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The Impact of R&D Collaboration Networks on the Performance of Firms and Regions: A Meta-Analysis of the Evidence

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**The Impact of R&D Collaboration Networks on the
Performance of Firms and Regions:
A Meta-Analysis of the Evidence**

Gunnar Pippel

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The Impact of R&D Collaboration Networks on the Performance of Firms and Regions: A Meta-Analysis of the Evidence

Abstract

Innovation is the result of an interactive process. Knowledge-intensive interactions among different partners are associated with a variety of advantages and disadvantages for the actors involved. Therefore, a rich body of literature investigating the impact of R&D collaboration networks on the innovation performance of firms and regions has developed over the last two decades. Those studies come to different results. The aims of this paper are manifold. First, the paper summarizes the results of the relevant literature. Second, a brief overview of the established methods and approaches used in the literature to investigate this research question is given. The third objective is to answer the question whether the achieved results in the literature are predetermined by the employed methods. Finally, relevant gaps for further research are identified. To answer these questions a meta-analysis of the relevant literature is conducted. This study shows that knowledge-intensive interactions have a rather positive impact on the performance of firms and regions. There is also evidence that the employed methods and approaches used in the literature to investigate this research question predetermine the outcome of the research.

Keywords: innovation, collaboration, network, performance, meta-analysis

JEL Classification: O32, O33, R10, R11

Der Einfluss von FuE-Kooperationsnetzwerken auf die Leistungsfähigkeit von Firmen und Regionen: eine Metaanalyse

Zusammenfassung

Wissensintensive Interaktionen sind mit einer Reihe von Vor- und Nachteilen für die beteiligten Akteure verbunden. Deshalb hat sich ein Literaturstrang entwickelt, welcher der Fragestellung nachgeht, wie sich FuE-Kooperationen auf die Leistungsfähigkeit von Firmen und Regionen auswirken. Diese Studien kommen zu unterschiedlichen Ergebnissen. Das Papier versucht die verschiedenen Ergebnisse der Literatur zusammenzufassen. Ein weiteres Ziel ist es, die in der Literatur verwendeten Methoden zur Bearbeitung der Fragestellung kritisch zu diskutieren. Zudem geht das Papier der Frage nach, inwiefern die in der Literatur verwendeten Methoden und Ansätze die Ergebnisse der Studien beeinflussen. Zur Bearbeitung dieser Fragestellungen wird eine Metaanalyse der relevanten Literatur durchgeführt. Dabei wird gezeigt, dass FuE-Kooperationen einen positiven Effekt auf die Leistungsfähigkeit von Firmen und Regionen haben. Zudem gibt es starke Evidenz dafür, dass die verwendeten Methoden und Ansätze die Ergebnisse der Studien beeinflussen.

Schlagwörter: Innovation, Kooperation, Forschung und Entwicklung, Metaanalyse

JEL-Klassifikation: O32, O33, R10, R11

1. Introduction

Economists and economic geographers have long been interested in the contribution of knowledge intensive interactions among organizations and regions to their economic performance and innovativeness (Ahuja, 2000; Nelson and Winter, 1982; von Hippel, 1987). Therefore, this relationship has already been discussed in the economic literature using a wide range of different approaches and methods. One of the basic ideas behind this body of literature can be seen in the thought, that knowledge networks are associated with the transfer of ideas and knowledge between the involved players resulting in an increased performance of the respective unit under analysis. The literature dealing with this issue can fundamentally be divided into two sub-categories. The first category can be identified as business management literature handling the question whether the involvement in such R&D collaboration network activities has an impact on the success of a business. The second type of literature is the literature on regional development which employs the same question on a regional level. The literature also provides comprehensive theoretical arguments for positive and negative relationships between innovation collaboration and performance.

One argument for a positive impact is the assumption, that R&D collaboration networking provides access to external knowledge. Also, the division of risks and the sharing of costs for innovative projects can be seen as a source of benefits due to collaborative R&D. The division of labor as well as the access to a higher specialized labor force can result in a higher innovation performance. R&D collaboration networking can also result in a higher market diversification of a firm. Finally, an additional advantage may arise from the cross-fertilization of ideas among the involved network partners (Hagedoorn, 2002; Katz and Martin, 1997; Nelson and Winter, 1982; Teece, 1986).

However, searching for partners and building up trust is associated to transaction costs such as travelling, communicating and the exchange of information (Bleeke and Ernst, 1993; Koput, 1997). In addition, lock-in situations and overembeddedness may be a source of harm resulting from intensive collaboration (Broekel and Binder, 2007; Fritsch, 2004).

Nevertheless, missing in the literature is a summary of the results of the empirical scientific discussion on the impact of knowledge intensive interactions on the performance of firms and regions, as well as an overview of the utilized approaches and methods to survey this relationship. Therefore, this paper seeks to fill this gap by systematically reviewing the literature on this matter. This paper also seeks to identify gaps in the literature for further research. An additional objective of this meta-analysis is to shed some light on the question whether the results of scientific surveys examining the relationship between R&D collaboration network activities and performance of a firm or a region are predetermined by the employed methods.

The paper is structured as follows. The subsequent section provides a brief overview of the relevant theoretical background. Section 3 describes the methodological approach. The literature selection procedure and the literature inclusion criteria for the meta-analysis will be explained. Section 4 shows the results of the meta-analysis. Finally, section 5 summarizes the results, makes some conclusions, states various limitations and shows several directions for further research.

