncertainty (e.g., Granovetter, 1985; Gulati, 1995a,b). Since legal services, such as other professional services, satisfy the characteristics of credence goods, whose value can only be assessed after consumption or even not at all, clients generally have a difficult time assessing the quality of a law firm (Coates, 2001). Own experience and status positions have been found to be important means of managing these uncertainties in other professional service industries (Jensen, 2003), and our findings show that they are also significant in the world of legal counsel.

However, the relatively weaker effect of embeddedness on the quality of legal counsel suggests that clients rely too easily on the network resources of their advisors. In fact, our analysis demonstrates that the acquiring companies in our sample face a dilemma in their selection of a legal advisor, because they have to weigh a higher level of familiarity and status against a more tailored legal expertise (Table 5.3). The dilemma is a consequence of the specific situation in the international legal service market. Over the past two decades, the demand for cross-border mergers has shifted from mostly British and American companies to a truly international demand also involving continental European and East Asian firms (Black, 2000; OECD, 2001). The dynamics entail a particular challenge for the traditional law firm-client relation, which is based on loyalty and trust, because it is at odds with the inflexible nature of the underlying social norms and agreed-upon expectations. Instead, what clients require in this truly globalized market is the case-by-case provision of deal-specific legal expertise. In this light, our results support the conjecture that social network embeddedness might constrain the set of business partners that an actor takes into account, thereby interfering with the selection of economically more meaningful alternatives (Portes and Sensenbrenner, 1993; Gulati and Gargiulo, 1999).

A difference between the scenario outlined here and earlier studies on the "overembeddedness" phenomenon is that not all parties lose in our context. Our findings imply that their network resources help law firms to acquire new advisory appointments. Surprisingly, they do so despite the fact that embedded law firms deliver weaker services as compared to their rivals with better local expertise. An explanation for this seemingly paradoxical trait is the information conveyed from social networks. Through their close business ties, law firms gain access to first-hand information about planned transactions of their clients. Moreover, since clients cannot easily detect and distinguish the quality of the legal services provided by the different firms, they refer to other signals of law firm quality, such as their reputation or status position in the market (Podolny, 1993; Ribstein, 2004). Hence, law firms who have a central position in the network and interact with prestigious business partners are more visible in the market.

An alternative rationale for the observation might, however, be related to the strategic selection of alliance partners. During the period studied in this chapter, all of the large law firms have co-advised most of their transactions with a small and stable group of national and international law firm partners (see Table 5.1 and Figure 5.2). Also, the findings from our analyses show that a law firm's chances of nomination as a counsel increase in the number of prior ties with the other co-advisors in a merger. These observations might reflect the fact that the large and traditional firms strategically discriminate against rival law firms in their recommendation of co-advisors to their long-term clients. Some clients pursue several mergers per year and one way to secure such a client is to first get introduced to him by becoming a member of a co-advisor team (Corwin and Schultz, 2005; Ljungqvist et al., 2007). Thus, in relying on "friends", who are expected to reciprocate a prior recommendation, a law firm can reduce the risk of losing a long-term client to a more competent expert. In other words, choosing ones co-advisors from a small and stable group of partners reduces the competition for follow-up deals and increases the likelihood of future appointments. Hence, our findings also support an economic theory of overembeddedness, according to which law firms exclude rivals from their alliances for strategic reasons.

Before these implications can be confidentially accepted, it is important to acknowledge the limitations of our analysis. A first limitation relates to the internal validity of our results, meaning the extent of network failure in the international legal service market. In order to get a more comprehensive picture of the size of the adverse effects, it would be ideal to complement our analyses of the likelihood of merger completion and the time to completion with analyses of other performance measures for the merger process. For example, previous research has suggested that embedded ties help a client to reduce the time and costs for finding an appropriate legal counsel (Uzzi and Lancaster, 2004). What is the relationship between the public completion time of a merger, which has been used in this study, and the actual completion time including the search time? Is there a trade-off between a higher service quality and a lower service tariff? Moreover, the idea that lawyers are appointed to reduce transaction costs (Gilson, 1984) suggests that measures of the monetary value-added of legal counsel may capture additional positive effects of embeddedness.

Second, it is important to investigate how the results relate to contextual factors. We have argued that the recent structural changes on the demand side made the international legal service market susceptible to an overembeddedness phenomenon. Yet, some advisor-client relations are probably more prone to be overembedded than others and this is likely to depend on the characteristics of the underlying merger transaction. Mizruchi and Stearns (2001), for instance, find that informational ties between bankers are more likely to be overembedded, the higher their environmental uncertainty. Among other dimensions, uncertainty comprises the complexity of the financial transaction a banker seeks advice on. The different complexity dimensions of a merger, such as the attitude of the target's management, or the legal and cultural distance between the acquirer's and the target's country, can motivate similar moderating variables in our context. Therefore, some appropriate moderating variables should be included in our analyses to be able to relate our results to previous studies on embeddedness effects in market transactions (Powell and Smith-Doerr, 1994; Podolny and Page, 1998). Ultimately, researchers should aim at the construction of a contingency framework that relates the different positive and negative effects of embeddedness to the contextual factors of a transaction or the charactertistics of a market.

Despite its limitations, the study in this chapter sheds new light on the role of network embeddedness and the existence of related adverse effects. It is one of a few empirical studies that simultaneously test the implications of embeddedness for the actions and outcomes on a market. By showing that network resources only have a marginal effect on the performance of market transactions, but are crucial in the selection of a business partner, this study suggests that social networks can have distorting effects on the efficient allocation of goods and services in the marketplace.

Chapter 6

Summary and suggestions for future research

6.1 Summary of the findings

Social and economic networks are currently at the top of the research agenda in the social sciences. Several theoretical perspectives have been proposed that roughly ask the same research questions: (i) how can we explain the structural properties of the empirically observable social and economic networks? (ii) What are the consequences of these networks for the actors or organizations embedded in them? The four chapters of this dissertation try to improve our understanding of these questions by investigating a specific type of a social and economic network, namely the networks of inter-firm collaborative partnerships, and by refining the economic and the sociological network theories, as two of the most influential theoretical perspectives on this topic.

In Chapters 2–4, we use the economic perspective to examine networks of R&D partnerships between firms from the manufacturing industries. From the economic viewpoint, these networks are a means for the generation and dissemination of technical know-how. A tension is perceived to exist, however, between the private incentives of firms to collaborate in R&D and the social benefits from these partnerships. Private enterprises engage in joint R&D projects for strategic reasons, to reap their rivals' market shares or to create market power. In contrast, the relevant effects from the social-welfare viewpoint are the creation of information and knowledge at reasonably low costs. It is therefore not surprising that the economic perspective predicts a discrepancy between the observable structures of inter-firm networks and the socially desirable structure. Yet, a different question is to what extent economic theory can predict the structures and dynamics of these networks? Moreover, in how far do the structures of the real-world networks deviate from the socially optimum? These two questions guide the topics in the three chapters.

Chapter 2 presents a descriptive analysis of the networks of R&D partnerships in the worldwide manufacturing industries. The focus in this chapter is on a re-examination of previously found regularities concerning the structural patterns and the evolution of these networks (Duysters and Vanhaverbeke, 1996; Knoke et al., 2002; Hagedoorn, 2002). Our findings confirm some of the results of previous studies, but also shed new light on other properties of the network structures and their dynamics. A first important finding from our analysis is that the overarching network that spans the different countries and industries is extremely sparse. The typical manufacturing company forms an R&D partnership about every thirty-five years. However, our results also show that, despite the sparseness of the network, there are some well-known companies from the high-tech industries with a considerable number of partnerships every year. These observations serve as the stepping stone for our following analyses. Can such a highly concentrated network structure be explained by the strategic formation of R&D alliances? Are concentrated inter-firm networks socially desirable?

The analysis in Chapter 3 relates to the first question. The chapter presents an econometric test of existing economic theories to explain the formation of inter-firm alliance networks. According to Goyal and Joshi (2003, 2006) and Billand and Bravard (2004), the concentration of collaborative activity is a natural consequence of increasing returns, or scale advantages, in the formation of R&D partnerships. Scale advantages arise because the expected profitability of a R&D partnership is positively related to the stock of prior partnerships of a firm. Using a panel of firms from thirty-two manufacturing industries, we test the presence of scale effects against the alternative explanation of unobserved heterogeneity among firms. This heterogeneity captures firm characteristics that are unrelated to a firm's past collaborative activities, but that can still explain why some firms form more alliances than others. The results of our test suggest that, even though firm-level heterogeneity plays a partial role, scale effects are an important factor to explain the structure of the network observed in Chapter 2.

Chapter 4 addresses the question concerning the social desirability of the observed network structures. Even though it seems counterintuitive at first thought, there is still good reason to expect that a concentrated alliance network is welfare efficient. In his seminal article, Arrow (1962) has pointed to an indivisibility in the use of research output and to the implications for the market structure in innovating industries. The chapter provides a rigorous theoretical derivation of this assertion. We investigate a game-theoretical model based on Goyal and Joshi (2003, 2006) that takes, next to the indivisibility of research output, also the detrimental welfare effects from concentration into account: the creation of market power and the disregarding of product variety.

The chapter determines the structural properties of the total welfare-maximizing network. Moreover, expanding on Goyal and Joshi's analysis of the equilibrium networks, we compare the structures of the equilibrium and the welfare-efficient networks. An important result from our analysis is that highly concentrated networks of R&D partnerships are efficient in a wide range of market settings. Moreover, our comparison of the network structures shows that every sufficiently sparse equilibrium network is inefficient, because it exhibits too little concentration in its structure.

Altogether, our analyses of the economic aspects of inter-firm networks might have some implications for the design of policy programs to foster collaborative activity. In particular, our findings from Chapter 2 suggest that it seems rather pointless to foster the augmentation of knowledge spillovers through networks of inter-firm R&D partnerships. Even if prior research on this topic is correct and knowledge spills along chains of alliances (Ahuja, 2000; Hagedoorn et al., 2006; Schilling and Phelps, 2007), the worldwide network is simply too sparse to assimilate these spillovers. Instead, our theoretical results of Chapter 4 point to a potentially more fruitful avenue. They suggest that an effective policy program should exploit scale advantages in the formation of R&D partnerships. The reason is that an increase in the number of partnerships of an already actively collaborating firm yields high social returns, because the incremental value of an innovation is positively related to a firm's market share. Practically, this means that an effective policy should foster R&D partnerships between the central players in an industry network and the smaller and younger firms at its periphery.

In Chapter 5 of this dissertation, we investigate inter-firm networks from a sociological perspective. Here, we consider that, apart from their collaborative partnerships, the firms in a market are also connected through other types of social relations, such as inter-personal ties between their personnel. In the chapter, we examine the role of these personal ties for the formation and the effects of the formal inter-firm partnerships. Two questions are at the heart of our analysis: does the network consisting of the personal ties as well as of the other market relations determine which firms collaborate with each other? And if so, does the network facilitate the formation of welfare-improving inter-firm partnerships?

Chapter 5 presents an empirical enquiry into these questions, where we focus on the specific context of the personal and market ties of law firms operating in the market for legal services in international mergers and acquisitions (M&A). To operationalize the network embeddedness of the firms, two types of measurable inter-firm relations are used: the past co-advisor alliances between the law firms and the past advisor-client relations between the law firms and their clients. Hence, in line with much prior sociological work, our analysis rests on the assumption that the network of formal inter-firm relations reflects the structure of personal ties itself (see, e.g., Podolny, 1993; Gulati and Gargiulo, 1999; Powell et al., 2005). Moreover, next to the social resources of the law firms, the analysis in this chapter includes another important law firm resource. Due to high entry barriers for foreign lawyers, many law firms focus their operations relating to merger advice on clients from their home country. We argue that this geographical focus matters, because it determines the specific field of legal expertise of a firm.

Our ambition in Chapter 5 is to investigate whether there is a tension between the effects of embeddedness on the profitability of a law firm and the quality of its counseling services. An interesting aspect of the two types of law firm resources under study is namely that embedded law firms are typically not endowed with the proper legal expertise. The reason is that the personal ties of a law firm are static and inflexible in their nature, which is at odds with the high volatility of the transactions in the international merger market. Hence, the market is prone to a situation, where it is in a client's best interest to get a law firm into his advisor team that is an expert in the laws and regulation of the countries, where the client and his contract partner are incorporated. However, the other members of the advisor team recommend a previous alliance partner to the client, because of their personal and trustful relations with the former partner.

Our statistical tests support such an ambiguous effect of embeddedness. We find that the most important factor for the quality of the legal services is a law firm's specific field of legal expertise and not its network resources. On the other hand, it turns out that the latter are the decisive factors for a law firm, when it comes to its nomination as a legal counsel. Furthermore, because our results indicate that clients face a dilemma between choosing an embedded counsel and a merger-specific expert as part of their advisor team, embeddedness typically leads to the selection of suboptimal counseling services.

The findings of this chapter have some important implications for a literature investigating the benefits and costs of embeddedness (Portes and

Sensenbrenner, 1993; Uzzi, 1996; Mizruchi and Stearns, 2001). By showing that its network resources help a law firm to acquire new advisory appointments, although at the same time interfering with the selection of tailored legal expertise, we provide statistical evidence for a so far unexplored trade-off between the private benefits and the social value of embedded business partnerships. Our findings might also have some practical consequences for the management of large business transactions. An implication from our study is that managers should be careful in their selection of a legal counsel and should not overrate the value of a lawyer's social capital.

