Chapter 3
Death of Distance in Science? A Gravity Approach to Research Collaboration

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3.1 Introduction

One of the major transitions in recent scientific research is the rise of network theory motivating a variety of new research programmes in and across various disciplines. Economic geography has been no exception. The work on networks in economic geography can be divided into two types of research. First, there are studies on inter-firm networks and their impact on firm performance. For a large part, such studies have been carried out in the context of geographical clusters, which are often characterised by strong network relations (Uzzi, 1997). A second approach, an example of which is presented below, concerns the study of inter-regional networks and their impact on regional growth. Here, the unit of analysis are territories, typically sub-national regions. The interest in this topic stems from Castells (1996) and others who have argued that regional growth increasingly depends on a region's position in global networks rather than its specific local characteristics such as institutions, endowments and amenities ('space of flows' versus the 'space of places').

The reorientation in economic geography from the study of the 'space of places' to the 'space of flows' has lead some to argue that a new 'relational economic geography' paradigm is emerging. In such a paradigm, territories are not to be seen as meaningful unit of analysis with certain objective characteristics, but as 'socially constructed' in the ongoing interactions between social actors (Bathelt and Glückler, 2003). Such a conception fits well with the concept of the knowledge-based society where economic development is increasingly dependent on intangibles.

The study of inter-regional networks and the Castells thesis also relate to evolutionary economics and its application to economic geography (Boschma and Frenken, 2006). In recent evolutionary models of network formation, network evolution is understood as an entry process of new nodes connecting with certain probability to existing nodes depending on the latter connectivity (Barabasi and Albert, 1999). This logic of 'preferential attachment' explains the emergence of

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spatial core-periphery structure among regions as a process of network growth. Such networks concern, for example, transportation systems, multinational corporations and labour mobility flows. More recent models have explicitly incorporated geography in evolutionary models of network evolution by having the connection probability of a new node to an existing node also depend on the geographical proximity between two nodes (Guimerà and Amaral, 2004; Barrat et al., 2005). In this way, a parameter can be introduced to reflect transportation costs such that different network structures can be explained by differences in transportation costs.

In this study, we are interested in inter-regional networks of scientific knowledge production as a specific example of spatial networks. Popular belief holds that geography no longer matters in scientific collaboration. With the arrival of cheap air travel, English as a global language and the Internet, science has become truly global – at least according to common wisdom. What is more, increasing funding opportunities to engage in international partnerships have further facilitated long-distance collaboration. A growing number of studies on international collaboration seem to evidence this trend (Narin et al., 1991; Luukkonen et al., 1993; Frenken, 2002; Wagner and Leydesdorff, 2005; Maggioni and Uberti, 2007).

Yet, without disputing the secular trend of the internationalisation of scientific research in recent history, the 'death of distance' hypothesis has not been proven in this particular field. One may wonder whether the forces that are 'flattening' the world indeed removed the geographical barriers to collaborate in science. Earlier studies looking at inter-regional collaboration found that geography is still relevant in facilitating scientific collaboration within countries. Studies on collaboration within the UK (Katz, 1994), China (Liang and Zhu, 2002) and The Netherlands (Ponds et al., 2007) show that geographical distance reduces the probability of researchers to collaborate.

We test the 'death of distance in science' hypothesis by focusing on both international and inter-regional research collaboration based on scientific publications with multiple addresses. Our data set consist of three distinct subsets that cover geographical areas at several spatial levels of aggregation. We explain the collaboration intensity between 36 countries in the world, 1316 regions in Europe and 40 regions in the Netherlands from their respective scientific output and geographical distance using gravity equations. In addition to possible barriers stemming from geographical distance, we also analyse barriers stemming from 'institutional distance' in the form of national borders and in the form of dissimilarities between organisational backgrounds, respectively.

3.2 Science and Proximity

If anything has characterised knowledge production in science during the twentieth century, it is its increased collaborative nature (Meyer and Bhattacharya, 2004). Co-authorships accounted for less than 10% of all publications at the start of the twentieth century, while co-authorships account for over 50% of all publications at the end of the twentieth century (Wagner-Doebler, 2001). The share of international collaboration has also been increasing (Narin et al., 1991; Wagner and Leydesdorff, 2005).

