The Structure and Dynamics of the Global Network of Inter-Firm R&D Partnerships 1989–2002*

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Abstract

This paper examines the structure and dynamics of the global network of inter-firm research and development (R&D) partnerships using longitudinal data for 1989–2002. We contribute to a recent literature that has attributed patterns and changes in the network to major political and technological developments, but which has omitted the structure in the underlying firm population. Two often made claims are that R&D collaboration is important in nowadays fierce competitive environment, but that the importance of international partnerships has declined over time. We integrate data on firms and alliances and confront both hypotheses with our data and a novel set of methods, which enable to control for structure in the firm population.

Key words: Inter-firm collaboration, R&D partnerships, International technology transfer, Social network analysis

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1 Introduction

Networks of inter-firm research and development (R&D) partnerships have recently attracted great attention by researchers (Mytelka, 1991; Gulati, 1998; Nooteboom, 2004; Goyal, 2007) and policy makers (Caloghirou et al., 2004). A central objective of the Seventh Framework Programme of the European Commission, for example, is the development of a pan-european inter-firm R&D network. To give another example, the Worldbank has set up several projects to foster the development of a collaboration network between firms from the least developed countries and partners from the strong economies. A major motivation behind programs like these is the belief that inter-firm networks play an important role in international technological development and economic growth. First, there are beneficial effects of R&D cooperation itself. As compared to in-house projects, collaborative R&D enables firms to avoid the duplication of research investments and to exploit complementarities between technology stocks (see e.g. Hagedoorn et al., 2000).

However, on top of this, inter-firm networks can provide benefits that go beyond the effects of the relationships they consist of. At the heart of this idea is some empirical evidence suggesting that inter-firm networks are means by which knowledge and information are efficiently generated and widely diffused (Powell et al., 1996; Ahuja, 2000; Hagedoorn et al., 2006). Related studies point to various mechanisms through which networks facilitate know-how production and diffusion: first, technologies can be transmitted along chains of partnerships from firm to firm; second, knowledge that "leaks" out of a collaborative project can be assimilated by other firms; finally, firms may use the network to gather timely information about technological novelties and trends (Ahuja, 2000).

In the context of a globalized economy, these *network externalities* imply the possibility that a few international partnerships link distinct knowledge pools in different parts of the world. Also, inter-firm partnerships might be effective mechanisms for transferring technologies to the least developed regions. However, network externalities also raise important questions about the structure of the global network. Is the network sufficiently connected to enable the diffusion of technologies? Is there sufficient overlap between regional networks in different parts of the world? Moreover, considering the benefits of R&D collaboration for the regional economic and technological development: are collaborative activities sufficiently equally dispersed around the globe?

The current paper contributes to these questions. We empirically investigate major structural properties of the inter-firm R&D alliance network on a global scale and over the extensive time period 1989–2002. We describe patterns and trends of its *connectedness*, *concentration*, and *integration* using measures taken from the social network literature (Coleman, 1958; Wasserman & Faust, 1994). As compared to previous work on these questions, the distinctive feature of our study is that we isolate an important but so far omitted factor to explain the structure of the inter-firm network: the structure of the global firm population.

To the best of our knowledge, all previous studies have formed their view of the global collaborative activities in R&D based on observations of the distribution of inter-firm partnerships around the world, only (Duysters & Hagedoorn, 1996; Knoke et al., 2002; Hagedoorn, 2002). We argue that disregarding the firm population logically leads to a distorted picture. The reason is that many structural properties of the network, such as its geographical concentration or the extent of internationalization, are determined by the sizes of the national firm populations. For example, previous studies found consistently that the largest share of the worldwide number of R&D partnerships is between firms from the strong economies in North America, Western Europe, and East Asia (e.g., Freeman & Hagedoorn, 1994). This has led to a rather pessimistic conclusion about the future technological gap between developed and less developed countries. We argue, however, that it is natural to find more inter-firm partnerships within the developed countries, because these countries also host the largest share of the worldwide firm population. Similar, it has been found that companies from the United States form a lot of domestic partnerships as compared to other countries (Hagedoorn, 2002). This pattern is explained by the favorable antitrust treatment of R&D joint ventures in the United States. However, given the large size of the U.S. economy as compared to, for instance, a country like the Netherlands we would expect a large share of domestic partnerships in the United States, simply because the number of available domestic partners is much larger there than elsewhere.

One might argue that these considerations alone do not necessarily make our exercise indispensable, because the firm population is just one explanatory variable of the network structure among many others. However, as compared to other factors we think that 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 causes on the network structure, we apply measures of network connectedness, integration, and concentration that control for the different sizes of the national firm populations.

By doing this, the analysis in this paper confirms the robustness of some of the previous findings. First, we find an unclear time trend in the total number of collaborative activities over the 1990s, such as Hagedoorn (2002) and Hagedoorn & van Kranenburg (2003) have done before us. Second, we reconfirm the trend towards the formation of segregated clusters in the global network, as firms show a steadily declining interest in international partnerships (Duysters & Hagedoorn, 1996; Knoke et al., 2002). On the other hand, our analysis provides some important novel insights: first of all, the network is less concentrated than suggested by previous studies. The dominance of U.S. firms in the network is to a large extent explained by the pure size of the U.S. economy. Japanese firms are comparably active collaborators controlling for the smaller Japanese firm population. Moreover, we find hat the inter-firm R&D network is extremely sparse. Relating the number of partnerships to the number of

firms, we calculate that a typical firm is involved in a partnership about every forty years. Hence, an important insight from our analysis is a rather different view of the global inter-firm R&D network than the one put forward in previous research (Harrigan, 1988; Mytelka, 1991; Powell et al., 1996; Ahuja, 2000). Our finding of an extremely low connectedness raises some serious doubts about the importance of R&D collaboration for the firms themselves, but also about its role as a spurring force behind a globalized economy.

The remainder of the paper is organized as follows. Section 2 reviews the state-of-the-art of what is known about the questions we will raise. Section 3 introduces the measures of network analysis and Section 4 the two datasets on inter-firm partnerships and national firm populations. Most of the established literature on inter-firm R&D collaboration uses the MERIT-CATI database, which contains information on strategic alliances and joint ventures on a global and cross-industry scale. We retrieve our data from the alternative Thomson SDC Platinum database, instead. Our results are presented in Section 5. Section 6 concludes.