6.2 Suggestions for future research

In the following, we will not repeat the limitations and extensions that are specific to the studies presented in the four main chapters. Their discussion can be found in the concluding section at the end of each chapter. Instead, we want to discuss a number of suggestions for future research that emerge from the multidisciplinary approach in this dissertation.

Before we come to our recommendations, let us point to the merits of a multidisciplinary research approach. At several points in this book, we have benefited from spillovers between the economic and the sociological perspective on networks. For our description of the worldwide network of R&D partnerships in Chapter 2, for example, we employ the homophily index introduced by (Coleman, 1958). The index is a good example for the homophily measures developed in the social segregation literature, where they are used to study issues of racial segregation (see, e.g., Massey and Denton, 1988). We hope that our discussions in Sections 2.3 and 2.5.3 have convinced the reader that the index is also of value in the analysis of the internationalization patterns in inter-firm networks. Moreover, an important finding from the model investigated in Chapter 4 is that it provides a micro-economic foundation for two network measures proposed by the social network literature. Lemma 2 in this chapter suggests that the density and the degree variance of the network capture all the relevant information on the total welfare generated by a collaboration network between innovating firms. The lemma can be of use in sociology to select suitable network measures for the study of inter-firm networks in specific industries.

The presence of spillovers between the economic and the sociological perspective is, of course, not coincidental. Current research in both disciplines is guided by very similar research questions. Economists and sociologists alike try to explain the formation of certain structural properties of a network and investigate their consequences for social and economic outcomes. The differences are to be found more at the level of how the questions are approached. From this dissertation, we notice that the differences emerge at two levels: (i) the network effects taken into consideration and (ii) the research methods.

With regard to the first point, the economic model of Chapter 4 asserts that all that matters to society (and the firms) is how many collaborative agreements each firm has. In contrast, the embeddedness framework underlying the study in Chapter 5 claims that the presence, or absence, of any particular relationship is of relevance for the outcome in a market. Hence, the embeddedness framework investigates richer effects from the structure of a network and, possibly, provides a more realistic picture. However, this adds some considerable complexity to the theoretical analysis. It is not surprising, therefore, that empirical sociological research on networks sometimes lacks systematic theoretical foundations (Granovetter, 1979; Flap, 2002).

Our suggestion for future theory development is to begin with a systematic investigation of (simple) network effects and to gradually enrich the analysis by additional effects. Concerning the question of which effects to add, researchers should guide their choices by the observation of the empirical reality. What are the distinctive structural properties of the examined network? In how far is the model capable of predicting its structure? To give an example for such an empirically driven theory development, the model in Chapter 4 of this thesis is motivated by a descriptive and statistical analysis of an existing inter-firm R&D network. Another example for such an approach is a recent stream in the economics literature, which gradually extends simple network formation models introduced in the statistical physics literature by richer models of actor behavior.[1]

With regard to the second point, while the development of economic theory is based on formal modeling techniques, it is still common sociological practice to derive hypotheses from verbal arguments.[2] A problem of this kind of argumentation is that it easily produces an undifferentiated picture. The formal model of Chapter 4 in this thesis for instance, predicts that, depending on the particular market setting, networks of medium density can be socially optimal. In contrast, our findings of Chapter 5 could support the - admittedly somewhat farfetched - conclusion that any kind of private

[1]For excellent overviews, see Jackson (2008, Chapter 5) and Vega-Redondo (2007, Chapter 6).

[2]Although there is a considerable number of noteworthy exceptions. See Edling and Stern (2003) for a general review and Raub and Weesie (1990), Buskens and van de Rijt (2008), and Corten and Buskens (2010) for some specific examples related to networks.

relationship between lawyers and their clients should be prohibited.

As a solution to this shortcoming, our suggestion for future empirical network research is that it should be founded more on formally developed hypotheses. The advantage of a formal hypothesis development is that it forces the researcher to think about the interaction of different network effects and their dependency on contextual factors, while ensuring the consistency of the hypotheses at the same time. Considering the complex nature of the network effects investigated in sociology, we admit that the usual practice of economists to analytically derive the set of hypotheses might not be the appropriate way. However, a promising avenue seems to be the use of computer-assisted simulation studies in sociological research (Cederman, 2005; Epstein, 2007).

For the near future of empirical network research, it seems worthwhile to explore the role of mediating effects that make the size and the direction of a network effect dependent on contextual factors. As is illustrated in some recent excellent studies (Uzzi, 1996; Mizruchi and Stearns, 2001), such a contingency approach is able to provide a more realistic perspective on the different positive and negative aspects of the embeddedness in networks.

Appendix A

The international network of R&D partnerships: description of the data

Table A.1: Panel of public companies.

Country	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Australia	1,258	1,089	957	1,030	1,070	1,186	1,178	1,190	1,159	1,162	1,217	1,330	1,334	1,355
Canada	1,146	1,144	1,086	1,119	1,124	1,185	1,196	1,265	1,362	1,384	1,455	1,418	1,299	3,756
Israel	262	216	229	377	558	638	654	655	640	650	644	654	647	615
New Zealand	242	171	139	123	136	173	169	158	132	131	124	144	145	149
United Kingdom	2,015	1,701	1,623	1,874	1,646	2,070	2,078	2,171	2,157	2,087	1,945	1,904	1,923	1,701
United States	6,727	6,599	6,742	6,699	7,246	7,692	7,671	8,479	8,851	8,450	7,651	7,524	6,355	5,685
Anglo-Saxon	11,650	10,920	10,776	11,222	11,780	12,944	12,946	13,918	14,301	13,864	13,036	12,974	11,703	13,261
Finland	78	73	63	61	57	65	73	71	124	129	147	154	152	147
France	668	578	551	786	472	459	450	686	683	711	968	808	791	772
Germany	628	413	428	665	426	417	678	681	700	741	933	1,022	988	715
Italy	217	220	224	228	210	223	250	244	239	243	270	291	288	295
Netherlands	313	260	204	187	245	317	217	217	201	212	212	234	180	180
Sweden	135	258	230	205	205	228	223	229	245	258	277	292	285	278
Switzerland	177	182	182	180	215	237	233	213	216	232	239	252	263	258
Others	1,422	1,456	1,470	1,433	1,417	1,500	1,420	1,433	1,493	1,636	1,872	2,198	2,609	4,052
West. Europe	3,638	3,440	3,352	3,745	3,247	3,446	3,544	3,774	3,901	4,162	4,918	5,251	5,556	6,697
Hong Kong	284	284	333	386	450	529	518	561	671	693	717	779	857	968
Japan	2,019	2,071	2,107	2,118	2,155	2,205	2,263	2,334	2,387	2,416	2,470	2,561	2,471	3,058
Singapore	136	150	166	163	178	240	212	223	303	321	355	418	386	434
South Korea	626	669	686	688	693	699	721	760	776	748	1,178	1,308	1,390	1,518
East Asia	3,065	3,174	3,292	3,355	3,476	3,673	3,714	3,878	4,137	4,178	4,720	5,066	5,104	5,978
India	2,407	2,435	2,556	2,781	3,263	4,413	5,398	5 ,999	5,843	5,860	5,863	5,937	5,795	5,650
Mexico	203	199	209	195	190	206	185	193	198	194	188	179	167	166
Others	4,612	4,980	5,218	5,488	5,616	5,911	6,285	6,389	6,628	6,885	6,998	6,992	6,912	6,831
Develop. ctr.	7,222	7,614	7,983	8,464	9,069	10,530	11,868	12,581	12,669	12,939	13,049	13,108	12,874	12,647
Total	25,575	25,148	25,403	26,786	27,572	30,593	32,072	34,151	35,008	35,143	35,723	36,399	35,237	38,583

NOTE. The numbers are retrieved from the World Development Indicators (WDI) 2003 and represent the complete population of domestic public companies for a given country and year.

Country	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Australia	0	2	3	4	7	8	11	4	15	6	10	11	19	11
	(0)	(2)	(3)	(4)	(6)	(5)	(7)	(4)	(10)	(3)	(5)	(7)	(9)	(6)
Canada	3	9	22	31	59	79	51	31	48	19	16	11	16	11
	(3)	(8)	(18)	(25)	(50)	(66)	(43)	(27)	(34)	(16)	(12)	(8)	(12)	(9)
Israel	0	0	3	4	6	4	6	5	14	3	1	0	2	0
	(0)	(0)	(1)	(4)	(3)	(4)	(5)	(5)	(13)	(1)	(1)	(0)	(1)	(0)
New Zealand	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
United Kingdom	8	19	22	48	53	57	52	26	36	34	14	18	13	17
	(8)	(17)	(20)	(40)	(47)	(47)	(45)	(20)	(27)	(31)	(10)	(11)	(10)	(15)
United States	103	235	539	900	876	997	787	412	589	227	134	99	94	96
	(42)	(102)	(202)	(282)	(272)	(312)	(277)	(132)	(201)	(87)	(51)	(67)	(50)	(51)
Anglo-Saxon countries	106	255	571	957	966	1,095	863	452	660	263	165	130	136	128
	(45)	(119)	(226)	(325)	(343)	(384)	(333)	(162)	(243)	(112)	(68)	(83)	(74)	(74)
Finland	0	0	1	1	1	4	3	0	2	1	0	3	2	1
	(0)	(0)	(1)	(1)	(1)	(4)	(2)	(0)	(2)	(1)	(0)	(3)	(1)	(1)
France	2	11	14	30	20	20	14	10	15	10	2	4	7	5
	(2)	(8)	(13)	(24)	(16)	(16)	(13)	(9)	(15)	(8)	(1)	(4)	(7)	(5)
Germany	2	12	21	28	39	41	30	18	19	11	8	11	12	6
	(2)	(12)	(18)	(24)	(33)	(34)	(25)	(16)	(19)	(9)	(4)	(8)	(11)	(6)
Italy	1	5	5	13	6	7	7	1	4	0	0	1	2	0
	(1)	(5)	(4)	(12)	(5)	(7)	(7)	(1)	(4)	(0)	(0)	(1)	(2)	(0)
Netherlands	1	4	3	16	9	16	7	0	7	1	1	2	5	6
	(1)	(4)	(2)	(16)	(8)	(15)	(7)	(0)	(5)	(1)	(1)	(2)	(5)	(4)
Sweden	1	2	3	11	5	5	11	5	3	3	5	1	3	0
	(1)	(2)	(3)	(11)	(5)	(5)	(9)	(4)	(3)	(2)	(5)	(1)	(2)	(0)
Switzerland	2	8	11	12	9	8	3	0	2	5	4	4	2	8
	(2)	(8)	(9)	(12)	(9)	(8)	(3)	(0)	(2)	(5)	(3)	(3)	(1)	(7)
Others	1	5	5	8	8	9	7	5	7	2	4	2	7	1
	(1)	(5)	(5)	(8)	(8)	(8)	(7)	(5)	(7)	(2)	(4)	(2)	(5)	(1)
Western Europe	10	42	60	104	95	102	80	40	56	33	24	27	39	26
	(10)	(38)	(51)	(93)	(83)	(89)	(71)	(35)	(54)	(28)	(18)	(23)	(33)	(23)

Hong Kong	0	1	1	2	8	2	3	0	1	3	3	2	0	0
	(0)	(1)	(1)	(0)	(1)	(0)	(1)	(0)	(1)	(2)	(3)	(1)	(0)	(0)
Japan	38	67	172	213	214	257	136	56	57	33	27	122	50	55
	(35)	(64)	(139)	(147)	(167)	(192)	(115)	(43)	(48)	(25)	(20)	(40)	(24)	(32)
Singapore	0	0	1	2	7	12	9	6	5	2	0	2	3	0
	(0)	(0)	(0)	(1)	(4)	(9)	(4)	(2)	(1)	(0)	(1)	(1)	(0)	(0)
South Korea	13	7	4	11	5	16	17	7	11	7	7	8	8	6
	(0)	(4)	(3)	(6)	(5)	(16)	(16)	(5)	(5)	(6)	(2)	(7)	(8)	(3)
East Asia	38	72	176	223	231	284	160	67	68	43	32	131	62	61
	(35)	(69)	(143)	(156)	(184)	(215)	(139)	(53)	(57)	(31)	(24)	(46)	(33)	(36)
India	0	0	1	2	4	6	9	1	6	4	2	1	4	3
	(0)	(1)	(1)	(1)	(3)	(3)	(5)	(1)	(5)	(1)	(0)	(0)	(3)	(0)
Mexico	0	0	0	0	0	4	0	0	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(4)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Others	0	1	2	1	3	5	16	3	5	4	1	0	0	0
	(0)	(1)	(1)	(1)	(3)	(5)	(12)	(3)	(5)	(2)	(1)	(0)	(0)	(0)
Developing countries	0	1	3	2	7	15	24	7	11	4	1	0	3	4
	(0)	(1)	(3)	(2)	(7)	(15)	(19)	(4)	(11)	(2)	(1)	(0)	(2)	(1)
Total	129	304	691	1,149	1,152	1,317	1,003	512	717	310	199	256	215	196
	(65)	(161)	(304)	(439)	(470)	(524)	(438)	(200)	(287)	(140)	(88)	(120)	(117)	(111)

Table A.2: R&D partnerships between public companies.

NOTE. The numbers are retrieved from the Thomson Financial SDC Platinum database. In each cell, the total number of partnerships formed by the public firms from a certain country/region precedes the number of international/cross-regional R&D partnerships in parentheses.

