The Geographical and Institutional Proximity of Scientific Collaboration Networks

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Abstract

Collaboration and the exchange of knowledge is supposed to be eased by geographical proximity because of the tacit character of knowledge. Recently a number of scholars criticized this view on geographical proximity for being oversimplified and argue that the precise role of geographical proximity for knowledge exchange and collaboration still remains unclear. This paper analyses the role of geographical proximity for scientific research collaboration in science based technologies between universities, firms and other research institutions. We test the hypothesis that collaboration between different kinds of organizations is geographically more localized than collaboration between the same kinds of organizations due to institutional proximity. Using co-publications as an indicator for collaboration, this hypothesis is confirmed.

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1. Introduction

The relationship between scientific research, technological innovation and regional economic development has been an important theme in innovation studies and economic geography for many years now. The literature indicates that, in particular in science-based industries, the interaction between research institutes and firms is a crucial factor in innovation processes. A number of scholars have focussed on the role of geography in these interaction processes and have found evidence for localized knowledge spillovers from universities and other academic organizations (see amongst others; Jaffe 1989, Varga 1998, Anselin et al. 2000, Acs 2002). Geographical proximity is often assumed to render collaboration more likely to occur, because the tacit character of knowledge requires face-to-face interaction. Recently, however, this line of reasoning is questioned by several authors (Malmberg and Maskell 2002, Torre & Rallet 2005, Boschma 2005). They suggest that geographical proximity can only have an indirect role, and is neither a prerequisite nor sufficient for successful collaboration. Geographical proximity is assumed to play a more 'subtle and indirect role' (Howells 2002) in positively influencing collaboration and knowledge exchange.

Little is known about the role of geographical proximity in scientific collaboration and about how this affects the nature and probability of networking. Since collaboration in scientific knowledge production has become a central policy issue (Canton et al. 2005), it is surprising that only few researchers have tried to understand the geography of these research collaborations. An important part of research collaboration, especially within applied sciences, takes place in heterogeneous networks including universities, firms and governmental institutes (Etzkowitz and Leydesdorff, 2000). In this context, it has been argued that the regional scale is highly relevant for heterogeneous actors to overcome the differences in institutional contexts (Cooke et al., 1997). Put differently, we expect geographical proximity to compensate the lack of institutional proximity. Here, we test the hypothesis that research collaboration involving different kinds of organizations (firms, universities, governmental research institutes) is geographically more localized than collaboration in science between the same kinds of organizations. We analyse the collaboration patterns in eight science-based technologies at different spatial scales for the period 1988-2004. The eight individual technologies can be grouped in two rather homogenous clusters of either life-science based or physical science based base-technologies. In the following sections we first elaborate on the relation between proximity and knowledge exchange (section 2). In section 3 we embed our central hypothesis in the empirical literature on the subject of science and proximity. This hypothesis focuses on spatial characteristics of collaboration in scientific knowledge production between various organizations. Section 4 focuses on data and measurement issues. We measure the importance of geographical proximity for collaboration in science taking into account institutional proximity by differentiating to the background of the organization. Cognitive distance is controlled for by focusing exclusively on collaborations within scientific disciplines. Section 5 describes the spatial structure of scientific collaboration networks in the Netherlands on several spatial scales. In sections 6 and 7 the hypothesis that spatial collaboration between academic organizations and non-academic organizations (firms or governmental organizations) is more regionalized than collaboration between academic organizations is tested. We apply multiple chi-square analysis to see whether certain forms of collaboration are indeed more frequently occurring at certain spatial scales (section 6). We further test for the influence of geographical proximity on the intensity of different forms of collaboration within the Netherlands using a gravity model (section 7). Section 8 concludes.

2. Geographical proximity and knowledge exchange

Consensus has grown among economists and economic geographers that knowledge production and knowledge spillovers are to an important extent geographically localised (Jaffe 1989; Audretsch and Feldman 1996; Feldman 1999, Van Oort 2004). To test for knowledge spillovers, most scholars apply a knowledge production function approach to explain the regional production of patents or innovations as a result of public and private R&D inputs and a local spillover index. In more than one case, and for different spatial levels, scholars have been able to indicate that such spillovers turn out to be statistically significant, that is, exert a significant and positive effect on knowledge output as measured by patents or innovations. In particular, the money spent on university research in a region is said to be very beneficial for innovation in that region (Jaffe, 1989). Knowledge spillovers from universities and other academic research institutions seem to be spatially bounded, as shown by Jaffe (1989), who found that the large majority of citations to U.S. patents stem from the same state as the one from which the cited patent originated, even when corrected for differences in regional sector distributions.

Geographical proximity is often claimed to be beneficial for successful collaboration and knowledge exchange. Most often, this is explained by the importance of face-to-face contacts for the exchange of tacit knowledge. In many studies this localized interaction is however only assumed implicitly rather than examined in an explicit manner. Theoretically, a number of authors has questioned the importance of geographical proximity in itself for collaboration and knowledge exchange (see for example Breschi & Lissoni 2001, Howells 2002, Gertler 2003, Torre & Rallet 2005, Boschma 2005). The main argument is that 'simple' co-location is neither a prerequisite nor a sufficient condition' (Boschma 2005, p.71) for collaboration and knowledge exchange. Other forms of proximity are supposed to be necessary for successful collaboration and knowledge exchange. For example, cognitive proximity among researchers is required for meaningful communication in research projects.

3. Science and proximity

Hitherto, only a few scholars have focussed on the role of geographical proximity in scientific knowledge production (Katz 1994 and Liang and Zhu 2002) and they found that geographical proximity does have a positive effect on the intensity and frequency of scientific collaboration. However, several other scholars claim that internationalisation of collaboration in science a growing phenomenon due the improved communication possibilities, thereby reducing the importance of geographical proximity.

This evidence supports the thesis that scientific knowledge production is organised around a global discourse. Even if most of the new knowledge is produced locally, it is diffused globally by journal publications within an international epistemic community. An epistemic community can be defined as a group of agents sharing a common goal of knowledge creation and a common framework in order to communicate and to create mutual understanding (Cowan et al. 2000; Cohendet and Meyer-Krahmer 2001). Codification of new knowledge by a common codebook is the way new knowledge becomes accessible for all members. Another feature of an epistemic community is the fact that the knowledge created is also accessible for the outside world. Although this knowledge is codified, this does not mean it is easy for outsiders to understand and use this knowledge. Outsiders without knowledge of the codebook have difficulties understanding and interpreting this knowledge, even though it is codified. The understanding of the codebook discriminates between those who can understand and learn from the knowledge and those who cannot. In this way science can be seen as an international community bounded by a common codebook and driven by the goal of creating and adding knowledge around a global discourse.

Since the cognitive proximity between scientists is relatively high due to the use of a common codebook, collaboration within an epistemic community is therefore not per se bounded in space. The major determinant for collaboration is the understanding of the codebook and the membership of the community, which are not so much influenced by geographical proximity. Cognitive proximity does not have a relation with geographical proximity here and therefore one can expect that geographical proximity is in general not that important for collaboration in science. However one can think of two reasons why geographical proximity still matters in scientific knowledge collaboration. First, collaboration at longer distances is still supposed to be more costly than collaboration at shorter distances despite improved transportation possibilities and the rise of ICT. Second, collaboration between academic and non-academic organizations, which is a frequently occurring phenomenon in science-based technologies (Pavitt, 1984; DeSolla Price, 1984), is assumed to be more localized into space.