2. Theoretical background

2.1 The role of collaboration networks in the innovation related literature

The linear model of innovation with its nature to describe innovation as a linear process from research to marketing without any feedback loops has lost its importance in the literature on innovation, since the nonlinear model with its numerous feedback loops has evolved. By now, it is common knowledge that innovation is an interactive process (Kline and Rosenberg, 1986). A broad variety of theoretical approaches utilizing this insight have been developed especially since the early 1990ies. In particular, the economic geography and business management literature is aware of the beneficial, as well as the harmful impact of R&D collaboration on the performance of regions and businesses. For example the literature on innovative milieus examines the importance of informal relationships between local firms and other actors, while focusing on soft factors such as a common understanding and behavioral attitudes with the purpose of establishing and maintaining innovative processes within a region (Aydalot et al., 1988).

The literature on innovation systems argues that institutions in different countries, regions and sectors affect the innovation performance. Networks of protagonists such as universities, firms and other players are important for generation and diffusion of knowledge in a national innovation system (Lundvall, 1992; Nelson, 1993) as well as in a regional innovation system (Doloreux, 2002; Cooke et al., 2000).

Other authors strongly follow the network approach and focus almost solely on specific interactions and relationships between the different actors in the innovation process in a defined region, while motives for interactions as well as the role of trust and social capital is also a point of interest (Hagedoorn, 2002; Powell, 1998).

2.2 Definition of R&D collaboration networks

Before reviewing the empirical literature on R&D collaboration networks, those networks should be defined properly. The search for an appropriate definition of the term “R&D collaboration network” is a tough challenge. It is worth to mention that surprisingly few attempts to characterize this term have been made in the reviewed empirical literature. In many cases, the authors view on this issue only can be reproduced by examining the approach used in the paper in question, to construct the innovation collaboration relationships. On the other hand, the lack of a proper definition can be understood as a hint that the concept of joint R&D is commonly accepted and therefore does not need to be explained. Still, there are some efforts in the literature facing this nontrivial problem (Katz and Martin, 1997). A very shallow definition of this concept can be described as a group of two or more partners working together to achieve a common innovation related goal. Following Katz and Martin (1997), such a kind of definition raises the question how close the participating partners have to work together. It also raises the question how homogeneous the common goals have to be. On the one hand one can argue that the global scientific society is one big community working together by learning from each other to achieve the common goal of fostering the new innovations. On the other hand, it is doubtful that there are two partners which pursue truly on and the same objective and therefore do not collaborate by this definition.

Another option to shape the borders of a R&D collaboration network is to consider everyone as a partner who directly contributed to an innovation. But in the end, this approach runs into the problem that an ascertainable and an unmanageable number of partners potentially could be seen as contributors to an innovation, and therefore this definition does not provide sufficient validity to be used in this paper. Thus, in this paper a rather wide-ranging definition of R&D collaboration networking is used, in order to capture an extensive range of empirical studies for this meta-analysis. For this purpose, a R&D collaboration network mainly describes a number of partners working together target-oriented, with the aim to create new innovations or scientific knowledge. The definition includes strictly dyadic collaboration relationships as well as multi-partner alliances networks. Important is the common focus on R&D meaning that for example production networks are not included. Since this approach is rather loosely, a wider range of phrases such as knowledge networks, R&D collaboration and R&D networks refers to this definition in this paper.

2.3 Advantages and disadvantages of joint R&D

Over the last decades the importance of R&D collaboration has gone up for several reasons. One reason for this development can be found in the increasing costs for current edge technology research. As a consequence it has become more difficult for a single founding institution to provide sufficient resources for R&D projects resulting in the need to pool resources in order to carry out those projects. Another reason for the increasing relevance of collaborative R&D are the falling costs for communication and spatial mobility. This development stimulates scientific collaboration especially between more distant partners (Katz and Martin, 1997).

There is already a broad variety of literature investigating the question of benefits and drawbacks of R&D collaboration between firms or regions. One common argument for conducting joint R&D is the assumption that collaboration provides access to useful external knowledge. This perspective suggests that knowledge related interactions such as between firms and different types of partners, such as competitors, suppliers universities research institutes and customers, are an important source of external know-how (Tece,

1986). Formal and informal R&D collaboration networks are particularly important for the transfer of tacit knowledge that can not be easily codified (von Hippel, 1987). Sharing costs, costs for capital investments such as laboratories and dividing risks of innovation projects such as the uncertainty about the outcome of the R&D efforts is another advantage of collaborative research behavior (Hagedoorn, 2002). Division of labor provides additional benefits for engagement in collaborative research networks. This is especially true for larger, more complex innovation projects. If the division of labor increases the efficiency of the involved partners, the productivity of those partners may also go up.

R&D frequently needs highly specialized labor, which is often difficult to obtain on the market, since the supply for specialized labor is usually limited. Collaborative research also represents a potential source of diversity, which may result in a higher degree of a firm's market diversification (Nelson and Winter, 1982). Collaborative behavior in R&D also allows a firm to outsource specific tasks that otherwise had to be accomplished within the firm's hierarchy (Fritsch, 2004). To add one more benefit of R&D collaboration, one should note that cross-fertilization of new ideas may also result in innovative perspectives and therefore enhancing innovation performance of the involved collaboration partners. This perspective indicates, that research collaboration itself is a source of creativity (Katz and Martin, 1997). These mentioned benefits of R&D collaboration suggest, that firm's and regions that are more intensively involved in collaboration networks have a higher innovation performance than those relatively less involvement in innovation networks.

There is also a number of disadvantages associated with R&D collaboration. Searching for partners and building up trust usually is time consuming and the outcome often is uncertain. Therefore collaboration is related to transaction costs (Bleeke and Ernst, 1993). R&D collaborations often result in an increasing amount of information that has to be shared among the participating partners. The more partners involved in the joint project, the more complex is the exchange of information. Traveling, communication and coordination between the partners as well as the transfer of information is also a source of transaction costs (Koput, 1997). The costs of interaction are of special importance when collaborating with spatial or institutional distant partners (Gertler, 1995).