Appendix B

Natural cocentration in industrial R&D collaboration: proofs

This Appendix supplements Chapter 4 by first presenting the proofs of Lemmas 1, 2, and 4. Second, we show the detailed derivation of Examples 1 and 2. Third, we determine the normalized degree variance (used in Proposition 4) and the architecture (used in Proposition 5) of an efficient network in a large industry. Furthermore, we provide the details on how to derive the limit value of the transformed network stability condition (4.4). Finally, we present the robustness checks of the model in Chapter 4 with respect to allowing for market exit and industry-wide spillovers.

Proof of Lemma 1. Given that the product market is in equilibrium, let us write $q_i(g)$ to denote the equilibrium quantity of any firm i in network g. Moreover, let the term Δq_u^{ij} depict the change in equilibrium quantity of firm u upon the formation of link ij. Thus, for $u \in \{i,j\}$, it is $\Delta q_u^{ij} = -\gamma(\frac{\partial q_i}{\partial c_i} + \frac{\partial q_i}{\partial c_j})$, whereas for $u \in N\backslash\{i,j\}$, $\Delta q_u^{ij} = -2\gamma\frac{\partial q_i}{\partial c_j}$. In a first step, the effects of adding link ij to network g on industry profits, $\sum_{i\in N}\left[\Pi_i(g+ij) - \Pi_i(g)\right]$, and consumer surplus, $U(g+ij) - U(g)$, is determined. In a subsequent step, we prove convexity and submodularity of each of these terms.

Given that the product market is in equilibrium, one may depict the indirect utility difference between any two networks g and $g+ij$, with $ij \notin g$, in terms of the integral:

$$U(g+ij) - U(g) = \int_0^1 \sum_{k\in N}\sum_{l\in N}\left[\frac{\partial U}{\partial q_k}\frac{\partial q_k}{\partial c_l}\frac{\partial c_l}{\partial x} + \frac{\partial U}{\partial p_k}\frac{\partial p_k}{\partial c_l}\frac{\partial c_l}{\partial x}\right]dx, \qquad \text{(B.1)}$$

where the variable x, $x \in [0,1]$, can be interpreted as the weight of link ij. Note that $\frac{\partial c_u}{\partial x} = -\gamma$ for $u \in \{i,j\}$ and $\frac{\partial c_u}{\partial x} = 0$ for $u \in N\backslash\{i,j\}$. Applying the Envelope Theorem, from which it follows $\frac{\partial U}{\partial q_i} = 0$ for any $i \in N$, the expression simplifies to:

$$U(g+ij) - U(g) = \int_0^1 \sum_{k\in N} -\gamma\left[\frac{\partial U}{\partial p_k}\frac{\partial p_k}{\partial c_i} + \frac{\partial U}{\partial p_k}\frac{\partial p_k}{\partial c_j}\right]dx.$$

In equilibrium, the first order derivatives are $\frac{\partial U}{\partial p_k} = -q_k\big(c(g+x)\big)$ for any $k \in N$, where $c(g+x)$ denotes the cost vector $\{c_1(g+x), c_2(g+x), ..., c_n(g+x)\}$. Furthermore, $\frac{\partial p_i}{\partial c_i} = \lambda\frac{\partial q_i}{\partial c_i} + 1$, whereas for $k \in N\backslash\{i\}$ we get $\frac{\partial p_k}{\partial c_i} = \lambda\frac{\partial q_k}{\partial c_i}$. Substituting into the expression, we obtain for $u \in \{i,j\}$ and $v \in N\backslash\{i,j\}$:

$$\begin{aligned} U(g+ij) - U(g) &= \sum_{u\in\{i,j\}} \gamma\left[\lambda\frac{\partial q_u}{\partial c_u} + 1 + \lambda\frac{\partial q_u}{\partial c_v}\right]\left[\int_0^1 q_u\big(c(g+x)\big)dx\right] \\ &+ \sum_{v\in N\backslash\{i,j\}} 2\lambda\gamma\frac{\partial q_v}{\partial c_u}\left[\int_0^1 q_v\big(c(g+x)\big)dx\right]. \end{aligned}$$

Solving the integrals:

$$\begin{aligned} U(g+ij) - U(g) &= \sum_{u\in\{i,j\}} \frac{\gamma - \lambda\Delta q_u^{ij}}{2\Delta q_u^{ij}}\left[q_u(g+ij)^2 - q_u(g)^2\right] \\ &- \sum_{v\in N\backslash\{i,j\}} \frac{\lambda}{2}\left[q_v(g+ij)^2 - q_v(g)^2\right], \end{aligned}$$

where $q_i(g)$ denotes the equilibrium quantity of firm i in network g. Moreover, the term Δq_k^{ij} depicts the change in the equilibrium quantity of firm k upon the formation of link ij. Thus, if $u \in \{i,j\}$ then $\Delta q_u^{ij} = -\gamma(\frac{\partial q_i}{\partial c_i} + \frac{\partial q_i}{\partial c_j})$, whereas if $v \in N\backslash\{i,j\}$ then $\Delta q_v^{ij} = -2\gamma\frac{\partial q_i}{\partial c_j}$. In the case of quantity competition between firms, the terms become:

$$\Delta q_u^{ij} = \gamma \frac{2+\beta(n-3)}{(2-\beta)\,(2+\beta(n-1))} \quad \text{and} \quad \Delta q_v^{ij} = -\gamma \frac{2\beta}{(2-\beta)\,(2+\beta(n-1))},$$

and in the case of price competition:

$$\begin{aligned} \Delta q_u^{ij} &= \frac{\gamma}{\lambda_p} \frac{2+(3n-7)\beta+(n^2-6n+7)\beta^2}{(2+(n-3)\beta)\,(2+(2n-3)\beta)} \\ \Delta q_v^{ij} &= -\frac{\gamma}{\lambda_p} \frac{2\beta(1+(n-2)\beta)}{(2+(n-3)\beta)\,(2+(2n-3)\beta)}. \end{aligned}$$

Applying the binomial formula, $(a^2 - b^2) = (a-b)(a-b+2b)$, we may write:

$$\begin{aligned} U(g+ij) - U(g) &= \sum_{u\in\{i,j\}} \frac{\gamma - \lambda\Delta q_u^{ij}}{2}\Big[\Delta q_u^{ij} + 2q_u(g)\Big] \\ &- \sum_{v\in N\backslash\{i,j\}} \frac{\lambda\Delta q_v^{ij}}{2}\Big[\Delta q_v^{ij} + 2q_v(g)\Big]. \end{aligned} \tag{B.2}$$

In a similar way, the difference in industry profits can be written as:

$$\sum_{i\in N}\big[\pi_i(g+ij) - \pi_i(g)\big] = \sum_{i\in N} \lambda\Delta q_i^{ij}\Big[\Delta q_i^{ij} + 2q_i(g)\Big] - f. \tag{B.3}$$

We are now able to show convexity and submodularity. From (B.2) and (B.3), it follows immediately for any network g with $ij, ik \notin g$:

$$\begin{aligned} &\sum_{i\in N}\big[\Pi_i(g+ij+ik) - 2\Pi_i(g+ik) + \Pi_i(g)\big] \\ &= 2\lambda\Big[\Delta q_i^{ij}\Delta q_i^{ik} + \sum_{u\in N\backslash\{i,j,k\}} \Delta q_u^{ij}\Delta q_u^{ik} \\ &+\Delta q_j^{ij}\big(q_j(g+ik) - q_k(g)\big) + \Delta q_k^{ij}\big(q_k(g+ik) - q_j(g)\big)\Big], \end{aligned} \tag{B.4}$$

and

$$\begin{aligned} &U(g+ij+ik) - 2U(g+ik) + U(g) \\ &= \lambda\Big[\Delta q_i^{ij}\big(\frac{\gamma}{\lambda} - \Delta q_i^{ik}\big) - \sum_{u\in N\backslash\{i,j,k\}} \Delta q_u^{ij}\Delta q_u^{ik} \\ &+\big(\frac{\gamma}{\lambda} - \Delta q_j^{ij}\big)\big(q_j(g+ik) - q_k(g)\big) - \Delta q_k^{ij}\big(q_k(g+ik) - q_j(g)\big)\Big]. \end{aligned} \tag{B.5}$$

If $\eta_j(g) = \eta_k(g) + 1$ the expressions simplify to:

$$\begin{aligned} &\sum_{i\in N}\big[\Pi_i(g+ij+ik) - 2\Pi_i(g+ik) + \Pi_i(g)\big] \\ &= 2\lambda\Big[\sum_{u\in\{i,j\}} (\Delta q_u^{ij})^2 + \sum_{v\in N\backslash\{i,j\}} (\Delta q_v^{ij})^2\Big], \end{aligned} \tag{B.6}$$

and

$$U(g+ij+ik)-2U(g+ik)+U(g) \tag{B.7}$$
$$=\lambda\Big[\sum_{u\in\{i,j\}}\Delta q_u^{ij}\big(\frac{\gamma}{\lambda}-\Delta q_u^{ij}\big)-\sum_{v\in N\backslash\{i,j\}}\big(\Delta q_v^{ij}\big)^2\Big],$$

because then $q_j(g+ik)-q_k(g)=\Delta q_j^{ij}$ and $q_k(g+ik)-q_j(g)=\Delta q_j^{ik}$. Convexity of industry profits follows immediately from the fact that the summands in brackets of (B.6) are both positive and $\lambda>0$. Although the terms in brackets of (B.7) are of opposite signs, it can be shown that their sum is positive for any $n>2$ and $\beta\in(0,1]$ and regardless of whether firms compete in quantities or in prices. Moreover, it can be verified that if $\eta_j(g)>\eta_k(g)+1$, (B.4) is even greater than (B.6), and (B.5) is greater than (B.7), which establishes part (i) of the lemma. (On the other hand, for $\eta_j(g)<\eta_k(g)+1$, we can find cost and demand parameters for which convexity is not satisfied.)

We now turn to part (ii) of the lemma. For any network g with $ij,kl\notin g$ and $k,l\in N\backslash\{i,j\}$ we may write:

$$\sum_{i\in N}\big[\Pi_i(g+ij+kl)-\Pi_i(g+kl)-\Pi_i(g+ij)+\Pi_i(g)\big] \tag{B.8}$$
$$=2\lambda\Big[\sum_{u\in\{i,j,k,l\}}\Delta q_u^{ij}\Delta q_u^{kl}+\sum_{v\in N\backslash\{i,j,k,l\}}\Delta q_v^{ij}\Delta q_v^{kl}\Big],$$

and

$$U(g+ij+kl)-U(g+kl)-U(g+ij)+U(g) \tag{B.9}$$
$$=\lambda\Big[\sum_{u\in\{i,j\}}\big(\frac{\gamma}{\lambda}-\Delta q_u^{ij}\big)\Delta q_u^{kl}-\sum_{v\in\{k,l\}}\Delta q_v^{ij}\Delta q_v^{kl}-\sum_{w\in N\backslash\{i,j,k,l\}}\Delta q_w^{ij}\Delta q_w^{kl}\Big].$$

It can easily be verified that the expressions in brackets of (B.8) are negative for any $n>2$ and $\beta\in(0,1]$, irrespective of whether we consider price or quantity competition in the market. The term in brackets of (B.9) equals under quantity competition $-4\beta^2\frac{n-2-(n-1)\beta}{(2+(n-1)\beta)^2(2-\beta)^2}$, which is smaller zero if and only if $n>2$ and $\beta<\frac{n-2}{n-1}$. Under price competition, negativity requires again only $n>2$ and $\beta\in(0,1)$. □

Proof of Lemma 2. We will show that one may write:

$$U(g) = U(g^e)+\varphi_1 D(g)+\varphi_2 D(g)^2+\varphi_3 C(g),$$
$$\sum_{i\in N}\Pi_i(g) = \sum_{i\in N}\Pi_i(g^e)+\varphi_4 D(g)+\varphi_5 D(g)^2-\frac{1}{2}fn(n-1)D(g)+\varphi_6 C(g)\,,$$

where φ_1 to φ_6 are defined below. The claim follows immediately from this. In particular, if $Y[D,C]$ measures the consumer surplus it is:

$$Y[0,0]=U(g^e)\,,\quad \phi_1=\varphi_1\,,\quad \phi_2=\varphi_2\,,\ \text{and}\quad \phi_3=\varphi_3\,,$$

whereas if welfare is measured in terms of total surplus:

$$Y[0,0]=U(g^e)+\sum_{i\in N}\Pi_i(g^e)\,,\quad \phi_1=\varphi_1+\varphi_4\,,\quad \phi_2=\varphi_2+\varphi_5\,,\ \text{and}\quad \phi_3=\varphi_3+\varphi_6\,.$$

Let us begin by decomposing the welfare in network g into:

$$W(g) - W(g^e) = \big[W(g) - W(g^r)\big] \;+\; \big[W(g^r) - W(g^e)\big]\,,$$

where the regular network g^r is such that $D(g^r) = D(g)$. Note moreover that $C(g^r) = C(g^e) = 0$.