2 Previous empirical findings on the structure of the global inter-firm R&D network

Prior work has investigated trends and patterns in the distribution of inter-firm R&D partnerships around the globe (Duysters & Hagedoorn, 1996; Knoke et al., 2002; Hagedoorn, 2002; Moskalev & Swensen, 2007). These studies have attributed regional differences and temporal changes in the formation of new partnerships to important economic, political, and technological developments. Freeman & 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 in the 1970s as two important factors for the rise of global collaborative activity. On the political side, supranational efforts towards an integration of the world economy, such as the Uruguay Round in 1986–1994, 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 the current paper, we review their questions and findings here.

An often studied figure is the long-term trend in the number of newly formed R&D partnerships (Harrigan, 1988; Hagedoorn, 1996, 2002; Knoke et al., 2002). The interest roots in the question of whether or not collaboration is an important component of a firm's R&D strategy. Moreover, the figure is important, because the firms' propensities to collaborate also determines the connectedness of the global alliance network. Previous studies have built on the hypothesis 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 over time. Hence, we investigate in line with this research:

Research question 1 (Network connectedness over time) *Does the connectedness of the global network of inter-firm R&D partnerships increase over the period 1989–2002?*

Furthermore, because our study combines data on alliances with data on firm populations, we are able to investigate the level of connectedness in the global alliance network.

Research question 2 (Network connectedness) *Is the global network of inter-firm R&D partnerships a dense network?*

Prior studies have found consistently that the number of newly formed partnerships increased steadily over the 1960s and 70s until the mid 1980s. Therefore, they conclude that R&D collaboration has become an essential part of a firm's strategy. On the other hand, for the period 1990–1998, which is also the period studied in this paper, Hagedoorn & van Kranenburg (2003) did not find any such clear trend, but rather show that the time line of newly formed R&D partnerships resembles a random walk process. An explanation comes from Gomes-Casseres (1988), who argues that an autoregressive process in the formation of alliances can be explained by bandwagon effects. To succeed in the competition for scarce resources and to maintain a legitimate position in the market, a company is expected to adopt best practices of other, successful firms. Other research links the cyclical trend in alliance formation to the parallel merger wave of the 1990s (Desai et al., 2004).

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

Research question 3 (Network concentration) *Are there regional differences in the connectedness of the global network of R&D partnerships over the period 1989–2002?*

Freeman & Hagedoorn (1994) have found that firms from the strong economies in the triad North America, Western Europe, and East Asia were involved in the vast majority of partnerships. The authors conclude that the less developed economies lack the necessary technological and organizational capabilities for the complex tasks of R&D partnering. Hagedoorn (2002) has observed the pattern as well, but explained it by the fact that most R&D intensive sectors, such as the biotech industry or the information technology industry, are concentrated in the triad countries. It is well known, however, that in particular firms from these industry sectors are very active collaborators (Mytelka, 1991).

Another important and frequently studied feature of collaborative activity is its extent of internationalization (Duysters & Hagedoorn, 1996; Hagedoorn, 2002). International R&D partnerships are important, because they enable the exploitation of complementarities of distinct national knowledge stocks and can be effective means to transfer technologies to the least developed parts of the world. In the literature, there are two opposing hypotheses concerning the trend of international R&D collaboration over time. The still ongoing supranational efforts towards a liberalization of foreign ownership as well as progressing international division

of labor have split formerly integrated production processes into separate pieces scattered around the world. This suggests, on the on hand, that also international collaboration becomes more important (Duysters & 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 substitutes obsolete, firms could replace alliances by direct investments abroad. Hence, rather than increasing the importance of international alliances, the authors expected the opposite effect:

Research question 4 (Network integration over time) *Does the global network of R&D partnerships become more or less integrated over the period 1989–2002?*

According to Hagedoorn (2002), the share of international partnerships has been steadily declining over the period 1980–1998. Moreover, he observed a strongly declining trend for the United States. Knoke et al. (2002) made a similar observation for the information technology sector of the 1990s, where in particular Japanese semiconductor firms reduced their international partnerships. This supports the view of Desai et al. (2004) and suggests that, indeed, international alliances have been replaced by cross-border mergers and foreign direct investments. On the other hand, Hagedoorn (2002) has provided an alternative explanation, which is closely related to the argument developed in this paper. He argued that the share of international R&D partnerships declined in the U.S, not so much because of the changes in the international environment, but rather because of the domestic developments. The 1980s and 1990s have witnessed a strong growth in the U.S. biotech and information technology industries, aligned with the start-up of many new businesses. Hence, it was not so much the dislike for foreign partners, but rather the availability of interesting local partners that explains the diminishing importance of international alliances in the United States.

The previous findings have led authors, like Hagedoorn (2002) and Freeman & Hagedoorn (1994), to the question about regional differences in internationalization. In particular, the concern was that U.S. and Japanese firms segregated 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 developing countries, it is important to know whether these countries are at least connected to the network between the triad North America, Western Europe, and East Asia:

Research question 5 (Regional differences in network integration) *Are there regional differences in the integration of the global network of R&D partnerships over the period 1989–2002?*

Hagedoorn (2002) has investigated the differences in internationalization with the triad, and Freeman & Hagedoorn (1994) examined the link between the triad countries and the less

developed economies. Their findings confirmed the low degree of internationalization for U.S. firms, but not for Japanese firms. Moreover, they found that almost all partnerships involving firms from the less developed countries had a partner from the triad on board.

In the following sections, we reinvestigate the questions stated above using a novel set of measures and novel data. We complement data on inter-firm alliances by data on the populations of firms around the world, and examine the resulting dataset 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: the structure of the global firm population.

3 Methodology

Here, we present the three measures of network connectedness, concentration, and integration which will be applied in this study, and compare them with the measures that have been used previously to examine inter-firm collaboration.

In order to investigate the overall importance of collaborative R&D and its trends (Research questions 1 and 2), previous studies have counted the numbers of newly formed R&D partnerships per year (e.g., Hagedoorn, 1995, 2002). However, the 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 as 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 be led 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 control for the number of active firms in a given year. Such a measure is the *average degree* (Wasserman & Faust, 1994). For a formal exposition of the average degree, denote the degree of firm i in year t by η_i^t, which is a measure of 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 is defined by:

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

To address the question about concentration of collaborative activities in certain countries or regions (Research question 3), previous studies have calculated and compared the number of partnerships per country and region, respectively (Freeman & Hagedoorn, 1994; Duysters & Hagedoorn, 1996). Similar to the shortcoming of the previous measure of network connectedness, 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.