To understand the impact of geographical proximity in science-based technologies, we have to discuss the differences between science and technology more in detail. Scientific research is fundamentally different from industrial innovation (Dasgupta and David, 1994). Gittelman and Kogut (2003, p.367) state it like this; *'…the logic of scientific discovery does not adhere to the same logic that governs the development of new technologies'*. Scientific research and (research for) industrial innovation take place in different socio-economic structures (Dasgupta and David, 1994). Because of these differences, the world of science and the world of technology can be seen as two different communities with their own set of rules and behaviour. Because of these differences in institutions this can be viewed as a source of institutional distance, i.e. as a lack of institutional proximity.

The major difference between these two communities lies in the goal of the research and as a consequence the underlying incentive structure (Dasgupta and David 1994, Frenken and Van Oort 2004). The main goal in science, and of scientific publishing, is to add new knowledge to the existing 'stock of knowledge' and to diffuse this new knowledge as widely as possible, whereas industrial research and innovation is concerned with *"…adding to the streams of rents that may be derived from possession of (rights to use) private knowledge"* (Dasgupta and David 1994, p 498). As a result the incentive structure regarding knowledge production in academia and industry is conflicting: in academia actors want to maximise diffusion of their knowledge, while actors in industry want to minimise diffusion of their knowledge. When universities and industries collaborate in research, the differences in incentive structure give rise to complex institutional arrangements. The complexity of these collaborations render it generally impossible to encode all contingencies in a contract, and, as a consequence, these networks have to rely at least partially on less formal institutions that reduce the risk of opportunism. One may therefore argue that in the case of collaboration between academic and non-academic organizations (like university-industry relations), as stressed by the regional innovation system literature, geographical proximity may be supportive to establish successful partnerships between organizations with structural different backgrounds.

The question remains why firms do scientific research and publish (some of) the results in scientific journals. The answer is that production and publication of scientific knowledge can be part of a firm's strategy to realise profits. Benefits of basic research can be first-mover advantages; advantages for a firm being the first to have new knowledge thereby creating an unique position to competitors (Rosenberg 1990; Pavitt 1984). Collaboration with academia can play an important role in this context, because it allows firms to access critical human resources and physical infrastructures. A second reason to invest in scientific research is absorptive capacity: by doing research, a firm is better able to reap the benefits from research done outside the firm (Cohen and Levinthal, 1990). These arguments explain why firms do scientific research but not why they publish their results of this research in scientific journals. Rosenberg (1990) sees the publication of the results of a firm's scientific research as 'a ticket of admission to an information network' (p.170). Cohen and Levinthal (1989) state that internal capability to generate knowledge and external collaboration to acquire knowledge or to learn from external knowledge, are not substitutes but complementary to each other. Internal scientific knowledge production brings new knowledge and creates an ability to learn from external sources. External collaboration provides access to new knowledge that cannot be generated inside the firm (Lundvall, 1992). Especially in industries like science-based industries with a complex knowledge base, consisting of a combination of knowledge from different fields, it is impossible for an individual firm to generate this knowledge by itself and to keep up with the development in all fields. To learn from external sources one has to collaborate with external actors and to be active in a network of research institutes, universities and other companies. To become a member of these networks, a non-academic organisation has to be part of the scientific community and by publication of the outcomes of scientific research in this community the firm becomes ‘a member’ (Cockburn and Henderson, 1998). In particular, when firms collaborate with universities or governmental research institutes, publication is almost inevitable. Goddard and Isabelle (2006) indicate for example that (co-)publications are the most frequently occurring outcome of research collaboration between French academic organizations and firms.

The main hypothesis underlying our study holds that geographical proximity can facilitate collaboration between organisations with different socio-economic structures. In such heterogeneous collaboration networks, problems typically arise from conflicts of interest or from differences based on a lack of institutional proximity. Geographical proximity may help to overcome these problems, because of a common interest to exchange labour, access to local funds and mutual trust induced by informal contacts and interaction. By contrast, when organisations with the same institutional background collaborate, that is, when institutional proximity is high, successful interaction is less dependent on geographical proximity as collaboration takes place within a common framework of incentives and constraints. Following Boschma (2005), geographical proximity can compensate for the lack of institutional proximity. And, reversely, institutional proximity facilitates interaction over long geographical distances.

In the following sections, the spatial characteristics of collaboration in scientific knowledge production between various organizations will be analysed. The main goal is to find out what the spatial patterns of different forms of collaboration in scientific knowledge production are. We try to measure the importance of geographical proximity for collaboration in science, taking into account institutional proximity by differentiating by the background of organizations. . Institutional proximity is proxied by the contesting differences in incentive structure between academic and non-academic organizations. Organizations with same incentive structure are hypothesized to be institutional nearby. Cognitive distance is controlled for by focusing exclusively on collaborations within scientific disciplines. Thus, in the following, we assume that cognitive distance is small.

4. Data

The main data source in scientometrics in general (and used in this study) is the Web of Science, a product offered by the Institute of Scientific Information (ISI, http://www.isinet.com/). Web of Science contains information on publications in all major journals in the world for 1988 onwards. It covers three databases: the Science Citation Index (SCI) including natural science journals, the Social Science Citation Index (SSCI) including social science journals, and the Arts and Humanities Citation Index (A&JCI) including journals belonging to the arts and humanities. Using Web of Science, one can construct data on a specific discipline in a relatively straightforward way. Once a list of journals is obtained that is representative for the scientific discipline in question, publications belonging to a discipline can be simply retrieved by using the set of journals as a query. We analysed publications for those disciplines that contributed the most to technological innovation in science-based technologies. The selection of the technologies and the relevant science disciplines was based on the analysis of citations from patents to scientific articles by Van Looy et al. (2003). They estimated the science intensity of a technology by comparing the share of citations to scientific articles for different technological coherent patent classes. Based on the ISI grouping of journals into sub-disciplines the relevant scientific fields for each science-based technology were estimated. For a further description of this method of linking science to technology see. Van Looy et al. (2003). Based on their analysis we selected the following technologies: agriculture & food chemistry, biotechnology, organic fine chemistry, analysis, measurement & control technology, optics, information technology, semiconductors and telecommunication .Some technologies are more alike in terms of their science base than others and based on a comparison of the relevant scientific subfields it is possible to make a distinction between life-sciences based technologies and physical sciences based technologies. Table 1 shows the relevant scientific subfields for each technology grouped into these broad sectors.

Table 1. The relevant science-fields* for technological innovation the eight selected technologies.

Collaboration is defined as the co-occurrence of two or more addresses on a publication. Although collaboration in its essence takes place between people, we focus on organisations. Addresses attached to the publications refer to institutional affiliations and not to single persons per se. Unfortunately it is not possible to link individuals to organisations in the data of ISI. This means that a single-author paper with two or more affiliations is also counted as collaboration whereas a multi-authored paper with one address (i.e. an intra-organisation collaboration) is not regarded as collaboration (see also Katz and Martin, 1997).

All publications in the relevant scientific subfields for the period 1988-2004 with at least one address in the Netherlands have been retrieved for each of the eight selected technologies. Figure 1 shows the shares of co-publications in the total number of publications for all technologies in every year between 1988 en 2004. For all technologies it becomes clear that collaboration is a growing phenomenon in scientific research, a finding that is line with findings of various other authors on collaboration in science (Luukkonen et al.., 1992 and 1993; Glänzel 2001, Wagner-Doebler 2001, Wagner and Leydesdorff 2005 and Wagner 2005).