We derive each summand in turn and begin with $W(g^r) - W(g^e)$. Using the fact that in equilibrium $p_i = \lambda q_i + c_i$, we can write for utility and gross industry profits:

$$U(g) = \sum_{i \in N} \big(\alpha - c_i(g)\big)q_i(g) - \big(\lambda + \frac{1}{2}\big)q_i(g)^2 - \frac{\beta}{2}\sum_{j \neq i} q_i(g)q_j(g)$$

and

$$\sum_{i \in N} \pi_i(g) = \lambda \sum_{i \in N} q_i(g)^2.$$

Since in g^r it holds $q_i(g^r) = q_j(g^r)$ and $c_i(g^r) = c_j(g^r) = \gamma_0 - \gamma(n-1)D(g^r)$ for any $i, j \in N$, the difference $W(g^r) - W(g^e)$ may be written as:

$$\begin{aligned}
U(g^r) - U(g^e) &= n\Big[\alpha - \gamma_0 + \gamma(n-1)D(g^r)\Big]q_i(g^r) - n\big[\alpha - \gamma_0\big]q_i(g^e) \\
&\quad - n\frac{2\lambda + 1 + (n-1)\beta}{2}\Big[q_i(g^r)^2 - q_i(g^e)^2\Big] \\
\sum_{i \in N}\Pi_i(g^r) - \sum_{i \in N}\Pi_i(g^e) &= n\lambda\Big[q_i(g^r)^2 - q_i(g^e)^2\Big] - \frac{1}{2}fn(n-1)D(g^r)\,.
\end{aligned}$$

Substituting $q_i(g^r)^2 - q_i(g^e)^2 = \big[q_i(g^r) - q_i(g^e)\big]\big[q_i(g^r) - q_i(g^e) + 2q_i(g^e)\big]$, we obtain:

$$\begin{aligned}
U(g^r) - U(g^e) &= \gamma n(n-1)D(g^r)q_i(g^e) \\
&+ n\Big[\alpha - \gamma_0 + \gamma(n-1)D(g^r)\Big]\Big[q_i(g^r) - q_i(g^e)\Big] \\
&- n\frac{2\lambda + 1 + (n-1)\beta}{2}\Big[q_i(g^r) - q_i(g^e)\Big]\Big[q_i(g^r) - q_i(g^e) + 2q_i(g^e)\Big]
\end{aligned}$$

and

$$\begin{aligned}
\sum_{i \in N}\Pi_i(g^r) - \sum_{i \in N}\Pi_i(g^e) &= n\lambda\Big[q_i(g^r) - q_i(g^e)\Big]\Big[q_i(g^r) - q_i(g^e) + 2q_i(g^e)\Big] \\
&- \frac{1}{2}fn(n-1)D(g^r)\,.
\end{aligned}$$

It can be verified that:

$$\begin{aligned}
&q_i(g^r) - q_i(g^e) = (n-1)D(g^r)\big[\Delta q_i^{ij} + (\frac{n}{2} - 1)\Delta q_i^{jk}\big] \\
&q_i(g^e) = \frac{\alpha - \gamma_0}{\gamma}\big[\Delta q_i^{ij} + (\frac{n}{2} - 1)\Delta q_i^{jk}\big],
\end{aligned}$$

where the terms Δq_i^{ij} and Δq_i^{jk} are defined in the proof of Lemma 1. Concerning the first term, for example, note that in g^r a typical firm is involved in $(n-1)D(g^r)$ links more than in g^e, and the remaining firms, $j \in N\backslash\{i\}$, are involved in $(\frac{n}{2}-1)(n-1)D(g^r)$ more links. Upon substitution we can simplify the expressions to:

$$\begin{aligned} U(g^r) - U(g^e) &= \varphi_1 D(g^r) + \varphi_2 D(g^r)^2 \\ \sum_{i\in N}\Pi_i(g^r) - \sum_{i\in N}\Pi_i(g^e) &= \varphi_4 D(g^r) + \varphi_5 D(g^r)^2 - \frac{1}{2} fn(n-1)D(g^r) \end{aligned}$$

where

$$\begin{aligned} \varphi_1 &= n(n-1)\big(\alpha-\gamma_0\big)\big[\Delta q_i^{ij} + (\frac{n}{2}-1)\Delta q_i^{jk}\big] \times \\ &\quad \frac{2\gamma - \big[2\lambda+1+(n-1)\beta\big]\big[\Delta q_i^{ij} + (\frac{n}{2}-1)\Delta q_i^{jk}\big]}{\gamma} \\ \varphi_2 &= n(n-1)\big[\Delta q_i^{ij} + (\frac{n}{2}-1)\Delta q_i^{jk}\big]\frac{2\gamma - \big[2\lambda+1+(n-1)\beta\big]\big[\Delta q_i^{ij} + (\frac{n}{2}-1)\Delta q_i^{jk}\big]}{2} \\ \varphi_4 &= 2n(n-1)\big(\alpha-\gamma_0\big)\lambda\frac{\big[\Delta q_i^{ij} + (\frac{n}{2}-1)\Delta q_i^{jk}\big]^2}{\gamma} \\ \varphi_5 &= n(n-1)\lambda\big[\Delta q_i^{ij} + (\frac{n}{2}-1)\Delta q_i^{jk}\big]^2. \end{aligned}$$

The reader might check that $\Delta q_i^{ij} + \big(\frac{n}{2}-1\big)\Delta q_i^{jk} > 0$ and $2\gamma - \big[2\lambda+1+(n-1)\beta\big]\big[\Delta q_i^{ij} + (\frac{n}{2}-1)\Delta q_i^{jk}\big] > 0$ for any $\beta \in (0,1]$ and $n > 2$ and regardless of whether competition is in quantities or in prices. Hence, φ_1, φ_2, φ_4, and φ_5 are all greater than zero.

Let us turn to the derivation of $W(g) - W(g^r)$ and start from

$$\begin{aligned} U(g) - U(g^r) &= \sum_{i\in N}\Big[\big(\alpha-\gamma_0+\gamma\eta_i(g)\big)q_i(g)\Big] \\ &- n\Big[\alpha-\gamma_0+\gamma(n-1)D(g^r)\Big]q_i(g^r) \\ &- (\lambda+\frac{1}{2})\sum_{i\in N}q_i(g)^2 - \frac{\beta}{2}\sum_{i\in N}\sum_{j\neq i}q_i(g)q_j(g) \\ &+ n\frac{2\lambda+1+(n-1)\beta}{2}q_i(g^r)^2 \\ \sum_{i\in N}\Pi_i(g) - \sum_{i\in N}\Pi_i(g^r) &= \lambda\sum_{i\in N}\Big[q_i(g)^2 - q_i(g^r)^2\Big]. \end{aligned}$$

The following properties help to simplify the expressions. For any $D(g) = D(g^r)$:

(i) $q_i(g) - q_i(g^r) = \big[\Delta q_i^{ij} - \Delta q_i^{jk}\big]\big[\eta_i(g) - \bar{\eta}(g^r)\big]$

(ii) $q_i(g)q_j(g) - q_i(g^r)^2 = \big[q_i(g) - q_i(g^r)\big]\big[q_j(g) - q_i(g^r)\big] + q_i(g^r)\big[q_i(g) - q_i(g^r) + q_j(g) - q_i(g^r)\big]$

(iii) $\sum_{i\in N}\big[\eta_i(g) - \bar{\eta}(g^r)\big] = 0$

(iv) $\sum_{i\in N}\eta_i(g)\big[\eta_i(g) - \bar{\eta}(g^r)\big] = nV(g)$

(v) $\sum_{i\in N}\sum_{j\neq i}\big[\eta_i(g) - \bar{\eta}(g^r)\big] = 0$

(vi) $\sum_{i\in N}\sum_{j\neq i}\big[\eta_i(g) - \bar{\eta}(g^r)\big]\big[\eta_j(g) - \bar{\eta}(g^r)\big] = -nV(g)$.

Applying all of them, we obtain:

$$\begin{aligned} U(g) - U(g^r) &= \varphi_3 C(g) \\ \sum_{i\in N}\Pi_i(g) - \sum_{i\in N}\Pi_i(g^r) &= \varphi_6 C(g), \end{aligned}$$

with

$$\varphi_3 = n\hat{V}(n)\big[\Delta q_i^{ij} - \Delta q_i^{jk}\big]\frac{2\gamma - \big[2\lambda + 1 - \beta\big]\big[\Delta q_i^{ij} - \Delta q_i^{jk}\big]}{2}$$
$$\varphi_6 = n\lambda\hat{V}(n)\big[\Delta q_i^{ij} - \Delta q_i^{jk}\big]^2.$$

The reader may check that $\Delta q_i^{ij} - \Delta q_i^{jk} > 0$ and $2\gamma - \big[2\lambda + 1 - \beta\big]\big[\Delta q_i^{ij} - \Delta q_i^{jk}\big] \geq 0$ for any $\beta \in (0, 1]$ and regardless of the competition mode (the equality holds if and only if the firms compete in quantities and $\beta = 1$). Thus, $\varphi_3 \geq 0$ and $\varphi_6 > 0$. □

The following lemma generalizes Proposition 3.3 of Goyal and Joshi (2003) in terms of the modes of market competition and the measures of welfare investigated.

Lemma 4. *Suppose that the measure of welfare is either the consumer surplus or the total surplus. Suppose, moreover, that there are no costs of link formation. Let the firms compete either in quantities or in prices. The complete network is the uniquely efficient network.*

Proof. We first prove the claim for the consumer surplus and refer, therefore, to expression (B.2) in the proof of Lemma 1. It can easily be verified that the expression is strictly positive for any g and regardless of the mode of competition, since $\lambda > 0$, $\Delta q_i^{ij} > 0$, $(\gamma - \lambda\Delta q_i^{ij}) > 0$, and $\Delta q_{k_2}^{ij} < 0$ for any $k_2 \in N\backslash\{i, j\}$. Moreover, from Assumption 1 in Chapter 4, $2q_k(g) + \Delta q_k^{ij} > 0$ for any $k \in N$. This implies that for $f = 0$ the consumer-surplus maximizing network is complete.

We now verify that $U(g+ij) - U(g) + \sum_{i\in N}\big[\pi_i(g+ij) - \pi_i(g)\big]$, as given by the sum of (B.2) and (B.3) in the proof of Lemma 1, is positive for any g and some well-defined ij. For this purpose, suppose that ij^*, $ij^* \notin g$, is such that $i = \text{argmin}\{\eta_i(g) : i \in N\}$ and the tuple $(i, j) = \text{argmax}\{|\eta_j(g) - \eta_i(g)| : j \notin N_i(g)\}$. Hence, ij^* connects the two firms i and j, where firm i has the lowest degree in network g and firm j has the highest degree among those firms that are not yet connected with firm i. Let us determine the network $\hat{g}$ that minimizes the contribution of ij^* to total welfare and show that, even in this network, ij^* increases total welfare.

In a first step, consider the class of networks where for any g in this class $\eta_i(g) = x$ and $\eta_j(g) = y$ for given x and y, with $0 \leq x \leq y \leq n-2$. Let us determine the network $\hat{g}$ within this class. Note that $q_i(g)$ and $q_j(g)$ are both declining in the number of links of any firm $u \in N\backslash\{i, j\}$, whereas $\sum_{u\in N\backslash\{i,j\}} q_u(g)$ is increasing in these links. Hence, because the sum of (B.2) and (B.3) is increasing in the quantities of firms i and j and declining in the sum of the quantities of $u \in N\backslash\{i, j\}$, in network $\hat{g}$ each firm k in the neighborhood of firm i, $k \in N_i(\hat{g})$, is connected to every firm $l \in N\backslash\{k\}$. Moreover, for every $m \notin N_i(\hat{g})$ it is $\eta_m(\hat{g}) = y$. Therefore, in network $\hat{g}$, the equilibrium quantity terms in equations (B.2) and (B.3) can be written as:

$$\lambda q_i(\hat{g}) = \mu\alpha - \nu(\gamma_0 - \gamma x) + \xi b\,, \qquad \lambda q_j(\hat{g}) = \mu\alpha - \nu(\gamma_0 - \gamma y) + \xi b\,,$$
$$\lambda q_k(\hat{g}) = \mu\alpha - \nu(\gamma_0 - \gamma(n-1)) + \xi b\,, \quad \lambda q_m(\hat{g}) = \mu\alpha - \nu(\gamma_0 - \gamma y) + \xi b\,,$$

where the parameters μ, ν, and ξ are defined in Chapter 4, and $b = \big[n\gamma_0 - \gamma x - (n-x-1)\gamma y - x\gamma(n-1)\big]$.