Also, knowledge spillovers, which we already found to be beneficial for knowledge collaboration, can be a source of harm. Firms often want to protect their specific knowledge, since it is frequently a source of their competitive advantage. Collaboration however, fertilizes knowledge spillovers in a way that the collaboration partners often can not control the flow of knowledge. This results in the possibility, that potential collaboration partners could choose a cheating strategy (Kesteloot and Veugelers, 1995).

Since collaboration is associated with transaction costs and the risk of cheating behavior, successfully established relationships may result in a lock-in situation. The possibility of loosing the spent resources for searching a collaboration partner and building trust provides a strong incentive to focus on long term relationships and therefore to maintain those successfully established partnerships (Fritsch, 2004). Lock-in situations have the harmful nature, that the collaborating partners occasionally cannot easily leave old trajectories and therefore may have difficulties to pursue new paths. Closely related to the idea of the lock-in effect, but still different, is the concept of overembeddedness. Over time, long-lasting network linkages can become strong and trustful. As a result, originally innovation oriented collaborations may perhaps turn into social linkages between the partners and finally those social linkages may overcompensate economic requirements resulting in inefficient or even harmful collaboration decisions. Since individuals often tend to develop knowledge relationships within their home region, the problem of overembeddedness can frequently form a regional problem (Broekel and Binder, 2007). Too close relationships comprise the risk of missing crucial developments outside the network, resulting in a reduced innovation performance of a firm or a region.

The described possible problems for collaborative behavior in R&D illustrate that joint innovation projects are not beneficial per se. It also points out that a closer look is necessary when it comes to evaluating the impact of innovation networks on performance. Table 1 summarizes the discussed advantages and disadvantages of R&D collaboration networks.

Table 1: Advantages and disadvantages of R&D collaboration networks

Advantages	Disadvantages
access to external knowledge	transaction costs
cost-sharing	unwanted knowledge spillovers
risk-sharing	lock-in
division of labor	overembeddedness
access to highly specialized labor force	
market diversification	
outsourcing of specific tasks	
cross-fertilization of ideas	

Source: Authors compilation

By now it was illustrated, that collaborative R&D efforts bear positive as well as negative aspects with respect to the performance of the participating partners. However, the literature provides a third option concerning the relationship between R&D collaboration network activities and the corresponding outcome. Some empirical literature suggests that there is an inverted U-shape relationship between those variables (Cantner et al., 2010; Laursen and Salter, 2006), meaning that with increasing levels of network embeddedness the performance also goes up until it reaches a certain point where an additional unit of network embeddedness does not have a positive impact on performance any longer. Increasing the network embeddedness beyond this point has a negative impact on the performance measure.

3. Methodes

3.1 Search strategy and selection procedure

In this paper we examine the research question using the method of meta-analysis. To do so, a search strategy is developed in a first step, to identify a large fraction of the relevant work in this field. The papers reviewed in this meta-analysis are obtained by searching the ISI Web of Science. The reasons for choosing this literature database are manifold. On the one hand, other authors have successfully proven, that the Web of Science is suitable for conducting a meta-analysis (Bergenholtz and Waldstrom, 2011). On the other hand, this literature database is one of the largest literature databases. It also contains only reviewed journals, ensuring a certain amount of quality. In order to make the selection process of the reviewed papers more transparent and reproducible, only this solely database is used to identify the relevant research. The search for relevant literature in the Web of Science database was conducted in May 2012. The time frame considered reaches from 1990 to 2012. There are no other restrictions regarding the search.

Furthermore, a set of keywords and search strings has to be defined. To do so, a brainstorming was carried out to find the relevant keywords for this topic. The obtained search strings were tested in the Web of Science database in order to identify the most promising search strings. As a result, some search strings were dropped due to unsatisfying or irrelevant search results. The final list of search strings used in this meta-analysis is displayed in table 2.

Table 2: List of search strings used in the meta-analysis

Search string	Number of search results*
Embeddedness AND network AND performance	457
Regional AND inno* AND performance	472
R&D AND collaboration AND network	226
inno* AND network AND analysis AND regional	317
Cooperation AND innovation AND performance	475
Innovation AND linkages AND performance	247
Collaboration AND R&D AND performance	248
Collaboration AND innovation AND performance	574
Cooperation AND R&D AND performance	202
Knowledge AND network AND innovation AND performance	717
Total	3935

* Number of search results in the ISI Web of Science on 15 May 2012

The total number of search results across all search strings is 3935. These search results still contain a huge amount of irrelevant publications resulting in the need for an additional step to identify the relevant work. Therefore, the title of every publication found in the database was analyzed and a decision whether the paper is potentially relevant or not was made. If the title was potentially relevant to the subject of this meta-analysis, the abstract of the paper was analyzed in a further step, with the aim to identify appropriate research. After screening the titles and abstracts, 79 papers were selected and the full text of these articles was examined. After reading the full text articles, 32 papers were excluded, since they did not match the inclusion criteria, resulting in a final number of 47 articles in this meta-analysis. Meta-analysis's usually have to deal with the trade-off between the sample size and the number of variables retrieved from the considered primary studies. Also the narrowness of the literature reviews research question is a potential source of limits to the sample size. As a result, it is difficult to discuss whether the number of studies reviewed in this paper is in line with the literature or not. While some literature review papers have considerable more research papers under examination (Beaudry and Schiffauerova, 2009), others have a more restricted approach (Provan et al., 2007).

3.2 Study inclusion criteria

To ensure a certain amount of transparency, it is important to develop a set of inclusion and exclusion criteria to define which primary studies are considered in this meta-analysis. These criteria were developed before selecting the primary studies and served as a guideline while selecting the studies.