The general facilitator of this trend has been technological advance in transport and in information and communication technology. Yet, there are also specific reasons that explain the increasing tendency to collaborate. With the universe of scientific knowledge ever expanding, researchers need to specialise to remain able to contribute to state-of-the-art knowledge production. Specialisation in turn necessitates to collaborate with relevant partners, which may only be found over longer distances. As the costs of training and research infrastructures are increasing, collaboration also provides opportunities to pool resources and to realise savings by avoiding duplication of research efforts (Katz and Martin, 1997).

Collaboration is expected to bring intellectual benefits from the cross-fertilisation of ideas that previously were unconnected. One way to indicate these benefits is by comparing citation rates. Co-authored papers receive more papers than single-authored ones, and internationally co-authored papers receive more citations than nationally co-authored ones (Narin et al., 1991; Katz and Martin, 1997; Frenken et al., 2005).

At the national and European level, particular funding schemes provide economic incentives to promote collaborative knowledge production. For instance, the particular aim of the European Union is to create an integrated pan-European research system (i.e. European Research Area). Hence, their funding schemes are explicitly focused on funding international research projects and on removing barriers that currently hinder researchers. The financial efforts of the European Union for collaboration in science and technology have once again been increased substantially in the seventh framework programme (2007–2013).

While the internationalisation trend in research collaboration has received a lot of attention in recent times, only a few scholars have focused on the specific role of geography in scientific knowledge production. Yet, we hypothesise that geography is still important for research collaboration for reasons related to the background of the scholar as well as to the context in which he/she operates. With regard to the latter aspect, transportation costs are still present and in view of this, costs of collaboration are expected to increase as a function of geographical distance. Hence, two researchers that are geographically proximate are more inclined to collaborate as compared to two researchers that are geographically distant. Furthermore, many barriers to collaboration still have to be overcome when crossing national borders as most of the relevant institutions such as property right regimes, labour markets, university regulations and funding schemes are still organised predominantly at the national level (Edquist and Johnson, 1997). Accordingly, two researchers operating in the same country are more inclined to collaborate as compared to two researchers operating in two different countries.

With respect to the background of the scholar, barriers exist when researchers from different organisations are collaborating due to differing goals and underlying incentive structures. For instance, academic scholars want to maximise the diffusion of their knowledge, while industrial agents want to minimise such diffusion.

The complexity of these collaborations renders it generally impossible to encode all contingencies in a contract and consequently, these collaborations have to rely, at least partially, on less formal institutions thereby reducing the risk of opportunism. Therefore, it is expected that in the case of collaboration between academic and non-academic organisations geographical proximity may be supportive in establishing successful partnerships. Geographical proximity may help to overcome problems related to differing goals and incentives, because of a common interest in exchanging labour, accessing local funds and mutual trust induced by informal contacts and interaction. Thus, two researchers from organisations with similar backgrounds are more inclined to collaborate over longer distances than two researchers with different backgrounds.

In short, despite the decreased costs associated with long-distance collaboration due to cheap air travel and the Internet, and despite the efforts of the European Commission to further promote international collaboration with the European Union, we expect ‘proximity’ – both in the form of geographical and in the form of institutional proximity – to remain an important determinant of research collaboration (Gertler, 2005; Boschma, 2005; Torre and Rallet, 2005).

3.3 Data and Methodology

3.3.1 Data

In this study, the quantity of scientific collaboration is measured using co-publications. Scientific publications are the most common form of output in scientific research, which implies that collaboration in scientific research will often be reflected in a co-publication. The data on these co-publications have been retrieved from *web of sciences* (wos). Web of science contains information on publications in all major journals in the world from 1988 onwards. From this database we retrieved the address information on publications and constructed three distinct data sets.

The first data set concerns international co-publications between countries for 36 countries in the world for the year 2004. The countries were selected based on their scientific output and population numbers.[1] Subsequently, the number of collaborations between countries was identified by using the AND query in the address field applied to each possible pair of countries and covering all scientific disciplines.