In the second step, let us minimize the contribution of ij^* with respect to x and y. Because the equilibrium quantities are linear in x and y, as expressions (B.2) and (B.3) also are, it follows $\hat{x} \in \{0, n-2\}$ and $\hat{y} \in \{\hat{x}, n-2\}$. Hence, network $\hat{g}$ is either (i) the empty network g^e with $(\hat{x}, \hat{y}) = (0,0)$, (ii) the dominant group network g^{n-1} with $(\hat{x}, \hat{y}) = (0, n-2)$, where only firm i is isolated, or (iii) a network g' with $(\hat{x}, \hat{y}) = (n-2, n-2)$, where g' induces the degree partition $\{h_{n-2}, h_{n-1}\}$ with $|h_{n-2}| = 2$ and $|h_{n-1}| = n-2$. It remains to check whether the contribution of link ij^* to total welfare, given by the sum of (B.2) and (B.3), is positive in each of these networks:
(i) It is $W(g^e + ij^*) - W(g^e) > 0$, since $\left(\gamma + \lambda \Delta q_i^{ij}\right) \Delta q_i^{ij} + \frac{(n-2)}{2} \lambda (\Delta q_k^{ij})^2 > 0$ and moreover because $\left[2(\gamma + \lambda \Delta q_i^{ij}) + (n-2)\lambda \Delta q_k^{ij}\right] q_i(g^e)$ equals in the case of quantity competition:

$$\frac{2\,(3 + \beta n - \beta)\,\gamma}{2 + n\beta - \beta} q_i(g^e) > 0\,,$$

and under price competition:

$$\frac{2\,(3 + \beta n - 4\beta)\,\gamma}{2 + n\beta - 3\beta} q_i(g^e) > 0\,.$$

(ii) In the dominant group network and under quantity competition, it holds:

$$\begin{aligned}
W(g^{n-1} + ij^*) - W(g^{n-1}) \;=\; & \frac{2\,(3 + \beta n - \beta)\,\gamma(\alpha - \gamma_0)}{(2 + \beta n - \beta)^2} \\
-\gamma^2 & \frac{n^3 \beta^2 (3 - \beta) + n^2 \beta (4 - 17\beta + 5\beta^2) - n(12 + 20\beta - 37\beta^2 + 9\beta^3)}{(2 + \beta n - \beta)^2\,(2 - \beta)^2} \\
-\gamma^2 & \frac{12 + 32\beta - 29\beta^2 + 5\beta^3}{(2 + \beta n - \beta)^2\,(2 - \beta)^2}.
\end{aligned}$$

The term is positive for any $n > 2$ and $\beta \in (0, 1]$, because

$$\begin{aligned}
& W(g^{n-1} + ij^*) - W(g^{n-1}) \;> \\
& \gamma^2 \frac{n^3 \beta^2 (1 - \beta) + n^2 \beta (8 - 5\beta + 3\beta^2) + n(12 - 16\beta + \beta^2 - \beta^3) - 12 - 8\beta + 9\beta^2 - \beta^3}{(2 + \beta n - \beta)^2\,(2 - \beta)^2} \\
& \geq\; \gamma^2 \frac{2 + \beta}{2 - \beta} \;>\; 0.
\end{aligned}$$

The first inequality follows from Assumption 1, which implies $(\alpha - \gamma_0) > \gamma \frac{(n-1)(n-2)\beta}{2-\beta}$, and the second one from the fact that the long expression is minimized for $n = 3$.
(iii) In network g' with quantity competition:

$$\begin{aligned}
W(g' + ij^*) - W(g') \;=\; & \frac{2\,(3 + \beta n - \beta)\,\gamma(\alpha - \gamma_0)}{(2 + \beta n - \beta)^2} \;+ \\
\gamma^2 & \frac{n^2 \beta (8 - 11\beta + 3\beta^2) + n(24 - 52\beta + 38\beta^2 - 8\beta^3) - 36 + 64\beta - 33\beta^2 + 5\beta^3}{(2 + \beta n - \beta)^2\,(2 - \beta)^2},
\end{aligned}$$

From Assumption 1, it follows:

$$\begin{aligned}
& W(g' + ij^*) - W(g') \\
& > \gamma^2 \frac{2n^3\beta^2(2-\beta) + n^2\beta(20 - 33\beta + 11\beta^2) + n(24 - 88\beta + 76\beta^2 - 18\beta^3)}{(2+\beta n - \beta)^2\,(2-\beta)^2} \\
& + \gamma^2 \frac{-36 + 88\beta - 53\beta^2 + 9\beta^3}{(2+\beta n - \beta)^2\,(2-\beta)^2} \\
& \geq \frac{18 + 2\beta - 7\beta^2}{(2\beta+3)\,(2-\beta)^2} > 0.
\end{aligned}$$

In the same manner, it can be shown that $W(g^{n-1} + ij^*) - W(g^{n-1}) > 0$ and $W(g' + ij^*) - W(g') > 0$ under price competition. Thus, if linking costs are zero the welfare-maximizingnetwork is complete. □

Example 1 *with $n = 3$ firms, price competition between firms, and welfare measured in terms of the total surplus.*

There are four network architectures in this example: (i) g^e with $D(g^e) = 0$ and $C(g^e) = 0$; (ii) g^2, a dominant group, with $D = 1/3$ and $C(g^2) = 1$; (iii) g^s, a star, with $D(g^s) = 2/3$ and $C(g^s) = 1$; and (iv) g^c with $D(g^c) = 1$ and $C(g^c) = 0$. Moreover, welfare in network g can be written as

$$W(g) - W(g^e) = \frac{3\,(3+2\beta)\,\gamma}{2\,(1+\beta)^2}\big((\alpha - \gamma_0)D(g) + \gamma D(g)^2\big) + \frac{(3-\beta)\,\gamma^2}{3\,(2-\beta)^2}C(g) - 3fD(g)\,.$$

The parameter of product substitutability splits the space of cost and demand parameters into two regions. On the one hand, if $\beta \leq 0.62$ there does not exist any f such that for $g \in \{g^2, g^s\}$, $W(g) > W(g^e)$ and $W(g) > W(g^c)$. Hence, only the empty and the complete network are efficient. On the other hand, for $\beta > 0.62$, each one of the four architectures is efficient in some well-defined cost interval:

$$\big(g^*, D(g^*)\,,\,C(g^*)\big) \quad = \quad \begin{cases} \big(g^c\,, 1\,, 0\big) & \text{if } 0 \leq f \leq f_1\,, \\ \big(g^s\,, 2/3\,,\,1\big) & \text{if } f_1 \leq f \leq f_2\,, \\ \big(g^{n'}\,, 1/3\,,\,1\big) & \text{if } f_2 \leq f \leq f_3\,, \\ \big(g^e\,, 0\,, 0\big) & \text{if } f_3 \leq f\,. \end{cases}$$

The critical cost levels are given by $f_1 = \frac{(3-\beta)(1+\beta)(3\alpha - 3\gamma_0 + \gamma)\gamma}{6(1+2\beta)} + \frac{(3+5\beta)(1+\beta)\gamma^2}{3(2+3\beta)^2(1-\beta)}$, $f_2 = \frac{(3-\beta)(1+\beta)(\alpha - \gamma_0 + \gamma)\gamma}{2(1+2\beta)}$, and $f_3 = \frac{(3-\beta)(1+\beta)(3\alpha - 3\gamma_0 + 5\gamma)\gamma}{6(1+2\beta)} - \frac{(3+5\beta)(1+\beta)\gamma^2}{3(2+3\beta)^2(1-\beta)}$.

Example 2 *with $n \to \infty$ firms, quantity competition between firms, and welfare measured in consumer surplus.*

The analysis of the limit case has an intriguing advantage over the case of a network with finite n. The reason is that the welfare function, as given by equation (4.3) in Chapter 4, becomes continuous and differentiable with respect to density and degree variance. Moreover, following from Proposition 2, the characterization of the efficient network reduces to an optimization of welfare with respect to one variable, the density, only. Hence, an efficient network has to satisfy the standard first- and second-order conditions of a univariate maximization problem.

However, the analysis requires two further parameter specifications: first, the costs of linking need to be proportional to the number of firms, since otherwise costs are negligibly small as compared to gross welfare, when the number of firms grows large. Hence, let us specify $f = n\rho$ and let us investigate changes in the network with respect to varying ρ. Second, depict the effective market size in a large network, $\alpha - \gamma_0$, by a parameter A. More precisely, A is defined as $\alpha - \gamma_0 = A\sigma$, where $A > 1$ and σ denotes the minimal market size of footnote 8 in Chapter 4. It can now be shown that a monotone transformation of the consumer surplus satisfies the following equality:

$$\lim_{n\to\infty} \frac{U\left[D,C\right]-U\left[0,0\right]}{n^3} = \gamma^2 \frac{A}{2-\beta} D + \gamma^2 \frac{(1-\beta)}{(2-\beta)^2} \lim \hat{C}(D,n) - \frac{1}{2}\rho D \,,$$

where the expression for $\lim \hat{C}(D,n)$ is given in the following part of the Appendix.

Moreover, the following part of the Appendix shows that if the solution to the maximization problem, D^*, is greater than 0.5, the efficient network has approximately a dominant group architecture, where a share of $n'/n = \sqrt{D^*}$ firms is in the center group. In contrast, if $D^* \leq 0.5$ the efficient network has an inter-linked star architecture that induces a two-point degree partition, $\{h_p, h_c\}$. The peripheral group, h_p, comprises a share of $\sqrt{1-D^*}$ of the total number of firms and for each $i \in h_p$, $ij \in g$ if and only if $j \in h_c$. We arrive at the following characterization of a consumer-surplus maximizing network in a large industry. Suppose $\beta = 0.5$, $\gamma = 1$, and $A = 2$. Then:

$$\left(g^*, D(g^*)\,, C(g^*)\right) \quad \approx \quad \begin{cases} \left(g^c\,, 1\,,\, 0\right) & \text{if } 0 \leq \rho \leq 2.4\,, \\ \left(g^{n'}, 5.6 - 1.9\rho\,,\, 1 - 20(\rho - 2.7)^2\right) & \text{if } 2.4 \leq \rho \leq 2.7\,, \\ \left(g^x, 10.1 - 3.5\rho\,,\, 1 - 20(\rho - 2.7)^2\right) & \text{if } 2.7 \leq \rho \leq 2.9\,, \\ \left(g^e\,, 0\,,\, 0\right) & \text{if } 2.9 \leq \rho\,. \end{cases}$$

Efficient network in a large industry. In the following, we determine the normalized degree variance and the architecture of an efficient network in a large industry. The normalized degree variance is determined in two steps: first, we replicate a result from Snijders (1981) on the architecture of a variance-maximizing network for given density. Then, we calculate the degree variance of this architecture.

Define the *complementary* network to network g by $g_c = \{ij : i,j \in N, i \neq j, ij \notin g\}$, which has its links exactly where g does not. Note that $D(g_c) = 1 - D(g)$ and $C(g_c) = C(g)$. Snijders (1981) shows that for any $n > 2$ and for any $0 < D < 1$, a variance-maximizing network $\tilde{g} = \text{argmax}\{C(g)|D(g) = D\}$ satisfies the following properties:

either $\tilde{g}$ has an architecture g', or $\tilde{g}_c$ has an architecture g'', where:
(i) g' and g'' both partition the set of firms into a four-point degree partition $\{h_0, h_{l_1}, h_{l_2}, h_{l_3}\}$, with[1]

$$l_1 = |h_{l_3}|\,, \qquad l_2 = |h_{l_2}| + |h_{l_3}| - 1\,, \text{ and } \qquad l_3 = |h_{l_1}| + |h_{l_2}| + |h_{l_3}| - 1.$$

Moreover, it is $|h_{l_1}| = 1$ and
(iia) in architecture g', $I_1 \equiv |h_{l_2}| + |h_{l_3}|$ is the largest integer satisfying $I_1(I_1 - 1) \leq$

[1]See Chapter 4 for the definition of a degree partition.

$n(n-1)D$, and
(iib) in architecture g'', $I_2 \equiv |h_{l_2}| + |h_{l_3}|$ is the largest integer satisfying $I_2(I_2-1) \leq n(n-1)(1-D)$.

According to this, either $\tilde{g}$ or its complement $\tilde{g}_c$ have a dominant group-like architecture, where the size of the group of connected firms, $|h_{l_2}| + |h_{l_3}|$, is maximal given the density. The remaining links originate from a single peripheral firm in h_{l_1} that is only connected to the group of connected firms.

The (normalized) degree variance of the maximally concentrated network is now determined by $C(\tilde{g}) = \hat{C}(D,n) = \max\{C(g'), C(g'')\}$, where

$$C(g') = \frac{1}{\hat{V}(n)} \frac{\big(|h_{l_3}| - \bar{\eta}\big)^2 + |h_{l_3}|\big(I_1 - \bar{\eta}\big)^2 + \big(I_1 - |h_{l_3}|\big)\big(I_1 - 1 - \bar{\eta}\big)^2 + \big(n - I_1 - 1\big)\bar{\eta}^2}{n}$$

and $C(g'')$ is obtained by replacing I_1 by I_2 and $\bar{\eta}$ by $(n-1-\bar{\eta})$. If n is a finite number, determining $C(\tilde{g})$ is difficult, because this involves a constrained maximization with respect to I_1 and I_2. However, for $n \to \infty$, architecture g' has approximately the normalized degree variance of a dominant group $g^{n'}$, which is obtained from g' by removing the links of the peripheral firm in h_{l_1}. More precisely, for the dominant group architecture $g^{n'}$, with $n' = I_1$, and for any $0 \leq |h_{l_3}| \leq n' < n$, it is

$$\lim_{n\to\infty} \Big[C(g') - C(g^{n'})\Big] = \lim_{n\to\infty} \left[256|h_{l_3}| \frac{n(2n'-1) - 4n'(n'-1) + |h_{l_3}|(n-4)}{(3n-2)^2\,(n-2)\,(3n+2)}\right] = 0\,.$$

Similarly, one can approximate $C(g'')$ by the normalized variance of the sparser dominant group $g^{n''}$. We obtain for the maximum variance of a network of density D:

$$\begin{aligned}
\lim_{n\to\infty} \hat{C}(D,n) &= \lim \Big[\max\big\{C(g^{n'})\,,\, C(g^{n''})\big\}\Big] \\
&= \frac{256}{27} \lim \Bigg[\max\Big\{D\Big(\frac{\sqrt{1 - 8|h_{l_3}| + 4Dn(n-1)} - 1}{2n} - D\Big)\,, \\
&\qquad (1-D)\Big(\frac{\sqrt{1 - 8|h_{l_3}| + 4(1-D)n(n-1)} - 1}{2n} - 1 + D\Big)\Big\}\Bigg] \\
&= \frac{256}{27} \max\Big\{D^{\frac{3}{2}}(1-\sqrt{D})\,,\,(1-D)^{\frac{3}{2}}(1-\sqrt{1-D})\Big\}\,.
\end{aligned}$$

The first equality follows from the approximation described above. To establish the second equality, we rewrite $\lim C(g^{n'}) = \lim \frac{n^2}{\hat{V}(n)} \times \lim \frac{1}{n^2} V(g^{n'})$ and solve $\lim \frac{n^2}{\hat{V}(n)} = \frac{27}{256}$ and:

$$\begin{aligned}
\lim \frac{1}{n^2} V(g^{n'}) &= \lim \frac{1}{n^2} \frac{n'\big(n' - 1 - \frac{n'(n'-1)}{n}\big)^2 + \big(n - n'\big)\big(\frac{n'(n'-1)}{n}\big)^2}{n} \\
&= \lim \frac{1}{n^2} \frac{n'(n'-1)}{n}\Big(n' - 1 - \frac{n'(n'-1)}{n}\Big) = \lim D\Big(\frac{n'-1}{n} - D\Big).
\end{aligned}$$

This follows from $D(g^{n'}) = \frac{n'(n'-1)}{n(n-1)} = D - \frac{2|h_{l_3}|}{n(n-1)}$, and hence $\lim n'(n'-1)/n^2 = D$. The second equality is now established by replacing $n' = \frac{1}{2} + \frac{1}{2}\sqrt{1 - 8|h_{l_3}| + 4Dn(n-1)}$. The third equality follows from noting that $\lim \sqrt{1 - 8|h_{l_3}| + 4Dn(n-1)}/n$ equals $\lim \sqrt{(1 - 8|h_{l_3}|)/n^2 - 4D/n + 4D} = 2\sqrt{D}$. Note that the final expression for $\lim \hat{C}(D,n)$ is continuous in density and differentiable almost everywhere (with the only exception being $D = 0.5$).