Figure 1. The share of co-publications in the total number of publications.

Every co-occurrence of two organizations is counted as collaboration. This means that a co-publication with *n* organizations has $n(n-1)/2$ collaborations. The number of collaborations is growing over time in all technologies. This is not only because of the growth of the number of co-publications over time but also because of the growth of the average number of organizations per co-publication.

5. Spatial structure of scientific collaboration networks

The spatial scale of a collaboration was determined by analyzing the addresses of the organizations involved. At the international level we distinguished between the collaboration at the EU level (a collaboration between an organization located in the Netherlands and an organization in one of the EU countries), the 'USA-level' (all collaborations between Dutch and American organizations) and the international level (collaborations with other countries). Within the Netherlands we distinguished between the NUTS3, NUTS2, NUTS1 and national level. NUTS is the official EU classification of sub-national territories. Within the Netherlands, the NUTS3 classification is commonly based on regional labour markets (most of the times consisting of a city and its surrounding municipalities), a NUTS2 region is a province (consisting of several NUTS3 regions) and the NUTS1 regions corresponds to a 'country part', consisting of several NUTS2 regions. There are 40 NUTSNUTS3 regions, 12 NUTSNUTS2 regions and 4 country parts. The spatial scale of each collaboration within the Netherlands is based on the co-location of both organizations in a region. So, a collaboration between organizations located in the same NUTS3 region is labeled as a NUTS3 collaboration and a collaboration between two organizations located in a different NUTS3 region but in same NUTS2 region is labeled as a NUTS2 collaboration and so on.

Figure 2 shows the importance of the various spatial scales for collaboration in science for the different technologies. Collaboration in science has a clear international focus. The majority of all collaborations is at the international level. The EU countries are by far the most important partners.

Figure 2. Importance of various spatial scales for collaboration in science per technology.

However this does not mean that the regional level is not a relevant spatial scale for collaboration in science. Figure 2 also shows that between one third and one fifth of all collaborations are taking place within the Netherlands and especially the NUTS3 and the NUTS1 level seem to be relevant sub-national levels for collaboration.

Figure 3 till 10 show the spatial pattern of scientific collaboration in the different technologies within the Netherlands at the NUTS3-level for the period 1988-2004 . The thickness of the lines show the intensity (in terms of the total number of collaborations) of collaboration between two NUTS3 regions and the size of the dot the intensity of collaboration within a region.

Figure 3 till 10. Maps of the spatial structure of collaboration in science.in the period 1988-2004

The spatial patterns of collaboration within the different life-sciences based technologies are very much alike. To a lesser extent, this is also the case for the different physical science based technologies. The earlier made distinction between two broad sectors of life-sciences based and physical-sciences based technologies seems therefore justified. The close resemblance of the spatial structures of related technologies is offcourse related with the earlier noticed similarities in the science base of these technologies.

A comparison of the physical science based technologies with the life-sciencesbased technologies shows that the spatial structures or collaboration are clearly different, suggesting regional specialization in related scientific subfields. Collaboration in life-sciences like biotechnology take for a large extent place between and within regions in the Western part of the Netherlands like Amsterdam, Leiden and Utrecht, in the economic center called the Randstad. The spatial structure of collaboration in the different physical sciences based technologies show a somewhat different picture. The importance of the region South-East Brabant (around the city of Eindhoven) is apparent and can be traced back to a concentration of (micro-) electronics firms and related organizations clustered around the Dutch electronics multinational Philips and the Eindhoven University of Technology.

In order to analyze whether collaborations between different kinds of organizations have another spatial configuration than collaborations between the same kind of organizations we distinguished three different types of organizations: academic organizations, firms and governmental/non-profit organizations. Academic organizations are those organizations with the advance of science as primary goal - universities and other academic research organizations alike. Many governmental and non-profit organizations are additionally engaged in scientific research, but their main goals are often not the advance of science itself but lies merely in the use of the results of this research for society-broad goals. Figure 11 shows the share of the various forms of collaboration. Academic organizations are abbreviated as ‘acad’, companies as ‘com’ and governmental and non-profit organizations as ‘gov’. Not surprisingly collaboration between academic organizations is the most important form of collaboration in science. However collaboration between governmental organizations and academic organizations and between firms and academic organizations is also frequently occurring. The share of collaborations between firms and between firms and governmental organizations is low. This is not because collaboration in fundamental research does not occur. On the contrary, this is a common phenomenon in science-industries (see for example Powell et al. (1996) for life-sciences and Stuart (2000) for high-technology industries). However, it seldom leads to co-publication. Note that there are differences between life-sciences and physical sciences; collaboration between firms and academic organizations is considerably more important in physical sciences whereas collaboration between academic organizations and governmental organizations seems to be more important within life-sciences. The latter can be related to the importance of organizations as hospitals and governmental health institutes in life-sciences research (Owen-Smith et al. 2002).

Figure 11. Share of different forms of collaboration in science per technology.

With this distinction between different forms of collaborations we can analyze whether the spatial patterns of collaboration between organizations with a different institutional background are different from those between organizations with the same. Because of relatively minor importance of other forms of collaborations we have done this for those collaborations with at least one academic organizations involved; ‘acad’, ‘acad-com’ and ‘acad-gov’.

6 Internationalization and regionalization

To test our hypothesis that spatial collaboration between academic organizations and non-academic organizations (firms or governmental organizations) is more regionalized than collaboration between academic organizations, we perform multiple significance tests on independency to see whether different types of collaborations significantly differ in their spatial scale (Hair et al.. 1998, p.355). The Chi-square test of independence hypothesizes that spatial scale and form of collaboration are unrelated; the column proportions are the same across columns and any observed discrepancies are due to chance variation. Because multiple tests are performed, the Bonferroni adjustment is applied. The Bonferroni adjustment ensures that the α-level of each individual test is adjusted downwards to ensure that the overall risk of making a Type-1 error for a number of tests remains at the chosen α-level[†] .

We tested whether or not certain forms of collaborations are indeed more regionalized than others. Six ascending spatial scales were distinguished; ranging from NUTS3 level to countries outside the EU. Table 2 shows the results for the eight technologies. A distinction is made between life science based and physical science based technologies.

The different spatial scales form the column categories and each column has a ‘key’ (A-G). The different forms of collaboration form the row categories. As said before, this test compares column proportions on significance differences for each row category. If there exists a significant difference between two column proportions, the key of the column with a significant smaller proportion appears under the column category with the larger proportion. For example within agriculture & food chemistry, in the row ‘acad-gov’, the letters B till G indicate that collaborations between academic and governmental organizations have a

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[†] When performing *k* multiple independent significance tests each at the α level, the probability of making at least one Type I error (rejecting the null hypothesis inappropriately) is $1-(1-\alpha)^k$. For example, with k=10 and α=0.05, there is a 40% chance of at least one of the ten tests being declared significant under the null hypothesis.

significant higher proportion in column A, than in all other columns. This shows that 'acad-gov' collaborations occur relatively more at the NUTS3 level that at all other than at all other distinguished spatial levels. A further look at table 2 shows that this is also the case in the other life sciences indicating that this form of collaboration has a clear regional dimension. This seems not to be the case for collaborations between academic organizations and firms, which is significantly more occurring at the national level than at the regional level in the Netherlands (with the exception of the NUTS2 level for agriculture & food chemistry). University-industry collaboration in life sciences is not a clear localized phenomenon – as suggested in general in the international literature (e.g. Cooke 2004), which suggests that the regional dimension of the innovation system in life sciences should not be overemphasized. Academic collaboration on the other hand is significantly more occurring at the international level; especially the USA seems to be an important partner for academic collaboration.