[1] More specifically, we selected all countries with a population of more than one million inhabitants and with a total scientific output of more than 5000 articles in 2004. We ended up with the following 36 countries: (1) Argentina, (2) Australia, (3) Austria, (4) Belgium, (5) Brazil, (6) Bulgaria, (7) Canada, (8) China, (9) Denmark, (10) Finland, (11) France, (12) Georgia, (13) Germany, (14) Greece, (15) Hungary, (16) Ireland, (17) Israel, (18) Italy, (19) Japan, (20) Korea, (21) Mexico, (22) Netherlands, (23) New Zealand, (24) Norway, (25) Poland, (26) Portugal, (27) Romania, (28) Singapore, (29) South Africa, (30) Spain, (31) Sweden, (32) Switzerland, (33) Taiwan, (34) Turkey, (35) United Kingdom, (36) United States.

The second data set (Frenken et al., 2007) was constructed for two scientific disciplines. The disciplines concern ‘biochemistry and molecular biology’ (BMB) and ‘electrical and electronical engineering’ (EEE), following the classification of Verbeek et al. (2002). This database consists of all inter-regional co-publications in the EU27 and Norway and Switzerland for the period 1988–2004. Regions are classified on the NUTS3 level, which roughly corresponds to labour market areas. We were not able to locate all addresses and also removed some remote locations from the database. The outcome is a total number of 1316 NUTS3 regions instead of 1329.[2] Hence, all addresses occurring in publications have been assigned to one of the 1316 NUTS3 regions in the aforementioned 29 countries in Europe.

The third database (Ponds et al., 2007) contains all scientific publications in the Netherlands for eight selected scientific disciplines in physical and life sciences, again following the classification of Verbeek et al. (2002).[3] More specifically, all publications with at least one address in the Netherlands have been retrieved for the period 1988–2004 and subsequently classified at the NUTS3 level. This database also distinguishes between three different types of organisations: academic organisations, firms and governmental/non-profit-making organisations. In order to do so, we used an algorithm with a list of abbreviations and words to assign each address to one of three types of organisations. For example, organisations with ‘univ’ in its name are assumed to be a university and therefore an academic organisation. Furthermore, specific names of Dutch research organisations were included in the algorithm. In the end, 99% of the organisations were assigned correctly to one of the three types of organisations and one of 40 NUTS3-regions.

In all the data sets, a collaboration link is represented by a co-publication with multiple addresses, either in different countries (database 1) or in different regions (databases 2 and 3). The collaboration intensity between region i and j, labelled I_{ij}, is then defined by the number of times addresses from these two countries/regions co-occur in a publication. Intensity of collaboration between two countries or regions is thus measured by ‘full counting’. For example, if a publication contains three addresses in three different regions, the collaboration intensity between each pair of regions is 1. Alternatively, one can use fractional counting where a

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[2] We were not able to locate the addresses within the greater urban areas of London and Manchester and as a result consolidated them into two new ones. Furthermore, we excluded some islands due to their remote locations and disproportional great geographical distances to other regions. These islands are: Guadeloupe Las Palmas (ES), Santa Cruz de Tenerife (ES), Guadeloupe (FR), Martinique (FR), Guyane (FR), Réunion (FR), Região Autónoma dos Acores (PT) and Região Autónoma da Madeira (PT). The outcome is a total number of 1316 NUTS3 regions instead of 1329.

[3] These technologies are: (1) agriculture and food chemistry, (2) biotechnology, (3) organic fine chemistry, (4) information technology, (5) optics, (6) semiconductor technology, (7) telecommunication technology, (8) analysis, measurement and control technology. The two scientific disciplines analysed in exercise 2 are subdisciplines of biotechnology and semiconductor technology, respectively.

co-occurrence of two regions in a publication is divided by the total number of collaborations. For example, if a publication contains three addresses in three different regions, the collaboration intensity between each pair of regions is 1/3.[4]

3.3.2 Gravity Model

We apply a gravity model to explain the number of co-publications between two countries or regions from the respective size of the entities and their geographical and institutional proximities.[5]

Spatial interaction, the process whereby actors at different points in physical space make contacts, can be revealed by applying an analogical model of Isaac Newton's Theory of Universal Gravitation (Tinbergen, 1962; Sen and Smith, 1995; Roy and Thill, 2004). In a gravity model, the gravitational force – in this case the collaboration intensity between two objects – is assumed to be dependent on the mass of the objects and the distance between them. The basic gravity equation is therefore as follows:

$$I_{ij} = \alpha_1 \frac{MASS_i^{\alpha_2} MASS_j^{\alpha_3}}{DISTANCE_{ij}^{-\alpha_4}}. \tag{3.1}$$