Concerning the architecture of the variance-maximizing network, $\tilde{g}$, note that if $D \geq 0.5$ the maximum of the two values in the final expression for $\lim \hat{C}(D, n)$ is given by $D^{\frac{3}{2}}(1-\sqrt{D})$. Hence, $\tilde{g}$ has (approximately) the architecture of the dominant group, $g^{n'}$, described above, where a share of $n'/n = \sqrt{D}$ firms is in the group of connected firms. For $D \leq 0.5$, the maximum is $(1-D)^{\frac{3}{2}}(1-\sqrt{1-D})$. As an implication of Proposition 1 in Chapter 4, $\tilde{g}$ must have an inter-linked star architecture. Because the complementary network has the dominant group architecture, $g^{n''}$, network $\tilde{g}$ consists of a center group of firms, h_c, and a single peripheral group, h_p. Moreover, the periphery of $\tilde{g}$ comprises a share of $\sqrt{1-D}$ of the total of firms and for each $i \in h_p$, $ij \in \tilde{g}$ if and only if $j \in h_c$.

Transformed network stability condition. In the following, we provide some details on how to derive the limit value of the transformed network stability condition (4.4) in Chapter 4. In particular, we derive the incentive constraint of firms k and l from the center group of a sparse efficient network, g^*, to maintain their link $kl \in g^*$, given that the firms compete in prices (which is the inequality (4.5) in the proof of Proposition 5):

$$\lim_{n\to\infty} 2\frac{\pi_k(g^*) - \pi_k(g^* - kl)}{n} \geq \rho \,.$$

Note that a sparse efficient network, g^*, has an inter-linked star architecture with the degree partition $\{h_p, h_c\}$. Denote the cardinality of h_p by x. The cardinality satisfies $\frac{x(x-1)}{n(n-1)} = 1-D$, since the network complementary to g^* has a dominant group architecture of density $1-D$. Hence, we can write:

$$\lim_{n\to\infty} 2\frac{\pi_k(g^* - \pi_k(g^* - kl)}{n} = \lim_{n\to\infty} 2\lambda_p \Delta q_k^{kl} \times \lim_{n\to\infty} \frac{2q_k(g^*) - \Delta q_k^{kl}}{n} = \gamma \frac{\gamma A + \gamma\,(1-D)}{1-\beta} \,.$$

The first equality follows from a decomposition of the profit function, $\pi_k(g) = \lambda_p q_k^2(g)$, where $q_k(g^*) = \mu_p\alpha - \nu_p c_k + \xi_p \sum_{i\neq k} c_i$ with $c_k = \gamma_0 - (n-1)\gamma$ and $\sum_{i\neq k} c_i = (n-x-1)(\gamma_0 - (n-1)\gamma) + x(\gamma_0 - (n-x)\gamma)$.[2] Concerning the second equality, it is easily verified that $\lim 2\lambda_p \Delta q_k^{kl} = \gamma$ and $\lim \Delta q_k^{kl}/n = 0$, which follows from the repeated application of L'Hospital's Rule. Moreover, we can decompose $\lim q_k(g^*)/n$ into:

$$\begin{aligned}
&\lim_{n\to\infty} \frac{(1-\beta)}{\lambda_p} \frac{(\alpha-\gamma_0)}{n(2+(n-3)\beta)} \\
&+ \lim_{n\to\infty} \frac{\gamma}{\lambda_p} \frac{5\beta - 2 - 3\beta^2 + n(2 - 7\beta + 5\beta^2) + 2\beta n^2(1-\beta) - \beta x(1-2\beta) + \beta x^2(1-2\beta)}{n\,(2+(n-3)\beta)\,(2+(2n-3)\beta)} \\
&+ \lim_{n\to\infty} \frac{\gamma}{\lambda_p} \frac{\beta^2 n x(x-1)}{n\,(2+(n-3)\beta)\,(2+(2n-3)\beta)} \,,
\end{aligned}$$

where $(\alpha - \gamma_0) = A\gamma \frac{(1+(n-2)\beta)(n-1)(n-2)\beta}{2+(2n-5)\beta-(2n-3)\beta^2}$ and $x = \frac{1+\sqrt{1+4n(n-1)(1-D)}}{2}$. The first summand can be simplified by the use of $\lim \lambda_p = (1-\beta)$ and $\lim \frac{(\alpha-\gamma_0)}{n(2+(n-3)\beta)} = \frac{\gamma A}{1-\beta}$. The limit value of the second summand is zero, since the denominator is a polynomial of degree three. By the use of $\lim x/n = \sqrt{1-D}$ and L'Hospital's Rule, the third summand simplifies to $\frac{\gamma(1-D)}{1-\beta}$, which establishes the second equality. In the same manner, one can derive limit values for the other inequalities in network stability condition (4.4).

[2] The decomposition follows from application of the binomial formula, $(a^2 - b^2) = (a-b)(a-b+2b)$, to the profit function and from the definition $\Delta q_k^{kl} = q_k(\tilde{g}) - q_k(\tilde{g} - kl)$.

Market exit. Market exit of a peripheral firm in a concentrated network can be detrimental, because (1) competition in the product market will be reduced, and (2) the central firms lose a valuable collaboration partner.

In order to address the first concern, consider the following example. Let us compare total welfare in a regular network, g^r, and in a dominant group, $g^{n'}$, where $D(g^r) = D(g^{n'})$. To incorporate the effect of market exit, let Assumption 1 of Chapter 4 be violated for the x firms ($x = n - n'$) that are isolated in network $g^{n'}$. Their quantities are set to zero. The remaining firms in $g^{n'}$ compete in the market a la Cournot with homogeneous products. The market exit condition can be written as $\alpha - \gamma_0 \leq n'(n'-1)\gamma$ and consumer surplus becomes $\frac{1}{2}Q^2$. In the regular network with $n = n' + x$ firms in the market, total welfare can be written as:

$$W(g^r) = (n'+x)q_i^2(g^r) + \frac{1}{2}Q^2(g^r) - \frac{n'(n'-1)}{2}f\,,$$

where

$$q_i(g^r) = \frac{\alpha - c_i}{n'+x+1}\,, \qquad Q(g^r) = (n'+x)q_i(g^r)\ \text{, and} \qquad c_i = \gamma_0 - \frac{n'(n'-1)}{n'+x}\gamma\,.$$

Hence,

$$W(g^r) = Q(g^r)\left(\frac{1}{2}Q(g^r) + q_i(g^r)\right) - \frac{n'(n'-1)}{2}f\,.$$

First, note that for $x = 0$, $g^r = g^{n'}$ and therefore $W(g^r) = W(g^{n'})$. Second, differentiate $W(g^r)$ with respect to x. We get:

$$\frac{\partial W(g^r)}{\partial x} = \frac{\partial Q(g^r)}{\partial x}\left(\frac{1}{2}Q(g^r) + q_i(g^r)\right) + Q(g^r)\left(\frac{1}{2}\frac{\partial Q(g^r)}{\partial x} + \frac{\partial q_i(g^r)}{\partial x}\right)$$

with:

$$\begin{aligned}
\frac{\partial q_i(g^r)}{\partial x} &= -\frac{\alpha - \gamma_0}{(n'+x+1)^2} - \frac{n'(n'-1)(2n'+2x+1)}{(n'+x)^2(n'+x+1)^2}\gamma\,,\\
\frac{\partial Q(g^r)}{\partial x} &= \frac{\alpha - \gamma_0 - n'(n'-1)\gamma}{(n'+x+1)^2}\,.
\end{aligned}$$

Clearly, the derivative of the individual output is negative. Moreover, under the market-exit condition, the total output is also weakly declining in x. Thus, the derivative of the welfare function is negative and, therefore, we obtain $W(g^r) < W(g^{n'})$ for any $n > n'$.

With regard to the second problem of market exit, the loss of potential collaboration partners is not necessarily detrimental from a welfare perspective, in particular when linking costs are high. To make this point clear, compare the regular network g^r from above with a dominant group, $g^{n'-1}$, where $D(g^r) > D(g^{n'-1})$. Clearly, there exists some linking costs, f, which are sufficiently large such that $W(g^r) < W(g^{n'-1})$. This suggests that highly concentrated networks may be efficient even in the case of market exit.

Industry-wide spillovers. Suppose firm i's marginal cost of production in network g is given by

$$c_i(g) \quad = \quad \gamma_0 - \gamma\Big[(1-\vartheta)\eta_i(g) + \vartheta\sum_{k\in N}\eta_k(g)\Big]\,,$$

where $0 < \vartheta < 1$. We first show that Lemma 1 and Proposition 1 still apply. Starting from equation (B.1) in the proof of Lemma 1, the effect of link ij on marginal costs is now $\frac{\partial c_u}{\partial x} = -\gamma$ for $u \in \{i,j\}$ and $\frac{\partial c_u}{\partial x} = -\vartheta\gamma$ for $u \in N\backslash\{i,j\}$. Equation (B.2) becomes:

$$\begin{aligned} U(g+ij) - U(g) &= \sum_{u \in \{i,j\}} \frac{\gamma - \lambda \Delta q_u^{ij}}{2} \left[\Delta q_u^{ij} + 2q_u(g)\right] \\ &\quad + \sum_{v \in N\backslash\{i,j\}} \frac{\vartheta\gamma - \lambda \Delta q_v^{ij}}{2} \left[\Delta q_v^{ij} + 2q_v(g)\right], \end{aligned}$$

where $\Delta q_u^{ij} = -\gamma(\frac{\partial q_i}{\partial c_i} + \frac{\partial q_i}{\partial c_j} + (n-2)\vartheta\frac{\partial q_i}{\partial c_j})$ and $\Delta q_v^{ij} = -\gamma(2\frac{\partial q_i}{\partial c_j} + \vartheta\frac{\partial q_i}{\partial c_i} + (n-3)\vartheta\frac{\partial q_i}{\partial c_j})$. Equation (B.3) remains unchanged. Suppose any $\vartheta < 1$ and $\eta_j(g) = \eta_k(g) + 1$. Suppose, moreover, that the firms compete in quantities and products are homogeneous. It holds:

$$\begin{aligned} U(g+ij+ik) - 2U(g+ik) + U(g) &= \gamma^2 \frac{(2+(n-2)\vartheta)^2}{(n+1)^2} > 0 \\ W(g+ij+ik) - 2W(g+ik) + W(g) &= \gamma^2 \frac{28 - 36\vartheta + 23\vartheta^2}{(n+1)^2} > 0\,. \end{aligned}$$

Hence, consumer surplus and total surplus are convex with respect to collaborative links. Thus, Proposition 1 of Chapter 4 carries over to a model with industry-wide spillovers. Furthermore, suppose $\vartheta < \frac{2\sqrt{(2n^3+8n^2+10n+4)} - 10n - 16}{n^2 - 10n - 20}$. Then,

$$\begin{aligned} &W(g+ij+kl) - W(g+kl) - W(g+ij) + W(g) = \\ &\gamma^2 \frac{-8n - 12 + \vartheta(20n+32) + \vartheta^2(n^2 - 10n - 20)}{2\,(n+1)^2} < 0\,. \end{aligned}$$

Hence, a dominant group or an inter-linked star are typical architectures of a total-welfare maximizing network.

We now turn to a robustness check of Lemma 2 and Proposition 2. Because the amount of spillovers does not depend on the structure of a network, social welfare can be expressed as a function of density and degree variance only. Thus, Lemma 2 applies to a model with industry-wide spillovers. Moreover, suppose ϑ is sufficiently small. It can be shown that total welfare and consumer surplus increase in the degree of concentration in a network. Therefore, given that spillovers are sufficiently small, Proposition 2 carries over as well.