We, therefore, use the *regional average degree* as a measure of country-specific propensities and constraints to collaboration in this study. Formally, denote the set of firms in country k and year t by N_k^t. The regional average degree is defined by:

$$\overline{\eta}_k^t = \frac{1}{n_k^t} \sum_{i \in N_k^t} \eta_i^t. \tag{2}$$

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

Furthermore, in order to trace patterns and trends in the openness towards foreign partners, Freeman & Hagedoorn (1994) and Hagedoorn (2002) have calculated the shares of international alliances in the total number of newly formed partnerships (Research questions 4 and 5). As already outlined in the work by Blau (1977) and more recently by Currarini et al. (2008), a problem with this measure is that the share of international alliances in a country is significantly determined by the number of firms in that country. To illustrate their argument, say we observe that the firms from a certain country form relatively many domestic as compared to international partnerships. There might be two possible explanations for this pattern:

1. The firm 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 we are interested in the first effect, the negligence of the second will likely lead us to a wrong conclusion about the role of preferences.

Thus, 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).[1] Formally, denote the share of domestic partnerships in the number of newly

[1]The measure (3) is a variant of Coleman's original measure, because in his paper 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. Our motivation for this deviation from the original definition is to apply a homophily measure in this study that is closely

formed partnerships in country k and year t by s_k^t. We define the inbreeding homophily index of country k as:

$$H_k^t = \frac{s_k^t - n_k^t/n^t}{1 - n_k^t/n^t}. \tag{3}$$

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 the fraction n_k^t/n^t be the relative size of the regional firm population.

Because firms from larger countries have more opportunities of finding interesting domestic partners, measure (3) is decreasing in the relative size of a country, n_k^t/n^t. According to measure (3), a country does not exhibit a preference-based tendency towards domestic partners, if the observed share of domestic partnerships equals the relative country size, $s_k^t = n_k^t/n^t$. This case is called baseline homophily. The observed share of domestic partnerships is then merely due to opportunities. On the other hand, there is a maximal tendency to form domestic partnerships in a country, if we observe that $s_k^t = 1$. In this case, the homophily index (3) prescribes the same preference-based homophily as the uncorrected share of domestic alliances does. Finally, a country is said to be heterophile, if the share of domestic partnerships is smaller than the relative country size.

4 Data

Our analysis demands quite a comprehensive dataset. Since we aim at a complete picture about the worldwide network of inter-firm collaboration, we need a sample of firms which is representative for the global firm population. An adequate dataset has to contain the numbers of firms per country for a series of consecutive years. Moreover, we need 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. What follows is a detailed description of the data sources underlying our study and the sample selection procedure.

Our study combines data from two sources which satisfy the requirements from above. The first source 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. The first recorded joint ventures date back to the early 1960s. Next to the above mentioned partnership characteristics the database contains variables on the partnership purpose, the mode

related to Hagedoorn's (2002) measure of internationalization, apart from the fact that ours controls for sizes of firm populations. In fact, the term s_k^t in the nominator of (3) corresponds to an uncorrected measure of homophily, which is directly related to Hagedoorn's share of international alliances, i_k^t, by $s_k^t = 1 - i_k^t$.

of governance (contract versus ownership), alliance activity descriptions, the participants' industry affiliations, and their public status.[2]

As compared to alternative data sources on R&D partnerships, the advantage of the Thomson SDC data is its global and cross-industry scope.[3] A limitation lies in the method of data collection. The occurrence of a partnership in the database depends on the self-interest of firms and news services to make the announcement of a joint venture public. 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 select only alliances and joint ventures between *public companies*, hence where all participants are listed on at least one stock market around the globe. Since the activities of public companies are of interest to financial investors and the general public, we suspect that also their partnerships are likely to appear more consistently in the business news than the alliances of privately owned firms. As a weak indication for this, 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.

Our second data source complements the partnership 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 at the national stock markets.[4]

The strength of the WDI data is that it covers a large set of countries and an extensive period of time including the late 1980s and the 1990s, where the numbers of R&D partnerships have reached its peak (Hagedoorn, 2002).[5] A major drawback is that it does not contain a split of the numbers of public companies by industries. This can be problematic, because for an analysis of the connectedness of the worldwide network, for example, one would want to sort out those companies from the network, where ex-ante considerations exclude the possibility of R&D partnerships. One might think of 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 joint research project or be considered as an alliance partner. However, as is explained below, we apply a very broad definition of an R&D partnership in this study, which also includes agreements involving a mere licensing of technologies and, as is shown in Table 1, the financial sector is involved in quite a lot of these agreements.

In order to obtain a complete picture of all R&D partnerships between the public compa-

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

[3]Alternative datasets on inter-firm R&D partnerships, which were previously investigated in the literature, are the databases from MERIT-CATI, CORE, NCRA-RJV, Recombinant Capital, and Bioscan. See Hagedoorn et al. (2000) for a more detailed overview.

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

[5]Alternative data sources on firms populations around the globe are the Worldscope company profile database as well as the United Nations UNIDO database that records the worldwide population of business establishments.

Industry sector	Count of alliance participations	% of total
Agricultural, forestry, fishing	1	0
Mining and construction	105	1
Manufacturing	6 853	69
Transportation, communications, electric services	353	4
Wholesale and retail trade	241	2
Finance, insurance, real estate	149	1
Personal and business services	2 272	23
Public Administration	1	0
	9 976	100

Table 1: Industry affiliation of alliance participants in the sample of R&D partnerships.

nies 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 results in the period 1989–2002 and a population of firms from 52 countries situated in different parts of the world. The countries under study comprise 27 countries 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 5 in the Appendix. Based on this selection, we choose those partnerships from the SDC Platinum data, which are between firms from the 52 countries and fall into the period 1989–2002. Moreover, we single out partnerships from the SDC Platinum database, where the purpose is either joint R&D or technology licensing. In this way, we apply the same broad definition of an R&D partnership, which has already been used in most of the prior studies and also includes technology licensing and exchange agreements (e.g., Freeman & Hagedoorn, 1994; Duysters & Hagedoorn, 1996; Hagedoorn, 2002). Finally, we single out bilateral agreements, because we suspect that the decision processes by which groups of firms establish multilateral alliances are of a rather different nature. By doing this, we keep a total of 4 988 R&D partnerships between, on average over time, 31 671 public companies. The numbers of partnerships per year and country are summarized in Table 6 in the Appendix and the industry affiliations of the involved companies are presented in Table 1.

5 Results

Figure 1 illustrates the network generated from our sample. The figure shows the aggregated network consisting of all partnerships formed within 1989–2002 and all those public companies that were at least once actively participating in an alliance.

In the following, we reproduce the gradual construction of this network, investigating

trends in the speed of construction and analyzing how the international ties in Figure 1 are related to the numbers of firms in the different regions.