Table 3. Multiple Chi-square tests on importance of various spatial scales for different forms of collaboration

To a certain extent these patterns can also be observed in case of the physical science based technologies. Collaboration between academic organizations is significantly more occurring at the international levels than at the national or regional level. A notable exception is the fact that academic collaboration seems to be relatively more important at the NUTS1- level than at the - higher – national level. Also surprising is the fact that no significant differences exist between the relative importance of the NUTS1-level and the international levels for academic collaborations in most of the physical sciences. Collaboration between academic organizations and firms and governmental organizations are more significant at the different regional levels and the national levels. Again no clear regional dimension can be observed for university-industry collaboration, different regional and the national level as well seem equally important here. This is also the case for collaboration between academic organizations and governmental organizations. All together these results suggests, as in the case of the life sciences that geographical proximity is more important for collaborations between academic and non-academic organizations than for collaborations between academic organizations which is more international.

Although some notable differences between life sciences and physical sciences exist between the importance of the regional and national level for collaboration between firms and academic organizations, the main conclusion is the same. Collaboration between academic organizations has a strong international focus whereas collaboration between academic and non-academic organizations is more regionalized. These results suggest that geographical proximity is more important for collaboration between organizations with a different institutional background than for collaboration between organizations with the same institutional background.

7 Geographical proximity and scientific collaboration

To formally test whether geographical proximity is more important for collaborations of institutionally different actors than for similar ones, we apply a gravity model approach. The gravity-model is a well-known and often used model in geography to predict or analyse the interaction between two places (see for example Maggioni and Umberti, 2005 or Dalgin et al. 2004 for recent applications). It is based on the gravitation law, which states that the force between two objects depends on the mass or size of both objects and the distance between.

The gravity model is described by the following formula:

$$I_{ij} = K\frac{M_i * M_j}{d_{ij}^b}$$

In this context *I* stands for intensity of collaboration (measured in numbers of collaboration) between regions *j, M* for the total number of collaborations with at least one organization in and *I* region *i* or *j* and *d* for the functional distance (measured in average travel time) between region *i* and *j*. K is a constant. Because the interaction I is based on collaboration (which has no direction) between regions, the distinction between the mass M of regions i and j is not applicable and this formula can be rewritten into this regression model:

$$(\log)I_{ij} = K + \alpha_1 \left(\log\right) M + \alpha_2 (\log) d_{ij} + \varepsilon$$

Since we have count data, we used a negative binomial regression model[‡] to analyse the effect of mass and travel time between and within regions on the intensity of collaboration. Intra-regional collaboration is also included and we used the average travel time[§] of intra-regional traffic in a region as the indicator for functional distance within a region.

Table 4 shows the results. Within this table the results for the life sciences are presented first, the results for the physical sciences secondly and the results for analysis, measurement and control technology last. The co-efficient of mass is in all technologies for all forms of collaborations significant and positive, which seems a logical outcome. We are especially interested in possible differences in the coefficients of travel time on the intensity of collaboration indicating possible differences in the effect of geographical proximity on collaboration. For the aggregated number of collaborations the co-efficient for travel time has a negative sign and is significant for all technologies. This seems to suggest that distance (still) matters for collaboration in science, a finding that is line with the findings of Katz (1994) and Liang & Zhu (2002).

Table 4. Negative binominal regression on the interregional intensity of collaboration in science per technology.

Within life sciences travel time has a significant and negative effect on the intensity of collaboration for all the three distinguished forms of collaboration. The coefficient for travel time is higher for collaboration between academic and governmental organizations than for academic collaboration and collaboration between firms and academics. However these differences are relatively small. Although the results of the multiple chi-square analysis in the previous section indicate that the international level is more important for academic collaboration, these outcomes suggest that geographical proximity still matters in explaining collaboration patterns between academic organizations in the Netherlands. The higher coefficients for collaboration between academic and non-academic organizations suggest that geographical proximity is more important for these forms of collaboration, which is in line with the findings of the multiple chi-square tests our hypothesis.

[‡] Using a *likelihood ratio test,* we determined whether the data follow a Poisson-distribution. In that case, it is appropriate to estimate a Poisson-regression model. This turned out to be not the case, hence we applied the estimation technique of negative binominal distributions to the data.

[§] The average travel time between and within functional regions is based on a research on the OVG 2003 research of Statistics Netherlands (CBS) where the average travel time is estimated by a weighted average of private and public transport time.

In the case of the physical science based technologies, travel time has no significant effect on the intensity of collaboration for semiconductors and optics. Within the field of information technology and telecommunication the coefficient is only significant at a significance level of 90%. In the field of optics average travel time has also not a significant effect on the intensity of collaboration between firms and academic organizations thereby indicating that geographical proximity is not important for university-industry collaborations here. There are no differences between the coefficient of travel time of academic-firm and academic-governmental collaboration in telecom and information technology, indicating that the effect of geographical proximity is more or less the same, which was also suggested by the multiple chi-square tests. The reason for the absence of travel time as a significant contributor to collaboration intensity might be embedded in the fact that physical science based technologies are more mature in nature, and firms in sectors that use these technologies have less opportunities to catch on new market niches. Relationships between firms, universities and governmental institutions are then more established, enhancing the institutional proximity based on trust and experience. This renders physical proximity less important in sectors that apply this technology.

The coefficient of travel time is also significant and almost the same in case of collaboration between academic and governmental organizations and academic organizations and firms in the analysis, measurement and control technology. Average travel time has as a smaller effect for academic collaboration indicating that geographical proximity is here also less important for collaboration.

These results suggest that geographical proximity is important for collaboration in research within the Netherlands and the importance varies between the form of collaboration and between life sciences and physical sciences. Within life-sciences geographical proximity seems to be more important for collaboration than within physical sciences and geographical proximity seems also be to more important for collaboration between academic and non-academic organizations than for collaboration between academic organizations. These results therefore seems to confirm our main hypothesis that geographical proximity is more important for collaboration between organizations with different institutional background than for collaboration between organizations with the same institutional background.

8 Conclusions

In this study we analyzed the spatial characteristics of collaboration in scientific knowledge production in the Netherlands. Within science-based industries, collaboration between governmental, academic and private organizations in scientific knowledge production is an important and growing phenomenon. Based on theoretical insights from the literature of the geography of innovation it was hypothesized that geographical proximity is more important for collaboration between organizations with different institutional backgrounds. Using co-publications in scientific subfields that are relevant for technological innovation as a proxy for collaboration in research, this hypothesis was tested for eight science-based technologies in the life sciences and the physical sciences.

The main finding of this study is that geographical proximity is more important for collaboration between academic and non-academic organizations than for academic collaboration. This suggests that geographical proximity is indeed a way of overcoming institutional differences between organizations, which is necessary for successful collaboration.