Appendix C

The dark side of network embeddedness: data description

	Variables	Mean	S.D.	1	2	3	4	5	6	7
1.	Completion likelih.	.93	.26							
2.	Completion time	85.06	117.53	-.12						
3.	Adv.-client rel. (st.)	1.98	7.43	.02	-.02					
4.	Co-advisor rel. (st.)	21.38	88.81	-.05	-.01	.09				
5.	Adv.client rel. (pr.)	.29	.45	.03	.01	.41	.07			
6.	Co-adv. rel. (pr.)	.37	.44	.03	.13	.14	.21	.12		
7.	Degree	224.93	173.66	-.01	.03	.23	.10	.24	.29	
8.	Affiliation with prest. partners	44.36	23.08	.01	.10	.16	.08	.38	.03	.56
9.	Target-ctr. exp.	30.54	34.48	.02	-.06	-.12	-.14	-.13	-.15	-.17
10.	Acq.-ctr. exp.	25.40	31.83	.01	-.02	.05	-.08	.17	.01	-.03
11.	General expertise	249.34	278.39	-.02	.01	.25	.18	.20	.21	.86
12.	Prest. law firm	.62	.49	.01	.08	.13	.07	.19	.33	.68
13.	Single advisor	.38	.48	-.05	-.15	-.06	-.19	.01	-.65	-.01
14.	Number of adv.	2.64	1.97	.01	.23	.03	.33	-.01	.46	.01
15.	Acquirer experience	45.31	162.60	.02	-.01	.69	.03	.37	.12	.09
16.	Public acquirer	.69	.46	-.01	.06	-.26	-.01	-.13	-.02	-.05
17.	Target adv.	.69	.46	.09	.13	.01	-.02	.01	.22	.02
18.	Deal value	5.46	1.78	.01	.32	.08	.01	.10	.37	.15
19.	Numb. of bidders	1.04	.22	-.30	.03	-.02	.01	-.02	.04	.01
20.	Public target	.33	.47	-.09	.18	-.08	.01	-.06	.16	.04
21.	Stock payment	12.81	30.70	-.05	.12	-.07	-.03	-.07	.02	-.06
22.	Hostile bid	.01	.12	-.18	.07	-.01	-.01	-.02	.04	.01
23.	Tender offer	.17	.38	-.06	.08	-.06	.04	-.06	.14	.01

	Variables	8	9	10	11	12	13	14	15	16
9.	Target-ctr. exp.	-.14								
10.	Acq.-ctr. exp.	.01	-.46							
11.	General expertise	.35	-.17	-.05						
12.	Prest. law firm	.90	-.14	-.01	.52					
13.	Single advisor	-.09	.15	-.03	.01	-.05				
14.	Number of adv.	.15	-.19	-.05	.01	.08	-.65			
15.	Acquirer experience	.03	-.07	.03	.09	.04	-.09	.07		
16.	Public acquirer	.01	.05	.04	-.06	-.01	-.04	.05	-.38	
17.	Target adv.	.02	.06	-.03	.01	.02	-.32	.26	.03	.03
18.	Deal value	.21	-.08	-.05	.10	.19	-.42	.47	.09	.04
19.	Numb. of bidders	.01	-.01	.01	.01	.01	-.07	.09	-.02	.01
20.	Public target	.10	.08	-.06	.02	.10	-.21	.20	-.11	.10
21.	Stock payment	.01	-.03	.09	-.06	.01	-.10	.11	-.10	.25
22.	Hostile bid	.01	-.01	-.01	.01	.01	-.06	.12	-.01	.05
23.	Tender offer	.07	.05	-.07	.01	.07	-.18	.19	-.10	.08

	Variables	17	18	19	20	21	22
18.	Deal value	.39					
19.	Numb. of bidders	.05	.13				
20.	Public target	.20	.31	.23			
21.	Stock payment	.08	.15	.03	.20		
22.	Hostile bid	.05	.17	.16	.17	.03	
23.	Tender offer	.15	.21	.24	.64	.04	.25

* No. advisor-merger dyads = 9,604.
** All models include year dummies not reported here.

Table C.1: Mean, standard deviations, and bivariate correlations: Advisor performance analysis.

	Variables	Mean	S.D.	1	2	3	4	5	6	7
1.	Legal advisor	.01	.06							
2.	Adv.-client rel. (st.)	.02	.14	.08						
3.	Co-advisor rel. (st.)	.03	.25	.18	.15					
4.	Adv.-client rel. (pr.)	.03	.16	.10	.52	.06				
5.	Co-advisor rel. (pr.)	.05	.18	.11	.14	.19	.16			
6.	Degree	50.33	95.49	.12	.19	.13	.19	.38		
7.	Affiliation with prest. partners	19.03	20.05	.08	.10	.07	.14	.31	.62	
8.	Target-ctr. exp.	15.05	31.30	.03	-.02	.03	-.02	.03	.03	.07
9.	Acq.-ctr. exp.	17.67	33.30	.02	.02	.03	.03	.04	.04	.07
10.	General expertise	46.97	109.94	.12	.17	.37	.18	.33	.94	.53
11.	Prest. law firm	.12	.33	.10	.13	.34	.14	.32	.76	.77
12.	Single advisor	.64	.48	-.03	-.05	-.28	-.05	-.38	-.01	-.01
13.	Acquirer experience	36.48	145.81	.01	.46	.06	.52	.06	.01	.01
14.	Public acquirer	.68	.47	.01	-.16	-.01	-.18	-.01	-.01	-.01
15.	Target adv.	.61	.49	.01	.01	.08	.02	.11	-.01	-.01
16.	Deal value	4.97	1.64	.02	.05	.14	.06	.18	-.01	-.01
17.	Numb. of bidders	1.03	.20	.01	-.01	.02	-.01	.02	.01	-.01
8.	Public target	.27	.44	.01	-.03	.06	-.03	.08	-.02	-.01
19.	Stock payment	10.71	28.59	.01	-.04	.01	-.05	.01	-.02	-.01
20.	Hostile bid	.01	.10	.01	.01	.02	.01	.02	-.01	-.01
21.	Tender offer	.13	.33	.01	-.03	.05	-.04	.07	-.02	-.01

		8	9	10	11	12	13	14	15	16
9.	Acq.-ctr. exp.	-.19								
10.	General expertise	.02	.03							
11.	Prest. law firm	.04	.04	.69						
12.	Single advisor	-.01	-.02	-.01	-.01					
13.	Acquirer experience	-.05	.02	.01	.01	-.10				
14.	Public acquirer	.09	-.01	-.01	-.01	-.03	-.33			
15.	Target adv.	.04	.02	-.01	.01	-.28	.02	.02		
16.	Deal value	.03	-.04	-.01	-.01	-.39	.10	.01	.37	
17.	Numb. of bidders	-.02	.02	.01	.01	-.06	-.01	.01	.05	.11
18.	Public target	.04	-.01	-.01	-.01	-.19	-.06	.06	.19	.26
19.	Stock payment	.02	.03	-.01	.01	-.09	-.08	.22	.05	.10
20.	Hostile bid	-.01	-.01	-.01	-.01	-.05	.01	.03	.05	.11
21.	Tender offer	.02	-.01	-.02	.01	-.17	-.07	.05	.17	.17

18.	Public target	.22			
19.	Stock payment	.01	.16		
20.	Hostile bid	.13	.15	.01	
21.	Tender offer	.22	.62	.03	.22

* No. law firm-merger dyads = 2,322,144.
** All models include year dummies not reported here.

Table C.2: Mean, standard deviations, and bivariate correlations: Advisor selection analysis.

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Samenvatting

Samenwerkingsnetwerken hebben zich in de afgelopen jaren tot één van de vooraanstaande onderzoeksgebieden binnen de economie en sociologie ontwikkeld. Voor 1980 ging de aandacht van het onderzoek vooral uit naar de gehele markt en het individueel bedrijf als de twee mogelijke alternatieven voor de organisatie van economische activiteit. Een bekende vertegenwoordiger van deze stroming is Oliver Williamson, die in 2009 de Nobelprijs voor zijn "transactiekosten theorie" heeft gekregen. In zijn grensverleggende boek uit het jaar 1975 maakt hij een onderscheid tussen de markt en de hiërarchie als de twee basale vormen voor de organisatie van economische transacties, maar laat weinig ruimte over voor andere organisatievormen.

Deze visie is sindsdien duidelijk veranderd. Samenwerkingsnetwerken zijn een populair onderwerp in de recente economische- en managementliteratuur en staan centraal op de politieke agenda's. Eén van de voornaamste doelen van de Framework Programma's van de Europese Commissie is, bijvoorbeeld, de ontwikkeling van een trans-Europees netwerk van onderzoeks- en ontwikkelingsallianties tussen de leidende Europese technologiebedrijven. Dit voornemen is gedreven door het idee dat een zodanig samenwerkingsnetwerk een belangrijke voorwaarde is voor de positieve economische ontwikkeling in de Europese Unie.

Meer dan alleen een populair onderwerp zijn samenwerkingsnetwerken ook een belangrijk empirisch fenomeen. Het aantal allianties en joint ventures tussen bedrijven is over de laatste drie decennia duidelijk gestegen. De Thomson SDC database, een van de grootste databases over dit onderwerp, telde in het jaar 1985 slechts 488 nieuw gevormde verbanden. Dit aantal is gegroeid naar een niveau van 2.476 nieuwe allianties in 2005. Naast deze enorme groei zijn er opvallende structurele verschillen tussen de posities die bedrijven in het netwerk innemen. Eerder onderzoek heeft duidelijk gemaakt dat niet alleen het aantal samenwerkingsverbanden per bedrijf wezenlijk verschilt, maar ook dat de sector waar het bedrijf toe behoort en het land van vestiging belangrijke verklarende factoren voor het bestaan van allianties zijn. Aangezien de mogelijke effecten die door de precieze structuur van een samenwerkingsnetwerk worden bepaald werpen deze fenomenen de volgende vragen op: hoe kunnen de bestaande structuren van samenwerkingsnetwerken verklaard worden? Leiden deze structuren tot efficiënt marktgedrag? Dit zijn de twee centrale onderzoeksvragen van deze dissertatie.

Om aan het multidisciplinaire karakter van dit onderwerp recht te doen, zullen de structurele opbouw en de effecten van samenwerkingsnetwerken uit twee verschillende oogpunten worden beschouwd. De beantwoording van bovengenoemde vragen hangt namelijk af van de soorten netwerkeffecten die door de onderzoeker in aanmerking worden genomen. Over de afgelopen twee decennia werd een reeks aan theoretische perspectieven over economische en sociale netwerken in verschillende wetenschappelijke disciplines ontwikkeld. Deze theorieën leggen de nadruk op de verschillende aspecten en effecten van het netwerk. In deze dissertatie worden samenwerkingsnetwerken vanuit het economisch en het sociologisch perspectief geanalyseerd, waarbij getracht wordt de bestaande theorieën te verfijnen en verder te ontwikkelen.

Hieronder zullen de probleemstellingen en de belangrijkste resultaten van de vier centrale hoofdstukken (2–5) van dit proefschrift worden gepresenteerd. In hoofdstuk 6 worden de opgedane inzichten samengevat. De voor- en nadelen van de economische en sociologische benaderingswijze worden met elkaar vergeleken, waarbij zowel op de toegepaste methodes als op de voorspellingskracht van de theorieën wordt ingegaan.

Economisch perspectief: In de hoofdstukken 2–4 worden samenwerkingsnetwerken vanuit het economisch perspectief beschouwd, waarbij de focus wordt gelegd op een specifiek type netwerk, namelijk de netwerken van onderzoeks- en ontwikkelings-(O&O-)allianties tussen bedrijven in de productiesector. In de economische theorie worden deze netwerken gezien als een middel voor de ontwikkeling en verspreiding van know-how en technologische innovaties. Echter bestaat er een spanningsveld tussen de privéprikkels van winstgerichte bedrijven om samen te werken, en de voordelen van O&O-allianties voor de sociale welvaart in een markt.[1] Winstgerichte bedrijven gaan vanuit strategische overwegingen samenwerken, om hun marktaandeel te vergroten ten koste van de gemeenschappelijke concurrentie of om marktmacht op te bouwen. Aan de andere kant is het vanuit het sociale welvaartperspectief belangrijk dat de ontwikkeling van kennis en innovatie tegen

[1]In de economie wordt de sociale welvaart in een markt gedefinieerd als de som van de winsten van alle bedrijven, die in de markt actief zijn, gecombineerd met het surplus, dat de consumenten door het consumeren van de verkochte goederen behalen.

redelijk lage kosten geschiedt.

Vanuit dit oogpunt is het niet verrassend dat de economische theorie het bestaan van een discrepantie tussen de observeerbare structuren van O&O-samenwerkingsnetwerken en de sociaal wenselijke netwerkstructuur voorspelt. Echter, de vraag blijft op welke manier de bestaande netwerken van het sociale optimum afwijken. Daarbij komt de vraag of de theorie überhaupt in staat is om de structuren en de dynamiek van de observeerbare netwerken te voorspellen. Dit zijn de twee centrale problemen die in de hoofdstukken 2-4 worden benaderd.