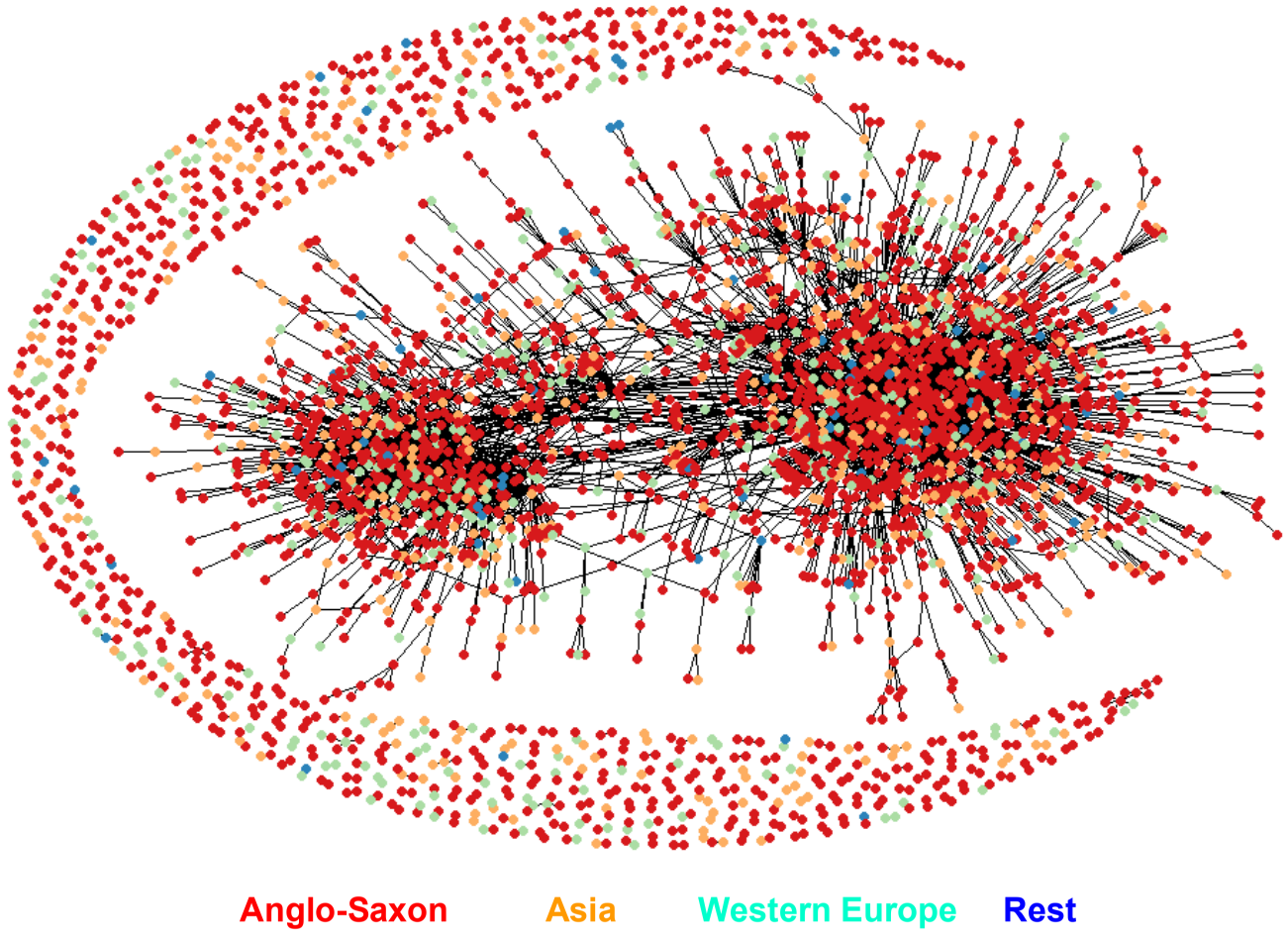


Figure 1: Global network of R&D partnerships, accumulated over the period 1989–2002.

NOTE.The figure shows the network of R&D partnerships between a sample 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, where the regions comprise the following countries: 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.

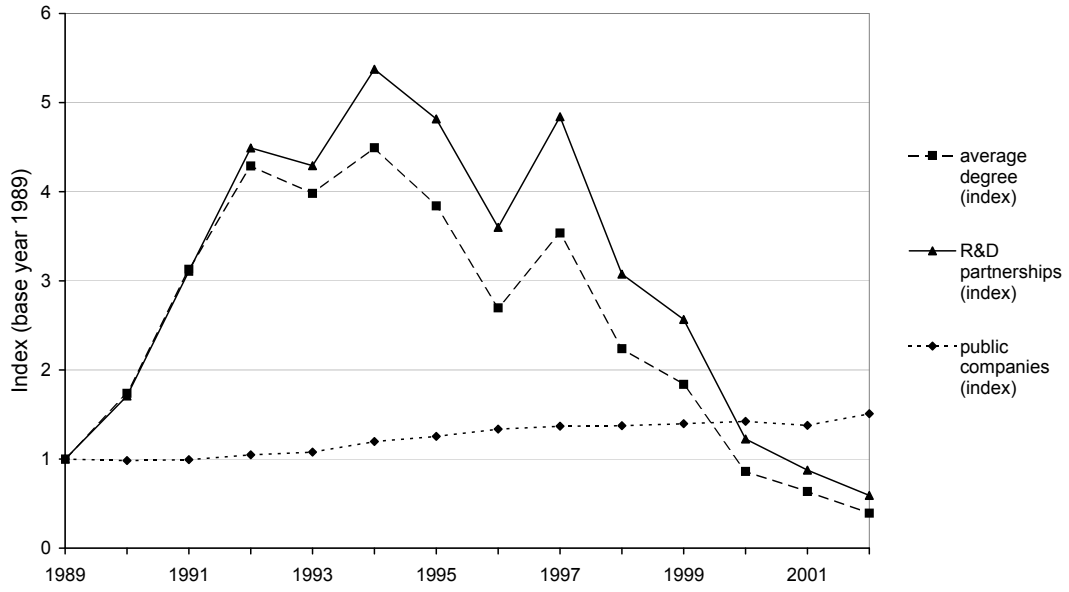
5.1 Network connectedness

Here, we investigate how the rate at which new partnerships have been added to the network of Figure 1 changed over time (Research question 1). Moreover, we make an observation about the level of connectedness in the network (Research question 2). In order to isolate the influence of the structure of the worldwide firm population on the structure of the network, we examine both connectedness measures, the average degree as well as the previously used number of newly formed R&D partnerships. In this way, we are able to check the robustness of prior findings with respect to an important, but so far omitted, determinant of the network structure. Figure 2 summarizes the results of our analysis.