However, this study also shows that the importance of geographical proximity does not imply that the regional level is therefore the relevant spatial scale. The national level seems to be more important for collaboration between firms and academic organizations than the regional level. For collaborations between academic and governmental organizations the regional level seems to be relatively important. These findings suggest that the regional dimension of the innovation system in science-based industries in the Netherlands should not be overemphasized. Geographical proximity plays a significant, yet minor role for collaboration between academic organizations within the Netherlands, which is also evident from the high share of international collaborations. Geographical proximity therefore especially seems to matter for collaboration in science if case of institutional differences, thereby facilitating successful collaboration. These results fit in the recent proximity debate about the exact role and effect of geographical proximity for collaboration and knowledge exchange between organizations (Boschma 2005, Torre and Rallet 2005) and suggest that geographical proximity is more important in an indirect way by overcoming institutional differences than it directly stimulates interaction as it is often assumed.

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Tables & figures

Table 1. The relevant science-fields* for technological innovation the eight selected technologies.

Agriculture & food chemistry
(n=40369)
Biochemistry & Molecular Biology
Plant Sciences
Microbiology
Genetics & Heredity
Food Science & Technology
Agriculture Dairy & Animal Science
Nutrition & Dietetics

Analysis, measure & control technology
(n=31175)
Biochemistry & Molecular Biology
Applied Physics
Instruments & Instrumentation
Electrical & Electronical Engineering
Immunology
Analytical Chemistry

Biotechnology
(n=43250)
Biochemistry & Molecular Biology
Microbiology
Genetics & Heredity
Immunology
Virology
Biophysics
Biotechnology & Applied Microbiology

Information technology
(n=8184)
Electrical & Electronical Engineering
Computer Applications
Computer Cybernetics
Telecommunications
Acoustics

Optics
(n=16499)
Optics
Electrical & Electronical Engineering
Applied Physics
Polymer Science

Organic fine chemistry
(n=46504)
Biochemistry & Molecular Biology
Organic Chemistry
Pharmacology & Pharmacy
Immunology
Genetics & Heredity
Microbiology

Semiconductors
(n=16289)
Electrical & Electronical Engineering
Physics Condensed Matters
Crystallography
Applied Physics
Nuclear Science and Technology
Material Science

Telecommunication
(n=14158)
Electrical & Electronical Engineering
Telecommunications
Optics
Applied Physics
Computer Applications
Computer Cybernetics

* as defined by the Institute for Scientific Information (ISI).

Figure 1. The share of co-publications in the total number of publications.

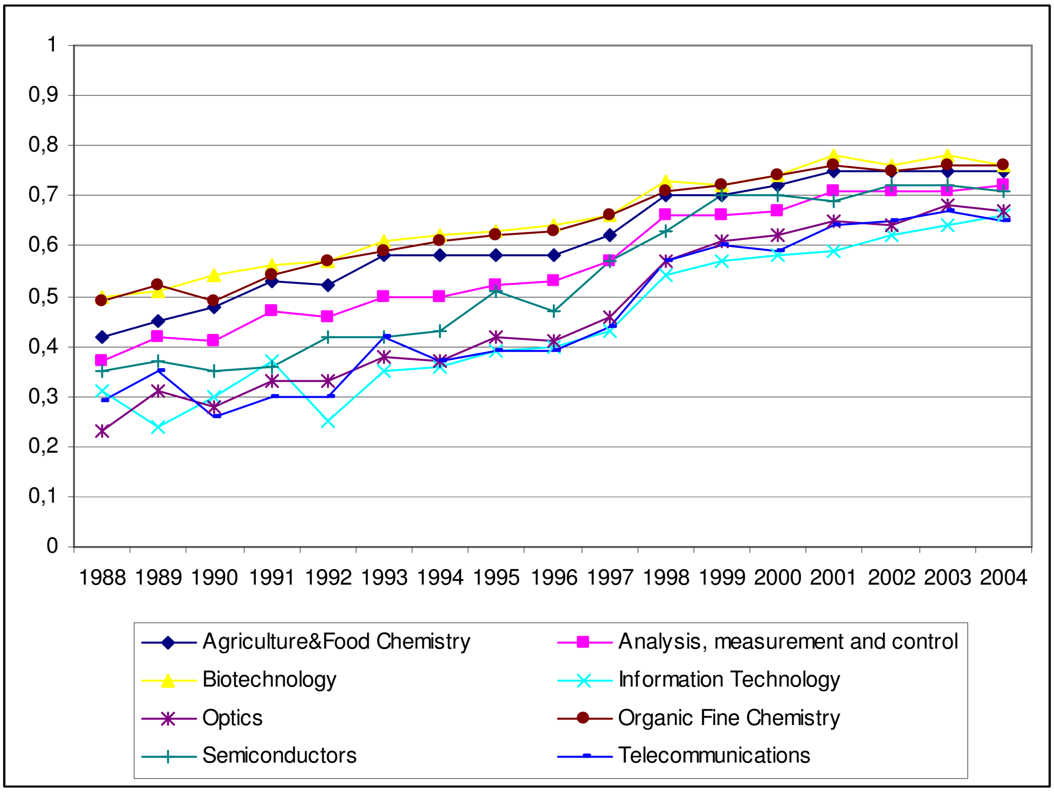

Table 2. Importance of various spatial scales for collaboration in science

	NUTS3	NUTS2	NUTS1	National	National (total)	EU	USA	International
Agriculture & food chemistry	0,08	0,02	0,07	0,11	0,28	0,42	0,16	0,13
Analysis, measurement and control technnology	0,07	0,02	0,06	0,08	0,23	0,45	0,17	0,15
Biotechnology	0,10	0,03	0,08	0,10	0,30	0,41	0,17	0,12
Information technology	0,08	0,03	0,07	0,12	0,30	0,40	0,16	0,14
Optics	0,06	0,01	0,04	0,12	0,23	0,44	0,14	0,19
Organic fine chemistry	0,10	0,03	0,09	0,11	0,33	0,40	0,16	0,11
Semiconductors	0,04	0,01	0,04	0,10	0,19	0,46	0,13	0,23
Telecommunication technology	0,06	0,02	0,04	0,11	0,23	0,42	0,17	0,18

Figure 3 and 4. Spatial patterns of scientific collaboration in agriculture & food chemistry and biotechnology