The publications selected must survey the impact of R&D collaboration networks on the performance of firms or regions. Therefore the respective papers need to have a concrete collaboration measure as well as a solid performance measure. Only empirical studies are included, publications with a theoretical approach are not considered. Since this review tries to identify the impact of R&D collaboration networks on performance, the papers in question also need to employ a regression model. Papers with a descriptive approach are not included. All reviewed papers are written in English language. It is also important to point out that this study only investigates papers concerning inter-organizational networks and no intra-organizational networks. The analyzed collaboration activities have to focus on R&D. Papers with a focal point on other network activities, for example production networks or social networks, are not included.

3.3 Data extraction and preparation

Prior reading the selected papers, a data extraction form was designed. This form is necessary to ensure that all relevant information in the considered primary studies are extracted and properly saved. The data extraction form can be described as a table with several variables in its columns and the different papers with their corresponding models in its rows. It was also pretested before extracting the data from the primary studies to ensure that the primary studies fit properly into the form. While reading the full text articles, all relevant information were retrieved and recorded in the form. To make the reviewed papers comparable, a classification for some of the gathered data was developed. This classification will be introduced later in this paper.

Another issue that needs to be handled is the fact that most studies do not arrive to one single conclusion. The relationship between R&D collaboration network embeddedness and performance of a firm or a region is often measured with different regressions. The

reasons for these different regressions are manifold. For example, some papers investigate different industries or regions, other papers test a number of different dependent or independent variables to explore the hypothesis. To approach the problem, every single regression was treated as an individual result and a total number of 426 regression coefficients were identified while analyzing the chosen literature. Consequently, this meta-analysis focuses on these regression coefficients while analyzing the hypothesis.

Many papers analyzed in this meta-analysis deal not only with our research question. Several of them also focus on a wide range of other research hypotheses. In such cases, only the information relevant for this meta-analysis was extracted from the primary studies. As a result it is very important to point out, that the scientific contribution of these reviewed papers is much more significant and diverse than it may appear in this study.

4. Results

As described earlier in this paper, the aim of this meta-analysis is not only to shed some light on the question whether R&D collaboration networks have an effect on innovation performance or not. An additional objective is the identification of potential research gaps in this particular sub-field of economic innovation research as well as providing a solid summary of the applied approaches and methods in the respective literature. Finally, there is also the question on how the research results are affected by the different approaches and methods used in the literature. To address these issues, this section provides a descriptive analysis of the gathered data.

Before having a more detailed look into this matter, the central research question on whether collaborative R&D behavior affects the innovation performance of firms or regions will be addressed. Table 3 contains the aggregated results of the 426 regressions on this question retrieved from the 47 reviewed papers.

Table 3: Aggregated regression results.

	# Regressions	% Regressions
Significant Positive	218	51,2 %
Significant Negative	17	4,0 %
Not Significant	191	44,8 %
Total	426	100,0 %

The majority of those regressions results provide solid evidence, that the engagement in R&D collaboration networks has a significant positive effect on the associated performance measures. About 51.2 percent of the considered regression results support this thesis, while only 4 percent of those regressions point to the opposite result, meaning that collaborative behavior in R&D is negatively related to the performance. After all, it is also important to note that about 44.8 percent of the identified relevant results are not significant. This observation is possibly an outcome of a publication bias, due to the thought that positive results are more likely to be published than negative or not significant results, since journal editors, reviewers as well as scientists probably have a preference for significant positive results (Dickersin, 1997).

To complete the analysis, one should note, that there are three papers that additionally search for a non-linear inverted U-shape relationship (Cantner et al., 2010; Colombo et al., 2009; Kang and Kang, 2010). In total, those three papers provide eight regression results for analysis. Five of those eight results describe a significant inverted U-shape relationship, while three results do not support this idea. Since the total number of papers and regressions investigating the non-linear relationship is considerably low, we do not include this thought in our further considerations.

4.1 Networks identification approach

For the purpose of determining the impact of R&D collaboration networking on performance, one has to measure the participation of the focal units in R&D networks. For

this reason, a broad variety of approaches to identify the R&D networks is used in the literature. Table 4 summarizes the utilized approaches, as well as its respective frequency in the literature and the corresponding regression results.

Table 4: Number of papers and distribution of regression results by network identification approach

Network identification approach	# Papers	% Papers	# Regressions	% Regressions	# Sig Pos.	% Sig Pos.	# Sig Neg.	% Sig Neg.	# Not Sig.	% Not Sig.	Total
Co-Patent	3	6,4 %	18	4,2 %	14	77,8 %	0	0,0 %	4	22,2 %	100,0 %
Co-Authorship	2	4,3 %	12	2,8 %	11	91,7 %	0	0,0 %	1	8,3 %	100,0 %
Public founded Co-R&D	2	4,3 %	19	4,5 %	2	10,5 %	4	21,1 %	13	68,4 %	100,0 %
Questionary/Interview	35	74,5 %	306	71,8 %	142	46,4 %	8	2,6 %	156	51,0 %	100,0 %
Newsdocuments and related databases	5	10,6 %	71	16,7 %	49	69,0 %	5	7,0 %	17	23,9 %	100,0 %
Total	47	100%	426	100%	218		17		191		426

The most common approach for the identification of R&D collaboration is the use of data generated by surveys and interviews (Cantner et al., 2010;de Faria et al., 2010;Asakawa et al., 2010;Kang and Kang, 2010;Gellynck and Vermeire, 2009;Kang and Park, 2012;Aschhoff and Schmidt, 2008;Belderbos et al., 2004;Belussi et al., 2010;Bougrain and Haudeville, 2002;Brettel and Cleven, 2011). With 35 out of the 47 surveyed papers, the main fraction of the literature belongs to this category. Within this group of papers, the community innovation surveys (CIS) are a popular set of data, especially when interactions with specific kinds of partners are described (de Faria et al., 2010;Faems et al., 2005;Frenz and Ietto-Gillies, 2009). Another way to assess R&D collaboration networks is the use of news-publications such as newspapers and magazines as well as related databases such as bioscan (Ahuja, 2000;Owen-Smith and Powell,

2004;Padula, 2008;Quintana-Garcia and Benavides-Velasco, 2004;Soh, 2003). Five of the analyzed papers follow this approach.