The figure shows the time lines of the average degree and the number of newly formed alliances using an index representation. Until 1994, the number of new partnerships rose sharply to a value five times larger than in 1989, but declined thereafter even below the original value. Similar, also the average degree was in 1994 more than four times larger than in 1989 and even thirteen times larger than in 2002. Hence, both measures confirm the somewhat unclear pattern in the worldwide collaborative R&D activities, which has already been found by Hagedoorn (2002) and Hagedoorn & van Kranenburg (2003). However, our analysis suggests that the previously found "alliance cycle" of the 1990s was to some extent an artifact of the growth of the worldwide firm population. This is indicated by the gap between the two indices. The gap appears in the mid 1990s and indicates the share of newly formed partnerships that is not explained by changes in the number of partnerships per firm, and hence the popularity of R&D collaboration. Instead, as is illustrated by the third index in the figure, this share is solely due to a growth in the worldwide population of public companies, which increased throughout the 1990s driven mainly by rapid growths in the United States and India.

Moreover, the small table in Figure 2 provides an important insight concerning the overall level to which firms were connected in the global alliance network. As becomes clear from the table, the number of newly formed partnerships per firm was extremely low throughout the whole period 1989–2002. In fact, averaged over time, the average degree was just 0.023, which means that the typical public company in our sample formed an R&D partnership about every forty years. On the other hand, as the literature on joint venture termination suggests, the average lifespan of such a partnership amounts to no more than just seven years (Kogut, 1989; Park & Russo, 1996). Hence, we are left to conclude that in the alliance network of the 1990s the typical public company was not involved in any ongoing R&D partnership at all.

Because there seems to be a contradiction between this observation and prior findings from the literature, let us briefly discuss their relation 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 & Schakenraad, 1992; Duysters & Vanhaverbeke, 1996; Powell et al., 2005). How can our observation be reconciled with these



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Average degree	.009	.016	.029	.040	.037	.042	.036	.025	.033	.021	.017	.008	.006	.004

Figure 2: Number of newly formed R&D partnerships and average degree over time.

Year	Number of public companies	Number of collaborating firms	Examples of top collaborators
1989	25 575	160	Sun Microsystems (12), Novell (9), Hitachi (7), Samsung (7)
1990	25 148	288	IBM (11), Novell (6), AT&T (5), Drexler (5)
1991	25 403	447	IBM (19), Hewlett Packard (14), SGI (11), Texas Instruments (11)
1992	26 786	579	IBM (31), Texas Instruments (21), Hewlett Packard (18), Apple (17)
1993	27 572	580	IBM (31), Novell (20), Microsoft (17), Apple (16), Intel (13)
1994	30 593	751	IBM (27), Microsoft (25), Hewlett Packard (20), Novell (13), Oracle (13)
1995	32 072	689	IBM (26), Microsoft (22), Hewlett Packard (19), AT&T (14), NEC (14)
1996	34 151	557	Microsoft (29), Netscape (19), IBM (16), Oracle (11)
1997	35 008	745	Microsoft (29), IBM (20), Hewlett Packard (20), Intel (13), Netscape (13)
1998	35 143	527	Microsoft (14), Sun (10), GlaxoSmithKline (9), IBM (8)
1999	35 723	463	IBM (6), GlaxoSmithKline (6), Microsoft (6), Eli Lilly (5)
2000	36 399	247	Microsoft (5), NEC (5), Sharp (5), Mitsubishi Electric (4)
2001	35 237	181	Samsung (7), Millennium Pharma (5), Matsushita Electric (4)
2002	38 583	121	Roche (4), GlaxoSmithKline (3), Samsung Electronics (3)

Table 2: Firms and collaborators in the global network of R&D partnerships.

findings? To investigate the issue, we take a closer look at the distribution of newly formed partnerships across the public companies in our dataset. Table 2 summarizes the findings.

As the table shows, during the period 1989–2002 all R&D partnerships were concentrated around a small fraction of the total population of public companies. In 1989, for example, the number of firms that announced an R&D partnership was just 160. This number rose to 751 in 1994. However, as compared to the total number of companies both were very small numbers. In fact, in a typical year, a share of only 1% of the total firm population announced any collaborative agreement at all. On the other hand, the table shows that there were a handful of firms who formed a considerable number of partnerships every year. Hence, a way to reconcile our observation of a low average degree with the findings of the previous literature is to recognize that the global network of R&D partnerships was very centralized: while the vast amount of collaborative activity was due to a small group of companies from the high-tech sectors, there is a large, but previously overlooked, mass of firms that was not involved in even a single alliance.

5.2 Network concentration

In the previous section, we have seen that most R&D partnerships are formed between a small group of companies throughout the period 1989–2002. Here, we investigate whether the concentration of collaborative activity is also reflected on the level of countries and world regions (Research question 3). Given the important role that the network of inter-firm collaboration might have for 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 collaborative activity is highly concentrated in

	Number of R&D partnerships	share of total in %	Regional average degree
Regions			
Anglo-Saxon countries	331	71	0.044
East Asia	91	19	0.028
Western Europe	40	8	0.011
Developing countries	5	1	0.001
Countries			
United States	312	61	0.066
Japan	81	16	0.041
United Kingdom	25	5	0.014
Canada	22	4	0.019
Germany	14	3	0.025
South Korea	9	2	0.012
France	9	2	0.016
Australia	6	1	0.005
Rest of the world	30	6	0.002

Table 3: Distribution of R&D partnerships and regional average degrees in 1989–2002.

NOTE. The table reports the time-averages of the number of newly formed R&D partnerships per region and the regional average degrees. The regions in the upper part of the table comprise the following countries: 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.

the world's strongest economic regions, the Anglo-Saxon countries, Western Europe, and East Asia (Freeman & Hagedoorn, 1994; Duysters & Hagedoorn, 1996; Hagedoorn, 2002; Knoke et al., 2002). Our findings summarized in Table 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 R&D partnerships initiated between 1989 and 2002 had a company from the triad Anglo-Saxon countries, Western Europe, and East Asia on board. Also, the average degree of Western European firms, as the least active region in the triad, was still more than ten times larger than the average degree in the developing countries.