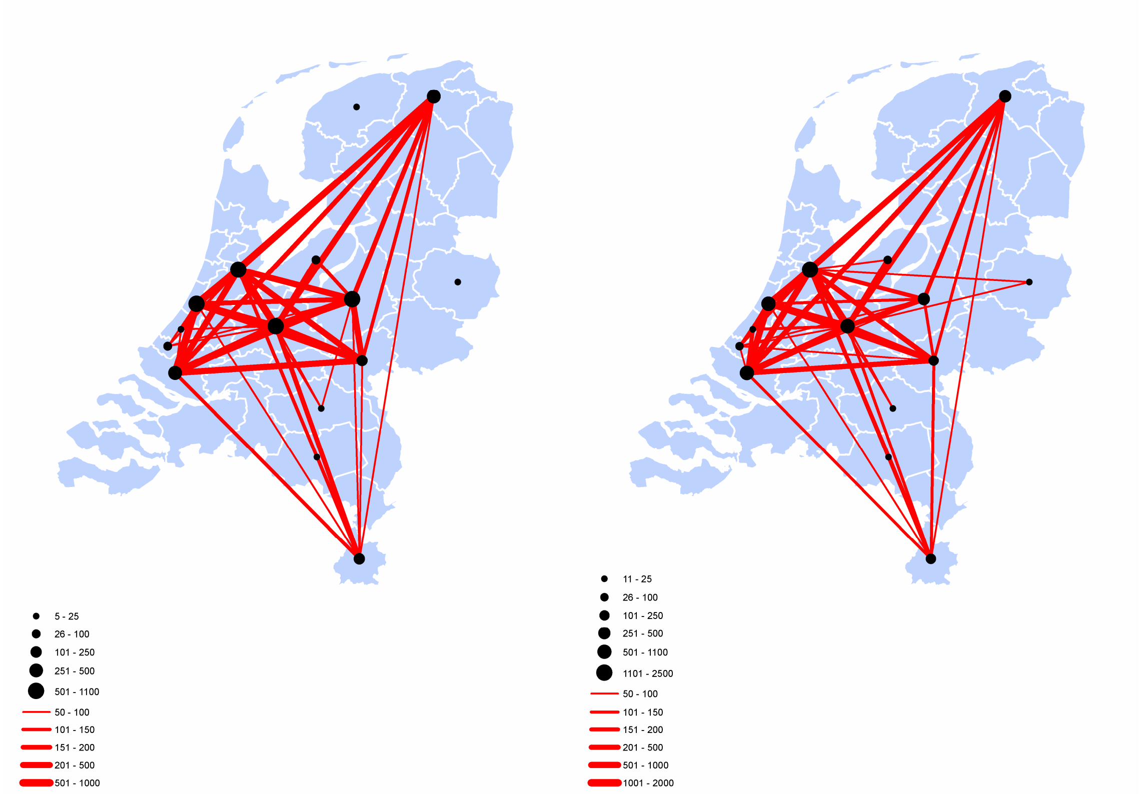

Figure 5 and 6. Spatial patterns of scientific collaboration in organic fine chemistry and analysis, control & measurement technology

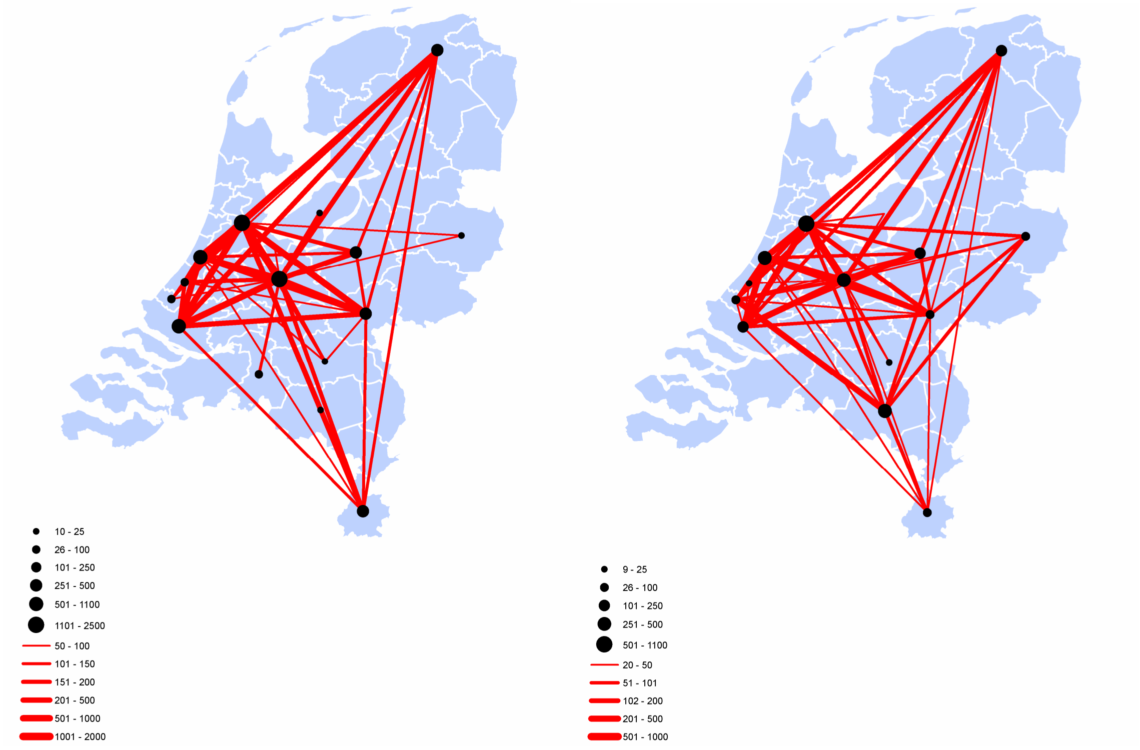

Figure 7 and 8. Spatial patterns of scientific collaboration in information technology and optics

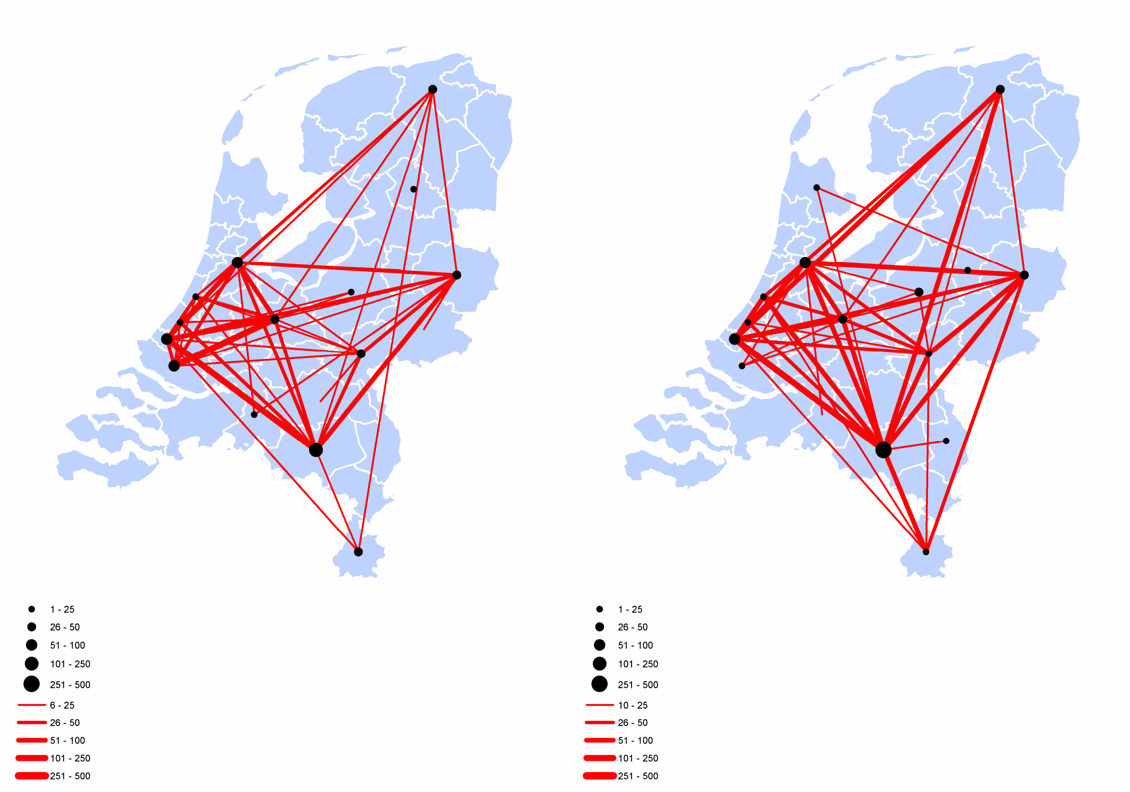

Figure 9 and 10. Spatial patterns of scientific collaboration in semiconductors and telecommunications