Patent data are a source of information that is used by three of the reviewed papers to expose R&D collaboration networks (Lee et al., 2011;Baba et al., 2009;Lecocq and Van Looy, 2009). Thereby, a knowledge intensive link between two (or more) players is assumed when both of them appear on a joint co-patent application. The basic idea behind this approach is the thought that a co-patent application requires intensive prior interactions to prepare the necessary substance for the patent application. A very similar approach to identify R&D collaboration networks is the use of bibliographic information's to create co-authorship networks as conducted in two of the examined papers (Almeida et al., 2011;Kumaramangalam, 2005). A link between two authors is assumed, when both appear on one publication. Likewise to the co-patent application networks, one can say that a joint publication requires intensive preceding knowledge interactions between the involved authors. One well-known database containing the necessary bibliographic information to develop a network is the ISI web of science (Almeida et al., 2011).

Finally, two further papers seek to identify R&D collaboration networks utilizing data on public founded R&D (Fornahl et al., 2011;Colombo et al., 2009). Those public founded R&D projects are often joint projects involving several partners. It is assumed that two or more partners working together in such a joint project perform an intensive exchange of knowledge during these projects. For example the German Förderkatalog (database including granted R&D projects) provides a suitable database for this kind of network research (Fornahl et al., 2011).

All the introduced approaches for the identification of R&D collaborations have their drawbacks and limitations. For example, the use of co-patent networks is probably characterized by diverse affections for patenting across different industries or regions. A similar problem potentially applies for the use of co-authorship networks, since scientists in different fields of science often have dissimilar publication behaviors. Another issue that has to be taken into consideration is the idea that every presented approach describes another level of knowledge collaboration, meaning that for example a common patent application covers a different kind of interaction than a joint R&D project.

As a result, one can expect that using different approaches to identify knowledge interactions lead to different results when it comes to identify the impact of those interactions on performance. A closer look into the reviewed papers reveals that there are indeed a number of notable differences. All regression coefficients based on co-authorship networks or co-patent application networks have disclosed only significant positive or not significant effects on performance, but no significant negative effects. In contrary, regression coefficients based on public founded co-R&D networks have found more often significant negative effects on performance than significant positive effects. Also, the share of not significant results is with about 68 percent by far the highest compared to regression results based on other network identification approaches.

4.2 Performance measures

The reviewed literature examines the impact of R&D collaboration networks on the performance of the considered units under analysis. Therefore, concrete performance measures have to be employed in the respective papers. These performance measures are very heterogenous across the surveyed literature, resulting in the need for classification of those measures for further investigation. An overview on the identified classes of innovation performance measures as well as their corresponding frequencies in the reviewed literature can be found in table 5. Note, that the sum of the papers using the different performance indicators is higher than the number of papers reviewed in this meta-analysis, because there are some papers using multiple performance measures.

One way to determine the innovation performance is the use of a regions or a firm's patent output as done in 14 of the 47 reviewed papers (Ahuja, 2000;Lee et al., 2011;Kang and Park, 2012;Baba et al., 2009;Belussi et al., 2010;Fornahl et al., 2011;Huang and Yu, 2011;Lecocq and Van Looy, 2009;Owen-Smith and Powell, 2004;Padula, 2008). Patent data are a suitable measure for innovation output since they are strongly related to innovativeness and they also ensure a certain amount of technological novelty of the innovation (Griliches, 1990). However, the use of patent data has its limitations when it comes to measure innovation performance. Several innovations are not patented for strategic reasons, other innovations are not patentable. Also, the

propensity to patenting may differ across industries and firm's (Griliches, 1990;Cohen and Levin, 1989).

Table 5: Number of papers and distribution of regression results by performance indicator

Performance indicator	# Paper	% Paper	# Regressions	% Regression	# Sig. Pos.	% Sig. Pos.	# Sig. Neg.	% Sig. Neg.	# Not Sig.	% Not Sig	Total
Patents	14	25,5 %	115	27,0 %	70	60,9 %	8	7,0 %	37	32,2 %	100 %
Introduction of innovations	15	27,3 %	160	37,6 %	68	42,5 %	9	5,6 %	83	51,9 %	100 %
Relative importance of innovation	9	16,4 %	70	16,4 %	26	37,1 %	0	0,0 %	44	62,9 %	100 %
Composite measure	11	20,0 %	48	11,3 %	35	72,9 %	0	0,0 %	13	27,1 %	100 %
Research quality	2	3,6 %	8	1,9 %	8	100,0 %	0	0,0 %	0	0,0 %	100 %
Not Innovation oriented	4	7,3 %	25	5,9 %	11	44,0 %	0	0,0 %	14	56,0 %	100 %
Total	55	100,0 %	426	100,0 %	218		17		191		426

Another measure of innovation performance is the successful introduction of innovations. This measure is often used by studies that utilities inquiries to gather their data in which firms are often asked whether they have successfully introduced innovations in a given amount of time. This approach differs from the above discussed patent indicator approach in manifold ways. This procedure allows to account for a wider range of innovations such as organizational innovations that are often not patentable. Furthermore, innovations that are only new to the firm and not new to the market, as well as innovations that are not patented for strategic reasons are also covered. Drawbacks of this method are to be identified in the potential heterogeneity of the definition of an introduced innovation. Different surveyed firms may have different ideas on what to call a new product or a new process. Nevertheless, this approach is followed in 15 of the reviewed papers (Kang and Kang, 2010;Un et al., 2010;Gellynck and Vermeire,

2009;Chang, 2003;Knoben, 2009;Nieto and Santamaria, 2007;Su et al., 2009;Kim and Park, 2008).