However, our analysis provides a rather different picture from the one proposed by previous research concerning the concentration of collaborative activity within the triad. Hagedoorn (2002) finds that most R&D partnerships formed during the 1990s involve an Anglo-Saxon company, and that in particular U.S. firms played a dominant role in both the Anglo-Saxon part of the network as well the global alliance network as a whole. As the upper part of Table 3 shows, this pattern is also reflected in our dataset. 71% of all newly formed R&D partnerships between the public companies in our sample involved an Anglo-Saxon company. Moreover, as is indicated in the lower part, in particular U.S. companies were with a share of 61% of all newly formed partnerships responsible for much of the collaborative activities in the period 1989–2002.

However, unlike the distribution of partnerships within the triad might suggest, the typical U.S. firm was not a much more active collaborator than any other firm from this region. Consider, for example, the case of Japan. Comparing the numbers in columns one and three of Table 3 for Japan and the United States, it becomes clear that Japanese companies were much closer to U.S. firms in terms of their collaborative activity, when comparing average degrees instead of numbers of partnerships. With an average degree of 0.066 in the United States and 0.041 in Japan, the typical U.S. firm had only about 1.5 times as many alliances as a typical Japanese firm. Hence, the huge difference in the numbers of partnerships between the United States and Japan was only to a small extent determined by different activity levels of U.S. and Japanese companies. Instead, the most important factor is that Japan had with, on average over time, only 2 330 public companies a relatively small firm population as compared to the 7 310 companies in the United States. Repeating the same exercise for the United States and any other country from the triad region, one can see that much of the seeming dominance of U.S. companies in the global alliance network is explained by the sheer size of the U.S. economy.

5.3 Network integration

We now turn to Research questions 4 and 5 concerning the extent to which the global network of R&D partnerships connected firms from different countries and regions in the period 1989–2002. As suggested by prior research, a globally integrated network is desirable, because complementarities between distinct national knowledge stocks can be exploited and technologies can efficiently be diffused around the globe (Pearce, 1989; Freeman & Hagedoorn, 1994).

Hagedoorn (2002) has come to a rather pessimistic conclusion about the worldwide trends in the integration of the network over the 1980s and 1990s. Even though he 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, he also observed a steadily declining trend. Hence, the network seemed to fall apart into more nationally segregated clusters, because firms chose increasingly more often domestic instead of foreign alliance partners. However, as we argue in this paper, 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 controls for opportunities is the homophily index (3). Figure 3 plots the worldwide average homophily over the period 1989–2002 and indicates the trend in homophily for the United States, the triad countries as well as the less developed countries. As can be seen from the development of the worldwide average, there was a slight but clear trend towards the formation of homophile clusters in the network. In fact, our findings suggest that the network was rather international in 1989, with an average homophily that did not reflect any preference towards or against international partnerships (baseline homophily). However,

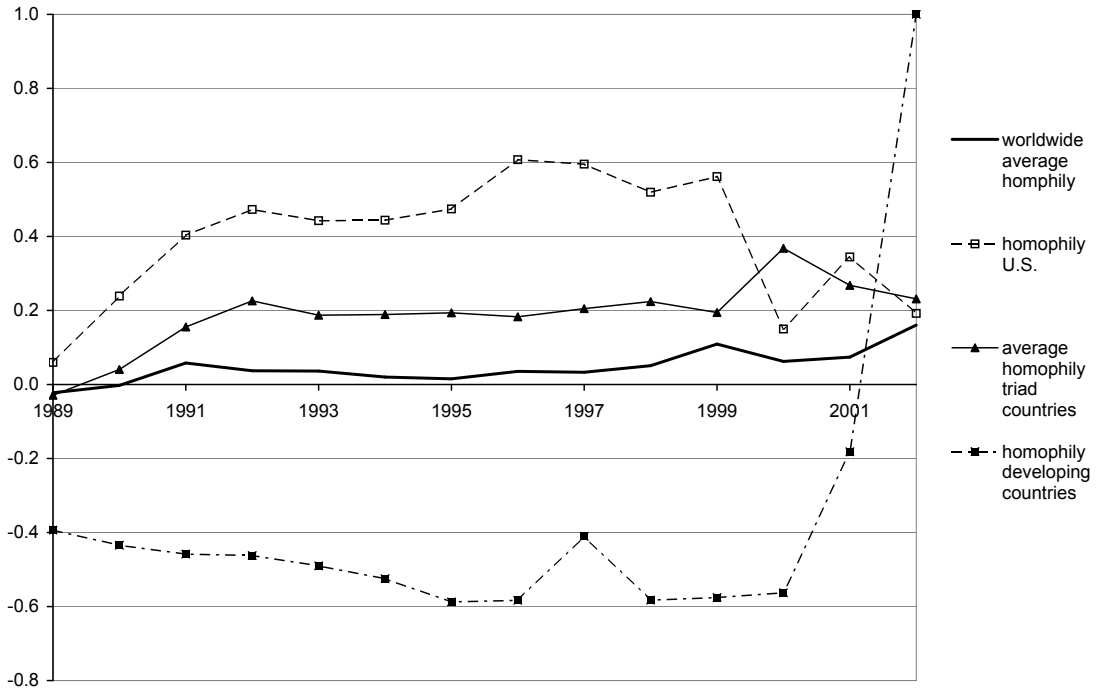


Figure 3: Regional and worldwide average homophily over time.

the upwards trend shows that international alliances became less popular over time, with a worldwide average homophily of 0.18 at the end of the year 2002. This suggests that Hagedoorn's (2002) conclusions about the role of international partnerships are robust with respect to controlling for opportunities.

In the following, we investigate national and regional differences in homophily. In his study, Hagedoorn (2002) has observed major differences in homophily within the triad North America, East Asia, and Western Europe. While foreign alliance partners were rather welcome in most of the triad countries, U.S. companies tended to form a lot of domestic alliances. In another study, Freeman & Hagedoorn (1994) has found that almost all R&D partnerships in the developing countries involved also a partner from one of the triad regions. Our results, which are summarized in Table 4, confirm the finding for the developing countries, but shed new light on homophily in the United States.

The first two columns of Table 4 report the share of domestic partnerships, as the previously used homophily measure, as well as our homophily index (3), respectively. Since these measures are hardly comparable, the third column presents a measure which is based on the homophily index of column two, but which is directly comparable with the shares of domestic alliances of column one. Because the measure in column three controls for the size of a national firm population and, therefore, the opportunities for domestic partnerships, it reflects

	Share of domestic/ intra-regional R&D partnerships in %	Homophily index	Hypothetical share of domestic/intra-regional partnerships in %
Regions			
Anglo-Saxon countries	65	0.54	66
East Asia	17	0.05	29
Western Europe	11	-0.02	23
Developing countries	10	-0.37	0
Countries			
United States	53	0.39	40
Japan	16	0.09	11
United Kingdom	8	0.02	4
Canada	7	0.03	5
Germany	7	0.05	7
France	5	0.03	5
Australia	5	0.09	11
South Korea	4	0.02	4
Rest of the world	5	0.03	5

Table 4: Regional differences in the share of domestic R&D partnerships and homophily in 1989–2002.