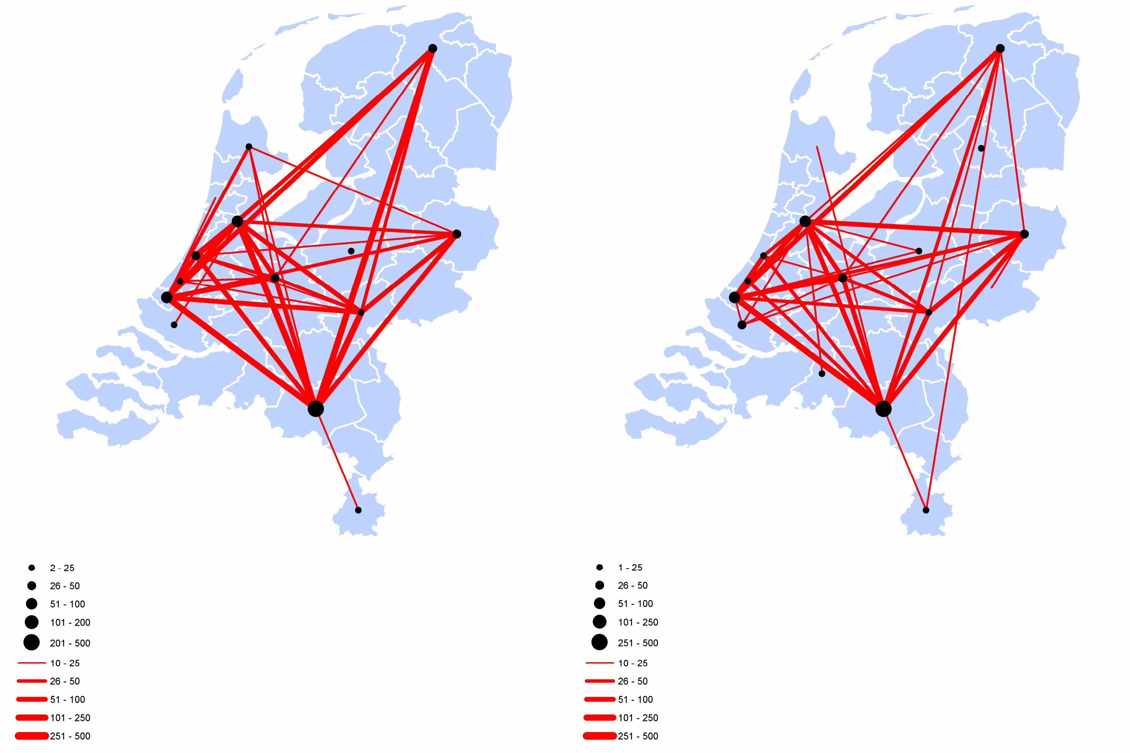

Figure 11. Share of different forms of collaboration in science per technology.

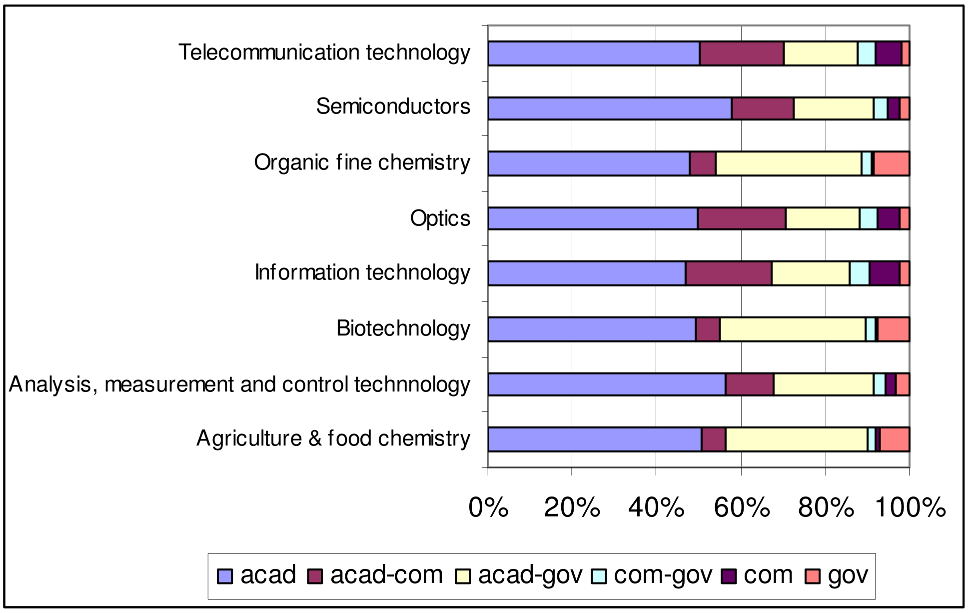

Table 3. Multiple Chi-square tests on importance of various spatial scales for different forms of collaboration