Another 11 papers use a composite measure generated from different performance indicators to capture the performance (Chiu, 2009;Tomlinson, 2010;Zeng et al., 2010;Hsueh et al., 2010;Molina-Morales and Mas-Verdu, 2008;Gronum et al., 2012;Hallin et al., 2011). Those multi-item indicators are conglomerates of diverse measures to capture different dimensions of performance. Therefore, this approach assesses the problem that individual measures have their specific advantages and disadvantages.

Nine of the analyzed papers try to capture the innovation performance by focusing on the relative importance of innovations to the firm (Aschhoff and Schmidt, 2008;Faems et al., 2005;Frenz and Ietto-Gillies, 2009;Wu, 2012;Deng et al., 2012). For example, the proportion of turnover contributed by new products (Faems et al., 2005) or innovative sales per employee (Frenz and Ietto-Gillies, 2009) are typical measures to assess the innovation performance in this category.

A minor fraction of the analyzed literature focuses on research quality to capture innovation performance. The status of the journal in which the research is published (Kumaramangalam, 2005) or the number of product awards a firm has won (Soh, 2003) are examples for this kind of performance measures.

Finally, there are four papers which try to use not innovation oriented measures (Belderbos et al., 2004;Oerlemans and Meeus, 2005;Rickne, 2006;Colombo et al., 2009). The ultimate aim of innovation efforts are growth and productivity gains of firms and regions. This approach tries to skip the level of innovation performance changes through collaboration focusing directly on changes in economic performance.

With regard to the individual regression results one should note that only performance indicators based on patents or the introduction of innovations deliver negative results. Regression results based on all other kinds of performance indicators have only positive or not significant findings. It is also worth to mention, that 100 percent of the models using research quality as performance indicator result in positive findings. However, only a total of eight regressions use this measure, and therefore the validity of this ob-

servation is probably limited. Finally, one should note that regressions employing a performance measure based on the relative importance of innovations result most frequently in not significant results.

4.3 Time lag

One more methodological matter that divides the reviewed papers in two groups is the use of time lags. The idea behind this issue is that R&D collaboration in a given period of time probably does not result in an increased performance in the same period of time, but in the following periods. For that reason, 18 of the 47 reviewed papers take this thought into account by integrating a time lag of usually one to two years between the collaboration activity and the performance measures (Frenz and Ietto-Gillies, 2009;Huang and Yu, 2011;Lecocq and Van Looy, 2009;Nieto and Santamaria, 2007;Padula, 2008;Soh, 2003;Gronum et al., 2012;Zhou, 2012;Wu, 2012). Based on this consideration one should expect that regression models allowing for time lags show different results. However, table 6 illustrates, that regressions with time lags and regressions without time lags show similar results.

Table 6: Number of Papers and distribution of regression results by implementation of a time lag

Time lag	# Paper	% Paper	# Regressions	% Regressions	# Sig. Pos.	% Sig. Pos.	# Sig. Neg.	% Sig. Neg.	# Not Sig.	% Not Sig	Total
Yes	18	38,3 %	179	42,0 %	91	50,8 %	10	5,6 %	78	43,6 %	100 %
No	29	61,7 %	247	58,0 %	127	51,4 %	7	2,8 %	113	45,7 %	100 %
Total	47	100 %	426	100 %	218		17		191		426

4.4 Science based sector vs. non science based sector

Some of the considered literature focuses explicitly on a science based industry, while other studies do not. Table 7 shows that 21 of the 47 analyzed publications focus on science based industries (Cantner et al., 2010;Chiu, 2009;Belussi et al., 2010;Brettel and Cleven, 2011;Chang, 2003;Eom and Lee, 2010;Fornahl et al., 2011). Since most studies utilize different industry classifications it is difficult to distinguish whether a paper is focusing on the science based sector or not. For classification of the papers, we use the information on whether the author of the paper in question considers the surveyed industry as science based or not. If the author makes a comment in his paper that the investigated industry is science based, the paper is put into the corresponding category. Papers which focus on science based sectors frequently argue that leading edge technologies often emerge from various sciences and therefore intensive R&D collaborations are necessary. Also, science based industries are often viewed as innovative industries and innovation can be described as an interactive process. Thus one can assume that science based industries have more to gain by collaborating in R&D than non science based industries. Analyzing the 426 regression results taken from the reviewed papers, one can observe that regression results based on data from science based industries find slightly more often significant positive as well as significant negative results and regression results based on non science based industry data get more insignificant results. Hence, this observation can be seen as an indication that the relevance of knowledge interactions is higher for the science based sector than the non science based sector.