NOTE. The table reports the time-averages of the share of intra-regional partnerships, the homophily index, and the hypothetical share of intra-regional partnerships. In the upper part of the table, the measures are calculated on the level of world regions, whereas the lower part shows the same measures on the country level. The hypothetical share of domestic/intra-regional partnerships is calculated on base of the rewritten homophily index (3), $s_k^t = (1 - n_k^t/n^t)H_k^t + n_k^t/n^t$. In order to determine s_k^t, we use H_k^t from column two of the table and specify the numbers of firms to be the same across all countries/regions, hence $n_k^t/n^t = 1/52$ for the country-level hypothetical shares and $n_k^t/n^t = 1/4$ for the regional-level hypothetical shares.

the share of domestic alliances that is due to preference-based homophily, only.

All three measures in the table present the same picture that the firms from developing countries, despite their overall low level of collaborative activity, had a strong preference for partnerships with firms from the triad Anglo-Saxon countries, East Asia, and Western Europe. In particular, the index value of -0.37 indicates a clear heterophily in this region. Moreover, the downwards trend in the region's homophily index suggests that the propensity to form interregional partnerships had even slightly increased in the developing countries (see Figure 3). Only in the final two years of our sample, the developing countries suddenly show a very homophile pattern. We should remark, however, that alliance activity in the developing countries was very low in 2001 and 2002, such that the homophily index is calculated on base of only four and one alliances, respectively.

Concerning homophily in the United States, the share of 53% domestic partnerships in the first column of Table 4 supports the observation by Hagedoorn (2002) that U.S. firms, unlike the firms from most other nations, tended to form quite a lot of domestic partnerships. 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 U.S. 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 0.39, a comparison between the first and the third column suggests that a considerable 13 percentage points of the share of domestic partnerships in column one is merely due to opportunities. The reason is that the United States offered with, on average over the 1990s, 7 310 public companies many more potential alliance partners than any other nation. Moreover, also the latest trends in our data put the importance of international alliances for U.S. firms in a rather optimistic light (see Figure 3). Although U.S. companies tended to segregate themselves from the rest of the international network throughout most of the 1990s, the homophily index indicates a clear turnaround in 1999, when U.S. firms became again more open towards foreign alliance partners.

Hence, even though our analysis confirms the finding of previous studies that U.S. firms tended to form a segregated national cluster throughout most of the 1990s, we also find that the size of the U.S. firm population conceals the country's true level of internationalization to some extent.

6 Conclusions

This paper studies the structure and dynamics of the global network of inter-firm R&D partnerships over the period 1989–2002. While we focus 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 underlying population of firms. The step is necessary, because the structure of the firm population produces a

natural inequality in the network which is, unlike other political and technological barriers or stimuli to collaboration, merely based on logical opportunities for partnerships.

In order to isolate the effects of structure in the firm population, we complement data on strategic alliances and joint ventures by data on the global population of public companies. Moreover, we apply methods of social network analysis that allow to control for regional and temporal patterns in the firm population. It turns out that many of the findings of prior studies on inter-firm collaboration are robust with respect to our analysis. The most important among these are the previously found "alliance cycle" of the 1990s (Hagedoorn, 2002; Hagedoorn & van Kranenburg, 2003); the concentration of collaborative activity in the triad Anglo-Saxon countries, Western Europe, and East Asia (Freeman & Hagedoorn, 1994); and the trend towards a formation of segregated national clusters in the 1990s, which has been found to be particularly distinct in the United States (Duysters & Hagedoorn, 1996; Hagedoorn, 2002). On the other hand, our analysis also produces a series of novel insights:

1. The global network of R&D partnerships was extremely sparse. Our analysis of the average degree in the network implies that the typical company was involved in a partnership about every forty years. Moreover, investigating the distribution of partnerships across firms, the share of firms that announced a collaborative agreement amounts to no more than 1% of the global firm population.

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

3. The size of the U.S. economy conceals the importance of international partnerships for U.S. firms to some extent. A significant portion of the large number of inter-firm partnerships within the United States can be explained by the fact that, as compared to other nations, there were so many U.S. firms and, therefore, many opportunities for domestic alliances.

It is obvious that in particular our first observation implies a rather different picture of worldwide collaborative activities in R&D than the one suggested by previous research on this topic. Although there might be some arguments that our data are not the ideal option to study the overall connectedness of the global alliance network, the extremely low average degree raises some serious doubts about the conclusions of at least two streams in the literature.

First, there is the often made claim that R&D joint ventures and technology licensing were widely used strategies in the fierce competitive environment of the 1980s and the 1990s

(e.g., Harrigan, 1988; Mytelka, 1991; Kleinknecht & Reijnen, 1992; Nooteboom, 1999). Our findings clearly disagree with this assertion. Instead, they rather support a view according to which R&D collaboration is some kind of "elite sports" exercised by the world's largest firms from the high-tech industries, whereas the vast majority of firms is never engaged in any collaborative activity at all.

Second, our finding of an extremely low average degree has some drastic implications for a literature investigating the role of inter-firm alliance networks in the diffusion of knowledge (Powell et al., 1996; Ahuja, 2000; Hagedoorn et al., 2006). The results of our analysis imply that the typical firm is not connected to any other firm in the alliance network throughout 1989–2002. Thus, even if prior research is correct and knowledge spills along chains of alliances in a network, our findings suggest that the global inter-firm network was simply too sparse to assimilate these spillovers. This grim view of the network is reinforced by the observation that the 1990s witnessed a worldwide trend towards the formation of more segregated national clusters in the network, which further inhibited the important international knowledge flows.

To put this rather pessimistic perspective into perspective, let us point out that the collaborative agreements investigated in this study are by far not the only possible channel for inter-firm knowledge spillovers. In fact, a problem of 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 for this study, where we expect that the Thomson SDC data provide a rather complete picture of the network between these firms, the firms in our data might still have 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.

Moreover, let us point to the fact that there are other potential spillover channels different from collaborative agreements between 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 but the reflection of this process of substitution. At the same time, there would be no reason to worry about the erosion of international knowledge spillovers. As another possible extension to our work, we therefore propose to investigate the network between firms taking also into account other inter-firm relationships such as mergers and acquisitions. A recent study in this spirit is M'Chirgui (2007).