		NUTS3	**NUTS2**	**NUTS1**	**National**	**EU**	**USA**	**International**
Life Sciences		*(A)*	*(B)*	*(C)*	*(D)*	*(E)*	*(F)*	*(G)*
Agriculture & food chemistry	*acad*	(39.9%)	A (54.9%)	A (51.2%)	A (50.3%)	A C D (58.8%)	A B C D E G (62.5%)	A C D (59.40%)
	acad-com	G (6.4%)	A E F G (9.5%)	E G (7.8%)	A C E F G (10.1%)	G (5.8%)	G (6.6%)	(3.50%)
	acad-gov	B C D E F G (53.7%)	(35.5%)	E F G (40.9%)	E F (39.6%)	F (35.4%)	(30.9%)	F (37.10%)
Biotechnology	*acad*	(38.3%)	A (48.0%)	A (49.9%)	A (52.8%)	A B C D (57.6%)	A B C D E G (60.1%)	A B C D (57.20%)
	acad-com	G (5.8%)	G (7.7%)	G (6.2%)	A C E F G (9.9%)	G (6.0%)	A E G (7.7%)	(3.20%)
	acad-gov	B C D E F G (55.9%)	D E F (44.3%)	D E F G (43.8%)	F (37.4%)	F (36.3%)	(32.2%)	E F (39.50%)
Organic Fine Chemistry	*acad*	(39.0%)	A (46.3%)	A (46.5%)	A C (49.8%)	A B C D (57.0%)	A B C D E (59.5%)	A B C D (58.40%)
	acad-com	G (5.5%)	A G (8.6%)	A G (7.8%)	A C E F G (11.1%)	A G (7.5%)	A G (8.3%)	(3.70%)
	acad-gov	B C D E F G (55.5%)	D E F G (45.2%)	D E F G (45.7%)	E F (39.0%)	F (35.5%)	(32.2%)	E F (37.90%)
Physical Sciences								
Information technology	*acad*	(39.3%)	(27.9%)	A B D (64.5%)	B (46.9%)	A B D (56.4%)	A B D (56.7%)	A B D E F (65.10%)
	acad-com	C E G (35.2%)	C E G (34.2%)	(14.1%)	C E G (35.4%)	(19.3%)	C E G (29.9%)	(14.30%)
	acad-gov	F (25.4%)	C D E F G (37.9%)	F (21.4%)	(17.7%)	D F (24.3%)	(13.4%)	F (20.60%)
Optics	*acad*	(19.7%)	(28.3%)	A B D (54.2%)	A B (44.2%)	A B D (57.4%)	A B C D E (64.1%)	A B C D E (67.30%)
	acad-com	C E F G (40.0%)	C E F G (50.0%)	G (29.0%)	C E F G (43.0%)	G (22.6%)	G (22.3%)	(10.40%)
	acad-gov	B C D E F G (40.3%)	(21.7%)	(16.8%)	(12.8%)	D F (20.0%)	(13.6%)	D F (22.30%)
Semiconductor technology	*acad*	(31.4%)	(33.6%)	A B D (64.6%)	A (46.9%)	A B D (65.5%)	A B D (65.3%)	A B D E (69.90%)
	acad-com	C E F G (32.7%)	G (19.5%)	G (13.1%)	B C E F G (39.7%)	G (14.7%)	G (18.0%)	(6.90%)
	acad-gov	C D E F G (35.9%)	C D E F G (46.9%)	D (22.3%)	(13.4%)	D (19.8%)	(16.7%)	D E F (23.20%)
Telecommunication	*acad*	(30.4%)	(21.8%)	A B D (60.4%)	A B (46.9%)	A B D (58.8%)	A B D (62.5%)	A B D E (65.90%)
	acad-com	C E F G (41.1%)	C E F G (44.8%)	G (20.8%)	C E F G (40.5%)	G (19.6%)	E G (23.9%)	(10.70%)
	acad-gov	D E F (28.4%)	C D E F (33.3%)	(18.8%)	(12.6%)	D F (21.6%)	(13.5%)	D F (23.40%)
Analysis, measurement & control technology	*acad*	(42.2%)	(49.4%)	A (51.5%)	A (54.0%)	A B C D (64.7%)	A B C D (67.2%)	A B C D (65.80%)
	acad-com	E F G (17.4%	C E F G (21.5%)	E F G (14.1%)	A C E F G (25.3%)	G (11.0%)	G (10.5%)	(6.60%)
	acad-gov	B C D E F G (40.4%	D F (29.1%)	D E F G (34.4%)	(20.7%)	D (24.3%)	(22.3%)	D E F (27.60%)

Table 4. Results of the negative binominal gravity model regression

Life Sciences		*mass*	*traveltime*	*constant*	*N*	*number of collaborations*	*Pseudo R2*	*Log likelihood*
agriculture & foodchemistry	Total	0,857*** (0,018)	-0,008*** (0,001)	-7,647*** (0,186)	1.521	16.084	0,2970	-2481,06
	Acad	0,937*** (0,030)	-0,003*** (0,001)	-8,363*** (0,328)	324	6.770	0,2840	-713,76
	acad-com	0,957*** (0,039)	-0,004*** (0,001)	-7,032***(0,308)	1.024	1.191	0,3260	-833,6
	acad-gov	0,955*** (0,028)	-0,007*** (0,001)	-8,177*** (0,274)	1.444	6.166	0,3120	-1681,04
biotechnology	Total	0,851*** (0,018)	-0,009*** (0,001)	-7,616*** (0,184)	1.521	19.759	0,2924	-2598,28
	Acad	0,912*** (0,028)	-0,004*** (0,001)	-8,122*** (0,308)	324	8.223	0,2985	-713,9
	acad-com	0,956*** (0,041)	-0,005*** (0,001)	-6,940*** (0,323)	1.024	1.298	0,3093	-895,36
	acad-gov	0,942*** (0,027)	-0,006*** (0,001)	-8,258*** (0,268)	1.444	7.953	0,3010	-1784,66
organic fine chemistry	Total	0,827*** (0,017)	-0,008*** (0,001)	-7,417*** (0,175)	1.600	22.220	0,2834	-2989,88
	Acad	0,943*** (0,025)	-0,004*** (0,001)	-8,642*** (0,281)	400	8.720	0,3353	-700,48
	acad-com	1,017*** (0,043)	-0,005*** (0,001)	-7,663*** (0,334)	1.089	1.592	0,2880	-1034,85
	acad-gov	0,975*** (0.028)	-0,006*** (0,001)	-8,769*** (0,281)	1.600	8.921	0,2914	-1957,25
Physical Sciences								
Information-technology	Total	0,927*** (0,034)	-0,006*** (0,001)	-7,047*** (0,289)	1.089	2.074	0,3118	-991,23
	Acad	0,953*** (0,066)	-0,002* (0,001)	-6,838*** (0,516)	289	873	0,2459	-481,66
	acad-com	0,927*** (0,049)	-0,006*** (0,001)	-5,874*** (0,343)	784	554	0,3721	-434,24
	acad-gov	0,894*** (0,071)	-0,006*** (0,001)	-5,381*** (0,448)	441	417	0,2416	-494,71
optics	Total	0,955*** (0,030)	-0,003*** (0,001)	-7,890*** (0,271)	1.024	2.939	0,3219	-1076,16
	Acad	1,043*** (0,061)	-0,000 (0,001)	-8,124*** (0,501)	225	1.004	0,2557	-447,97
	acad-com	0,935*** (0,046)	-0,002 (0,001)	-6,831*** (0,335)	900	1.025	0,3254	-667,01
	acad-gov	0,881***(0,065)	-0,005*** (0,001)	-5,517*** (0,445)	361	517	0,2895	-411,03
Semiconductor-technology	Total	0,954*** (0,033)	-0,005*** (0,001)	-7,612*** (0,291)	784	2.789	0,3522	-815,79
	Acad	0,974*** (0,057)	-0,001 (0,001)	-7,477*** (0,475)	196	1.179	0,3096	-377,47
	acad-com	0,902*** (0,060)	-0,004** (0,020)	-6,113*** (0,398)	529	783	0,2695	-480,78
	acad-gov	0,882*** (0,077)	-0,005*** (0,001)	-5,487*** (0,504)	324	544	0,2605	-413,58
Telecommunication-technology	Total	0,964*** (0,032)	-0,004*** (0,001)	-7,722*** (0,278)	1.089	2.530	0,3435	-975,47
	Acad	0,989*** (0,06)	-0,002* (0,001)	-7,326*** (0,469)	289	968	0,2668	-488,21
	acad-com	0,960*** (0,049)	-0,004*** (0,001)	-6,611*** (0,363)	784	830	0,3544	-497,37
	acad-gov	0,908*** (0,063)	-0,004*** (0,001)	-5,688*** (0,410)	441	428	0,2788	-456,64
analysis, control & measurement technology	Total	0,911*** (0,022)	-0,005*** (0,001)	-8,107*** (0,224)	1.521	8.160	0,3319	-1746,27
	Acad	0,914*** (0,043)	-0,002* (0,001)	-7,695*** (0,420)	289	3.650	0,2356	-685,66
	acad-com	0,932*** (0,039)	-0,006*** (0,001)	-6,736*** (0,301)	1.089	1.452	0,3187	-975,01
	acad-gov	0,855*** (0,033)	-0,007*** (0,001)	-6,333*** (0,289)	1.156	2.281	0,3396	-958,93

Significance levels: *** 0,99, ** 0,95, * 0,9