Table 7: Number of papers and distribution of regression results by sector

Science based sector	# Papers	% Papers	# Regressions	% Regressions	# Sig. Pos.	% Sig. Pos.	# Sig. Neg.	% Sig. Neg.	# Not Sig.	% Not Sig.	Total
Yes	21	44,7 %	203	47,7 %	110	54,2 %	11	5,4 %	82	40,4 %	100 %
No	26	55,3 %	223	52,3 %	108	48,4 %	6	2,7 %	109	48,9 %	100 %
Total	47	100 %	426	100 %	218		17		191		426

4.5 Micro vs. macro level

Most of the reviewed papers focus their analysis on the micro level, meaning that their objects of investigation are individual organizations such as firms (Huang and Yu, 2011;Knoben, 2009;Kumaramangalam, 2005;MacPherson, 2002;Niето and Santamaria, 2007;Oerlemans and Meeus, 2005;Owen-Smith and Powell, 2004;Padula, 2008;Kim and Park, 2008). Those papers investigate the relationship between the R&D network activities of an organization and its performance. Only 2 of the 47 considered papers emphasis the macro level, in the sense of an aggregate view on whole regions (Fornahl et al., 2011;Lecocq and Van Looy, 2009). Therefore, studies utilizing a macro view, investigate the impact of the network embeddedness of a region on its performance. The difference between those two groups is the object of investigation. Possible reasons for the distinct ratio between papers with micro level and macro level are manifold. One can argue that the majority of the papers is business management oriented and therefore the main interest is on micro level. Another argument can be seen in a more complex methodological challenge to make a macro level investigation, since most relevant data are available on micro level. Also the theoretical background of those two streams of literature is different. While the macro perspective literature argues with a theoretical background evolving from the regional development literature, the micro level literature often discusses a microeconomic perspective. Table 8 summarizes the results separated by those two approaches.

Table 8: Number of papers and distribution of regression results by micro or macro level

Level	# Papers	% Papers	# Regressions	% Regressions	# Sig. Pos.	% Sig. Pos.	# Sig. Neg.	% Sig. Neg.	#Not Sig.	% Not Sig.	Total
Macro	2	4,3 %	27	6,3 %	12	44,4 %	4	14,8 %	11	40,7 %	100 %
Micro	45	95,7 %	399	93,7 %	206	51,6 %	13	3,3 %	180	45,1 %	100 %
Total	47	100 %	426	100 %	218		17		191		426

From the 426 gathered regression results only 27 are based on a macro level perspective. It is also interesting to note that regressions focusing on the micro level find relatively more often positive results and research focusing on the macro perspective has a higher share of negative regression results.

4.6 Geographic area of investigation

The authors of the surveyed papers usually focus their investigation on restricted geographic areas of investigation. To give an overview how the literature covers the geographic regions and to search for regional differences in the results, the reviewed papers are grouped by continents based on their area of investigation, meaning that for example a paper focusing on Germany is assigned to Europe. From this point of view the most surveyed continent is Europe. Out of the 47 reviewed papers 23 focus their investigation on a region or country in Europe (de Faria et al., 2010;Un et al., 2010;Gellynck and Vermeire, 2009;Aschhoff and Schmidt, 2008;Belderbos et al., 2004;Belussi et al., 2010;Bougrain and Haudeville, 2002). Asia is also a frequently studied part of the world. In total 14 studies are a result of research in Asia (Chiu, 2009;Eom and Lee, 2010;Huang and Yu, 2011;Su et al., 2009;Zeng et al., 2010;Hsueh et al., 2010). Surprisingly low is the number of papers investigating the impact of R&D collaboration networks on performance on the North American continent. Only four of the analyzed pa-

pers deal with this area of investigation (MacPherson, 2002;Owen-Smith and Powell, 2004;Padula, 2008;Soh, 2003). Furthermore, there is only one paper exploring Australia (Gronum et al., 2012). Finally, there is a number of papers that analyzes multiple areas of investigation spread over different parts of the world and therefore cannot be assigned to a single continent. Overall, five research papers belong to this group (Ahuja, 2000;Almeida et al., 2011;Lee et al., 2011;Chang, 2003;Rickne, 2006). An interesting observation is the absence of research considering the other parts of the world such as Africa or South America.

Across the world, there are different innovation systems as well as different institutions. Thus, one can imagine that the effect of R&D networking differs across the globe. Analyzing the gathered regression results one should note that research investigating Australia and Asia has not found any significant negative relationships between R&D collaboration and performance, whereas studies based on data from the North American continent have delivered the highest share of negative relationships. Also the percentage of positive results varies over the different regions. While only 45.2 percent of the regression results from papers investigating European regions found a positive relationship, about 65.8 percent regression analysis for North America result in significant positive findings.

Table 9: Number of papers and regression results by geographic area of investigation

Geographic area	# Papers		# Regressions		# Sig. Pos.		# Sig. Neg.		# Not Sig.		Total
		% Papers		% Regressions		% Sig. Pos.		% Sig. Neg.		% Not Sig.	
North America	4	8,5 %	38	8,9 %	25	65,8 %	4	10,5 %	9	23,7 %	100 %
Europe	23	48,9 %	221	51,9 %	100	45,2 %	11	5,0 %	110	49,8 %	100 %
Asia	14	29,8 %	35	22,3 %	48	50,5 %	0	0,0 %	47	49,5 %	100 %
Australia	1	2,1 %	4	0,9 %	3	75,0 %	0	0,0 %	1	25,0 %	100 %
Multiple areas	5	10,6 %	68	16,0 %	42	61,8 %	2	2,9 %	24	35,3 %	100 %
Total	47	100 %	366	100 %	218		17		191		426

4.7 Network as a metaphor or analytic approach

As already discussed above in this paper, the literature on R&D collaboration networks does not provide a clear definition or boundary of the network concept. Following Bergholtz and Waldstøm (2011) inter-organizational networks can be conceptualized as a metaphor for the interdependent characteristics of organizations and their links across organizational boundaries. This vague concept is followed by 40 of the reviewed papers (de Faria et al., 2010; Almeida et al., 2011; Asakawa et al., 2010; Kang and Kang, 2010; Un et al., 2010; Kang and Park, 2012; Aschhoff and Schmidt, 2008; Baba et al., 2009; Belderbos et al., 2004). On the other hand, networks can be illustrated with a more analytic perspective where the whole network with its nodes and edges is captured and the specific social structure between the organizations can be analyzed. This more complex approach is followed by only seven of the 47 reviewed papers (Chiu, 2009; Ahuja, 2000; Lee et al., 2011; Fornahl et al., 2011; Owen-Smith and Powell, 2004; Padula, 2008; Soh, 2003). Since both approaches capture networks in different ways, one can presume that regression models based on a more analytic network approach have different results than regressions based on a metaphoric view on networks. Table 10 shows that regressions based on an analytic network approach have a lower percentage of insignificant results than regressions based on a metaphoric network approach. Therefore, the fraction of significant positive as well as significant negative results is higher in the group of regressions based on a more analytic approach.