In hoofdstuk 2 wordt het internationale netwerk van O&O-samenwerkingsverbanden in de productiesector geanalyseerd. Voor het onderzoek in dit hoofdstuk is gebruik gemaakt van de Thomson SDC database, aan de hand waarvan wij in staat zijn geweest het overkoepelende netwerk van alle productiemarkten en een groot aantal van landen in kaart te brengen. De focus van onze analyses ligt op het toetsen van eerdere bevindingen over de structurele eigenschappen en de dynamiek van het overkoepelende samenwerkingsnetwerk. Eerder empirisch onderzoek heeft de structuren en ontwikkelingen van alle bekende O&O-allianties in kaart gebracht. De structuren en ontwikkelingen van het onderliggend aantal bedrijven is echter buiten beschouwing gebleven. Deze omissie is problematisch omdat bijvoorbeeld verschillen in het aantal bedrijven per land tot een "natuurlijke" asymmetrie in de netwerkstructuur leidt. Deze asymmetrie is niet gebaseerd op verschillen in neigingen tot samenwerking of barrières voor het vormen van allianties, maar slechts op de mogelijkheden voor samenwerking.

In dit hoofdstuk wordt een database over de getallen van beursgenoteerde bedrijven uit 52 landen gecombineerd met de Thomson SDC database die de O&O-samenwerkingsverbanden van deze bedrijven bevat. Aan de hand van deze data en door middel van een set van methoden die het mogelijk maakt om voor de structuur en de dynamiek in de bedrijvenpopulatie te corrigeren, worden de bestaande hypotheses uit de literatuur getoetst. Onze resultaten onderbouwen sommige van de eerdere bevindingen, maar werpen nieuw licht op andere eigenschappen van het overkoepelende samenwerkingsnetwerk. Een eerste belangrijke resultaat is dat het netwerk extreem schaars is. Een typisch bedrijf in onze data vormt slechts iedere vijfendertig jaar een O&O-alliantie. Echter tonen onze resultaten ook aan dat er, ongeacht de schaarsheid van het netwerk, een kleine groep van bekende ondernemingen is die elk jaar een groot aantal van allianties vormt. Dus, in plaats van een egalitair netwerk lijkt het bestaande O&O-samenwerkingsnetwerk meer op een kern-periferie structuur, waar een handvol spelers de centrale rol inneemt. Deze bevinding levert een belangrijke bijdrage aan de literatuur die de effecten van samenwerkingsnetwerken beschouwt en dient als uitgangspunt voor de analyse in ons volgende hoofdstuk.

In hoofdstuk 3 ligt de focus op de vraag of de hoge concentratiegraad van O&O-samenwerkingsactiviteiten in de productiesector door een economische theorie kan worden voorspeld. Eén van de bestaande theorieën over de motivatie voor het sluiten van samenwerkingsverbanden tussen bedrijven wordt econometrisch getest. Volgens deze theorie is de hoge concentratiegraad in de netwerkstructuur een natuurlijke consequentie van stijgende opbrengsten, zogenoemde schaalvoordelen, bij het sluiten van O&O-samenwerkingsverbanden. De schaalvoordelen worden berijkt doordat de verwachte winstgevendheid van een samenwerkingsverband volgens de theorie positief gerelateerd is aan het marktaandeel van een bedrijf. De groei van dit aandeel wordt weer veroorzaakt door middel van innovatieve producten en processen, voortgekomen uit eerdere samenwerkingsverbanden.

Op basis van een panel data studie over 32 productiemarkten wordt in hoofdstuk 3 het optreden van schaalvoordelen bij het sluiten van O&O-allianties getoetst, waarbij voor niet observeerbare heterogeniteit tussen bedrijven wordt gecontroleerd. Deze heterogeniteit omvat bedrijfskarakteristieken die niet gerelateerd zijn aan samenwerkingsactiviteiten uit het verleden, maar die toch kunnen verklaren waarom sommige bedrijven meer allianties vormen dan andere. Eerder onderzoek heeft bijvoorbeeld laten zien dat de neiging voor samenwerking tussen sectoren en landen verschilt. Bovendien is te verwachten dat de neiging afhangt van de geografische afstand van een bedrijf ten opzichte van steden of andere industriële agglomeraties. De resultaten van onze tests tonen aan dat, ongeacht de verklaringskracht van heterogeniteit, schaalvoordelen een belangrijke rol spelen in het sluiten van O&O-samenwerkingsverbanden, en dus de structuur van het netwerk van hoofdstuk 2 kunnen verklaren.

Hoofdstuk 4 behandelt de vraag of een sterk geconcentreerd samenwerkingsnetwerk sociaal wenselijk is. Hoewel het in eerste instantie tegen de intuïtie ingaat, zijn er goede redenen waarom een hoge concentratiegraad efficiënt kan zijn. In de economische theorie wordt de output van een O&O-samenwerkingsverband, namelijk de nieuw gegenereerde kennis over een product of proces, als een zogenoemd ondeelbaar goed beschouwd. Deze eigenschap van kennis heeft belangrijke consequenties voor de welvaart-efficiënte marktstructuur in een innovatieve industrie. In dit hoofdstuk wordt een theoretische herleiding van deze stelling met betrekking tot de welvaartmaximerende structuur van een O&O-samenwerkingsnetwerk gepresenteerd. Wij analyseren een speltheoretisch model waarin naast de effecten van de ondeelbaarheid van kennis ook met de negatieve effecten van een geconcentreerde netwerkstructuur rekening wordt gehouden, met name het bevorderen van marktmacht en de negatieve consequentie van concentratie op de productdiversiteit in de markt.

In het hoofdstuk worden de structurele eigenschappen van het welvaart-maximerende netwerk bepaald. Op basis van de resultaten van eerder onderzoek naar de structuren van evenwichtsnetwerken worden vervolgens de structuren van de evenwichts- en de efficiënte netwerken vergeleken.[2] Het eerste belangrijke resultaat is dat een hoge concentratiegraad in vele gevallen een efficiënte uitkomst is. Bovendien laat de vergelijking van de netwerkstructuren zien dat een evenwichtsnetwerk dat uit een schaars aantal allianties bestaat te weinig geconcentreerd is ten opzichte van het efficiënte netwerk.

Al met al hebben onze analyses van de economische aspecten twee interessante implicaties voor beleidsprogramma's die gericht zijn op O&O-samenwerking. Met name tonen onze resultaten van hoofdstuk 2 aan dat het nutteloos blijkt de groei van kennisspillovers door samenwerkingsverbanden te bevorderen. Zelfs als de bevindingen van eerder onderzoek juist zijn en kennis inderdaad langs ketens van allianties wordt overdragen, blijken de bestaande samenwerkingsnetwerken gewoon te schaars om van deze spillovers effectief gebruik te kunnen maken. Aan de andere kant wijzen onze theoretische analyses in hoofdstuk 4 in de richting dat het vruchtbaarder is om schaalvoordelen bij het sluiten van samenwerkingsverbanden te steunen. Voor de praktijk betekent dit dat effectief beleid zich zou moeten richten op het steunen van samenwerking tussen de centrale spelers in een netwerk en de kleinere en jongere bedrijven in de periferie.

Sociologisch perspectief: In hoofdstuk 5 van deze dissertatie worden samenwerkingsnetwerken vanuit het sociologisch perspectief onderzocht. Hier houden wij rekening met het feit dat de bedrijven in een markt, naast hun samenwerkingsactiviteiten, ook door andere typen van sociale relaties verbonden zijn, zoals door de persoonlijke contacten tussen hun medewerkers. Deze relaties spelen een belangrijke rol voor vele marktuitkomsten, omdat zij het probleem van informatieasymmetrie tussen twee potentiële partners kunnen voorkomen. Het kan bijvoorbeeld voor de managers van een bedrijf lastig zijn om de ware waarde van de kennis die door een mogelijke alliantiepartner wordt aangeboden, in te schatten. Om een ander voorbeeld te

[2] In ons speltheoretisch model wordt een evenwichtsnetwerk gedefineerd als een netwerkstructuur waarbij geen bedrijf een prikkel heeft om een extra samenwerkingsverband met een ander bedrijf te vormen of om één of meerdere allianties te beëindigen.

noemen, zal het ook moeilijk zijn om te controleren wat de daadwerkelijke input van een bestaande alliantiepartner in een gemeenschappelijk O&O-project is. De vraag is dus hoe het grote aantal samenwerkingsverbanden in de Thomson SDC database, gegeven deze informatieasymmetrie, kan worden verklaard.

De sociologische "inbeddingstheorie" levert een mogelijke verklaring. Volgens deze theorie zijn markten doordrongen van netwerken van sociale relaties tussen bedrijven, hun managers en cliënten. Deze relaties hebben verschillende niveaus van intensiteit en omdat zij een sociale context aan een economische transactie toevoegen kunnen zij waardevol kapitaal voor de ingebedde acteurs zijn. Voor de analyses in hoofdstuk 5 spelen twee vraagstukken een belangrijke rol. Ten eerste benaderen wij de vraag of het netwerk dat bestaat uit de persoonlijke contacten en de voormalige samenwerkingsverbanden tussen bedrijven, kan verklaren welke bedrijven in de toekomst met elkaar samenwerken. Ten tweede is het de vraag of dit netwerk het sluiten van sociaal wenselijke samenwerkingsverbanden bevordert.

In hoofdstuk 5 wordt een empirische studie over deze vraagstukken gepresenteerd, waarbij de analyse gericht is op de specifieke context van de persoonlijke en samenwerkingsrelaties van grote advocatenkantoren, die juridisch advies in internationale fusies en acquisities (F&A's) geven. Om de inbedding van de kantoren en hun cliënten in het sociaal netwerk te kunnen meten, maken wij van twee types meetbare relaties gebruik: de coadviseursallianties tussen de advocatenkantoren en de adviseur-cliënt relaties tussen een kantoor en zijn clienten. Vergelijkbaar met eerdere sociologische studies veronderstellen wij dat het netwerk van formele marktrelaties ook de structuur van de persoonlijke contacten tussen de kantoren en hun cliënten weergeeft. Naast dit sociale kapitaal van een advocatenkantoor omvat de analyse in ons hoofdstuk nog een andere belangrijke soort kapitaal van een advocaat. Omdat de markttoetreding voor buitenlandse advocaten in vele landen door nationale wetgeving wordt geblokkeerd, richten vele advocaten hun diensten op de vraag van cliënten uit hun eigen land. Deze focus is van belang omdat het specifieke veld van juridische expertise van een kantoor wordt weergegeven.

Onze ambitie in hoofdstuk 5 is om te onderzoeken of er een tegenstelling optreedt tussen de effecten van de inbedding in een sociaal netwerk op de winstgevendheid van een advocatenkantoor en de kwaliteit van de aangeboden dienstverlening. Een interessant aspect van de twee onderzochte soorten kapitaal is namelijk dat een sociaal ingebed kantoor vaak niet de nodige juridische expertise bezit om goed advies bij een bepaalde F&A te kunnen geven. De reden is dat de persoonlijke contacten van een advocaat statisch en inflexibel van aard zijn, wat botst met de hoge graad aan volatiliteit in de vraag voor juridisch advies in de markt voor internationale F&A. De markt is met name gevoelig voor situaties waar het in het belang van een cliënt is om een advocatenkantoor dat gespecialiseerd is in de wetgeving van de landen waar de cliënt en zijn contractpartner staan geregistreerd, als juridische adviseur te benoemen. Daarentegen zullen advocatenkantoren hun voormalige coadviseurs aan cliënten aanbevelen vanwege hun persoonlijke en vertrouwelijke relaties met deze vroegere partners.

Onze statistische analyses onderbouwen dit ambigue effect van de inbedding in sociale netwerken. Onze bevindingen laten zien dat de meest belangrijke factor voor de kwaliteit van het juridisch advies het specifieke veld van de juridische expertise van een advocatenkantoor is en niet zijn sociale kapitaal. Anderzijds vinden wij dat juist dit sociale kapitaal de beslissende factor voor een kantoor is als het over de benoeming van een juridische adviseur gaat. Omdat onze resultaten verder aantonen dat de typische cliënt voor een dilemma wordt gesteld tussen de benoeming van een vertrouwd advocatenkantoor en een fusie-specifiek gespecialiseerd kantoor (en vaker kiest voor het eerste), volgt uit de analyse dat de inbedding in sociale netwerken verbonden is met suboptimaal juridisch advies bij internationale F&A.

De resultaten van hoofdstuk 5 hebben een belangrijke implicatie voor de literatuur die de economische kosten en baten van de inbedding in sociale netwerken onderzoekt. Doordat wij laten zien dat het sociale kapitaal van een advocatenkantoor aan de ene kant voordelen hebben voor de acquisitie van nieuwe opdrachten, terwijl het aan de andere kant de selectie van gepaste juridische expertise verhindert, leveren wij vernieuwend statistisch bewijs voor de mogelijke tegenstelling tussen de individuele voordelen en de collectieve waarde van sociaal ingebedde samenwerkingsverbanden. Onze analyses hebben wellicht ook een praktische implicatie voor het management van grote business transacties, omdat onze resultaten aantonen dat de managers meer aandacht moeten geven aan het vinden van een geschikte juridische adviseur en dat zij de waarde van het sociaal kapitaal conservatiever zouden moeten inschatten.

Curriculum Vitae

Bastian Westbrock (1977) was born in Hamm, Germany, where he completed his state education at the Beisenkamp Gymnasium in 1996. Between 1998 and 2000, he studied Business Administration at the Technische Universität Bergakademie Freiberg and received his Bachelor degree in 2000. From 2000 to 2004, he pursued his studies at Mannheim University and graduated as a Master of Business Administration. During this time, he also worked as a junior researcher at the Center for European Economic Research (ZEW). In February 2005, he became a PhD student at the Utrecht University School of Economics (USE), where he completed this dissertation. As of October 2010, he will take up a new position as an assistant professor at the USE.