Finally, in addition to the international pattern studied in this paper, other valuable

extensions are the examination of sectoral patterns in the network and a more detailed analysis of the high concentration of collaborative activity around just a few firms. As suggested by prior research (e.g., Gulati & Gargiulo, 1999), much of the visible clustering in the network of Figure 1 could be explained by the affiliation of firms to different industry sectors. Moreover, various academic fields have put forward theories to explain the phenomenon that social networks are often characterized by a high inequality among the actors in terms of their centrality in the network.

Appendix

Table 5: 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 countries	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	1022	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
Western 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
Developing countries	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 table shows a representative panel of the worldwide population of public companies in the period 1989–2002. The numbers in the cells are retrieved from the World Development Indicators (WDI) 2003 and represent the complete population of domestic public companies for a given country and year.

Table 6: Bilateral R&D Partnerships between Public Companies

Country	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Australia	0 (0)	2 (2)	2 (2)	7 (7)	5 (5)	6 (5)	6 (6)	2 (2)	15 (14)	6 (4)	6 (3)	7 (6)	11 (9)	5 (4)
Canada	2 (2)	9 (9)	11 (11)	17 (16)	28 (26)	43 (39)	41 (36)	33 (30)	41 (36)	32 (28)	24 (21)	13 (12)	10 (9)	5 (5)
Israel	0 (0)	1 (1)	2 (1)	2 (2)	2 (1)	4 (4)	4 (4)	0 (0)	9 (9)	6 (5)	3 (3)	1 (1)	2 (2)	2 (2)
New Zealand	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (1)	2 (2)	0 (0)	0 (0)	0 (0)	0 (0)
United Kingdom	9 (9)	11 (11)	26 (25)	32 (28)	29 (28)	40 (36)	41 (38)	33 (29)	36 (31)	36 (33)	28 (24)	15 (12)	6 (6)	13 (12)
United States	114 (79)	187 (105)	324 (142)	463 (183)	455 (187)	567 (236)	520 (208)	400 (118)	539 (163)	326 (119)	273 (94)	86 (58)	67 (36)	45 (31)
Anglo-Saxon countries	116 (72)	193 (94)	342 (135)	484 (162)	474 (156)	602 (204)	549 (166)	424 (91)	566 (104)	352 (79)	296 (69)	99 (43)	80 (30)	55 (24)
Finland	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	3 (3)	2 (2)	2 (2)	0 (0)	3 (3)	0 (0)	2 (2)	1 (1)	1 (1)
France	5 (5)	9 (7)	12 (11)	17 (13)	9 (9)	13 (11)	15 (15)	6 (6)	12 (12)	7 (7)	6 (6)	3 (3)	5 (5)	5 (5)
Germany	7 (7)	9 (9)	16 (15)	17 (15)	22 (19)	16 (16)	27 (26)	14 (14)	17 (17)	14 (14)	10 (9)	11 (6)	10 (9)	5 (5)
Italy	1 (1)	1 (1)	2 (2)	7 (7)	2 (2)	4 (4)	5 (5)	1 (1)	3 (3)	3 (3)	0 (0)	1 (1)	2 (2)	0 (0)
Netherlands	2 (2)	5 (5)	4 (3)	11 (11)	7 (7)	8 (8)	5 (5)	1 (1)	4 (4)	0 (0)	1 (1)	2 (2)	2 (2)	2 (1)
Sweden	1 (1)	1 (1)	2 (2)	10 (10)	3 (3)	5 (5)	5 (4)	4 (4)	0 (0)	3 (3)	3 (3)	0 (0)	4 (3)	0 (0)
Switzerland	1 (1)	6 (6)	7 (7)	6 (6)	8 (8)	4 (4)	5 (5)	1 (1)	3 (3)	7 (7)	1 (0)	3 (3)	3 (2)	8 (8)
Others	0 (0)	2 (2)	2 (2)	6 (6)	6 (6)	5 (5)	7 (7)	5 (5)	11 (11)	7 (6)	4 (4)	3 (3)	1 (1)	1 (1)
Western Europe	17 (17)	33 (31)	42 (36)	68 (56)	56 (51)	53 (46)	69 (65)	34 (34)	47 (44)	41 (37)	25 (23)	22 (14)	26 (21)	21 (19)
Hong Kong	0 (0)	1 (1)	1 (1)	0 (0)	1 (1)	0 (0)	1 (1)	0 (0)	1 (1)	3 (3)	3 (3)	2 (2)	0 (0)	0 (0)
Japan	49 (48)	73 (73)	126 (110)	150 (123)	140 (117)	172 (152)	106 (94)	55 (51)	58 (56)	45 (41)	48 (44)	65 (34)	25 (16)	19 (12)
Singapore	0 (0)	0 (0)	0 (0)	1 (1)	4 (4)	9 (9)	4 (4)	3 (2)	1 (1)	0 (0)	1 (1)	1 (1)	0 (0)	0 (0)
South Korea	13 (13)	7 (7)	4 (4)	11 (11)	5 (5)	16 (16)	16 (16)	7 (7)	11 (11)	7 (6)	7 (7)	8 (7)	9 (8)	4 (3)
East Asia	60 (57)	80 (79)	131 (115)	158 (127)	149 (125)	194 (171)	121 (103)	65 (60)	70 (67)	54 (48)	58 (53)	73 (38)	33 (22)	22 (13)
India	0 (0)	1 (1)	1 (1)	2 (2)	3 (3)	3 (3)	5 (5)	1 (1)	5 (5)	4 (4)	2 (2)	1 (1)	4 (4)	1 (0)
Mexico	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (4)	0 (0)	0 (0)	2 (1)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
Others	0 (0)	1 (0)	1 (1)	1 (1)	1 (1)	6 (6)	7 (6)	2 (2)	3 (3)	3 (3)	1 (1)	0 (0)	1 (1)	0 (0)
Developing countries	0 (0)	2 (2)	2 (2)	3 (3)	4 (4)	13 (13)	12 (12)	3 (3)	10 (9)	8 (8)	3 (3)	1 (1)	4 (3)	1 (0)
Total	120 (84)	205 (121)	373 (170)	539 (221)	515 (217)	645 (283)	578 (244)	432 (138)	581 (191)	369 (146)	308 (113)	147 (77)	105 (58)	71 (45)

NOTE. The table contains the numbers of bilateral R&D partnerships between the firms from the panel in Table 5. The numbers are retrieved from the Thomson Financial SDC Platinum database. In every cell, the total number of partnerships formed by firms from a certain country/region precedes the number of international/cross-regional R&D partnerships in parentheses.

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