Table 10: Number of papers and regression results by network approach

Network Approach	# Papers	% Papers	# Regressions	% Regressions	# Sig. Pos.	% Sig. Pos.	# Sig. Neg.	% Sig. Neg.	# Not Sig.	% Not Sig.	Total
Metaphor	40	85,1 %	354	83,1 %	174	49,2 %	9	2,5 %	171	48,3 %	100 %
Analytic	7	14,9 %	72	16,9 %	44	61,1 %	8	11,1 %	20	27,8 %	100 %
Total	47	100 %	426	100 %	218		17		191		426

5. Discussion, conclusions and limitations

This paper provides a meta-analysis of 47 papers dealing with the question how R&D collaboration networks impact the performance of firms and regions. While doing so, this paper analyses multiple problems. The first aim was to identify the existence and direction of a relation between R&D collaboration network participation and the corresponding performance of a firm or region. This relationship was found to be of heterogeneous nature. Most regression results (51.2 percent) retrieved from the 47 papers show a positive relationship, while only four percent discover a negative relation. However, there are about 44.8 percent of the regressions with no significant results. Additionally, there is also a small number of regressions discovering a nonlinear relationship. This observation leads to multiple conclusions. At first, one can tend to say, that knowledge intensive collaborations have a rather positive effect on innovation performance. However, it is not clear whether this result is a product of a publication bias, since one can easily imagine that scientist as well as scientific journals have a tendency to publish significant results rather than not significant results (Dickersin, 1997). Given that a meta-analysis can only provide a reflection of the literature, this paper can not address this issue in a more detailed way.

A further subject that is addressed by this paper is a description and overview of the employed methods and approaches used in the literature to handle their research question. In the last section these approaches and methods were introduced. However, at this point in the paper we can summarize some methodological gaps in the literature. One gap can be identified in the R&D collaboration network identification approaches applied in the literature. As pointed out earlier in this paper most studies seek to capture collaboration activities by using data gathered via questionnaires or interviews. Only a very small proportion of the literature attempts to identify the collaboration behavior by the use of co-authorship data, co-patent application data or data on public founded co-R&D for. A similar problem applies to the indicator employed to capture the performance. It is not a surprise that most studies use a performance indicator that measures the innovation performance. However, for policy implications it is often from outermost interest to assess the impact of R&D collaboration on productivity or growth of the unit under analysis. Therefore, one can assume that there is still some need for further re-

search to fill this gap. Another interesting observation is the underrepresentedness of literature concerning the embeddedness of regions in knowledge networks. The question whether regions are connected to other regions and how those connections contribute to the success of the region in question is an important matter in the regional development science and therefore represents an issue for further research. Finally, the meta-analysis discovered that there is a regional focus on Europe and Asia in the literature. None of the reviewed 47 papers has stressed this research question for less developed parts of the world such as Africa or South America. However, it will be interesting to see how R&D networking affects performance in those parts of the world.

A third objective of this paper is to give an idea on the question whether the utilized approaches to investigate the research question predetermine the result of a study. The driving force behind this objective is the thought, that the discovered variety of results in the surveyed literature is a consequence of the diversity of methods and approaches used in the literature. For example, the meta-analysis revealed, that research which measures R&D collaboration network activities via co-authorship or co-patent data usually find no significant negative relationship between networking and performance.

With regard to the employed performance measures one can say, that only analyses with a performance measure measuring patents or the introduction of innovations indicate negative relations. Also, all investigations using research quality for performance measuring find a significant positive relationship. These differences in the results probably arise from the different aspects captured by these indicators. Analyzing the literature this paper also reveals, that studies focusing on a science based sector find more often a significant positive relationship as well as a significant negative relationship, indicating that knowledge intensive industries are effected by R&D collaboration then non science based industries. Furthermore, research with a focal point on the macro level deliver more often negative results then research dealing with the micro level. Therefore, one can assume, that negative effects such as overembedded-ness or lock-in situations are more striking on a macro level. Limiting this particular conclusion, one should note, that only 27 regression retrieved form two papers are investigating the macro level. Also, analysis's from different parts of the world deliver heterogeneous results. For example, studies focusing on Asia or Australia have not found any negative

relationships between knowledge networking and performance, while a number of analyses conducted in North America or Europe have found negative relationships. This phenomenon is probably due to different institutional conditions across the world.

Therefore, the contribution of this paper to the scientific discussion in the literature is manifold. But it is still important to reveal some limitations this meta-analysis faces. One important thing to note is that not all relevant work in this field of science is included in the analysis. Only the papers gathered with the described selection process is captured. Also, even though the selection process is designed to limit a potential selection bias, the choice of the keywords can be a potential source of bias in the reviewed literature. Therefore, the selection procedure has been described properly in order to provide a sufficient amount of transparency. Furthermore, a common limitation for a meta-analysis is the idea, that the reviewed papers have their individual problems and limitations. Those limitations also impact the validity of this meta-analysis. An additional problem of this paper can be identified in the descriptive approach which does not allow to control for other factors. Finally, one can argue that the reviewed literature itself is biased due to a publication bias, but the appropriate counter-argument is the thought, that the idea of a systematic literature review is to provide an appropriate reflection of the literature.

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