Taking logarithms on both sides of the equation and introducing general exponents, such a gravity model can be estimated using linear regression:

$$\ln I_{ij} = \ln \alpha_1 + \ln \alpha_2 MASS_i + \ln \alpha_3 MASS_j + \alpha_4 \ln DISTANCE_{ij} + \varepsilon, \tag{3.2}$$

where $MASS_i$ stands for the total number of publications in country/region i, $MASS_j$ stands for the total number of publications in country/region j, and $DISTANCE_{ij}$ for the geographical distance between two countries/regions.[6] It is important to take into account the total number of publications in a country or a region, because collaboration intensity is highly dependent on size. If collaboration would be random, most collaborations will automatically occur between the largest spatial units.

[4] The final matrix of inter-regional interaction strength based on full counting is very similar to the final matrix obtained by fractional counting.

[5] In this, we follow Maggioni and Uberti (2007) who applied this model to EU regions using datasets other than co-publications (co-inventorships, student mobility flows, hyperlinks and EU framework projects). A similar approach was also followed by Maurseth and Verspagen (2002) using inter-regional patent citation data.

[6] Because collaboration links are undirected by definition, we included a pair of countries/regions only once, which implies that the value of the coefficient of the two masses may slightly differ. Note also that in the second exercise we added one to all masses in order to allow for logarithmic transformations of observations without any publications.

In the first exercise we analyse collaborations between countries. Although measuring geographical distances between countries is not straightforward, we use a proxy that captures the flight distances between the capitals of the respective countries. We also include a dummy for the countries that are members of the European Union to test whether these countries are more inclined to collaborate with each other. So, we get

$$\begin{aligned}\ln I_{ij} = \ln \beta_1 + \beta_2 \ln MASS_i + \beta_3 \ln MASS_j + \\ \beta_4 \ln DISTANCE_{ij} + \beta_5 EU_{ij} + \varepsilon.\end{aligned} \tag{3.3}$$

In the second exercise, we analyse collaboration intensity between NUTS3 regions, where we use the logarithm of geographical distance in kilometres, where geographical distance $DISTANCE_{ij}$ is calculated between the central points of the regions (as the crow flies) using maps made available by the European Spatial Planning Observation Network (ESPON). In addition, we specify institutional proximity by a dummy $COUNTRY_{ij}$ which takes on a value of 1 for two regions belonging to the same country and 0 otherwise. So we get

$$\begin{aligned}\ln I_{ij} = \gamma_1 + \gamma_2 \ln MASS_i + \gamma_3 \ln MASS_j + \gamma_4 \ln DISTANCE_{ij} \\ + \gamma_5 COUNTRY_{ij} + \varepsilon.\end{aligned} \tag{3.4}$$

In the third exercise, we analyse collaborations between Dutch NUTS3 regions, where we distinguish between three different types of collaborations: collaborations between academic organisations, collaborations between academics and firms and collaborations between academic and governmental organisations. Since we were able to trace back the travel times between NUTS3-regions in the Netherlands, we used the more accurate variable $TRAVELTIME_{ij}$ instead of the physical distance between the regions.

$$\ln I_{ij} = \delta_1 + \delta_2 \ln(MASS_i MASS_j) + \delta_3 \ln TRAVELTIME_{ij} + \varepsilon. \tag{3.5}$$

Following Ponds et al. (2007), we treat masses here as the product, which is a different yet equivalent specification of the gravity equation.[7]

For collaborations between countries in the first data set and for collaborations within the Netherlands in the third data set, the gravity equation is estimated using negative binomial regression techniques. As we deal with count data and we have a conditional variance that is larger than the conditional mean (overdispersion), the negative binomial regression model seems to be most appropriate.

In the second data set (inter-regional collaboration) an excessive number of zero counts biases the results, for which we corrected by the use of a zero-inflated negative binomial regression. This method considers the existence of two (latent) groups

[7] The treatment of zeroes differs as well compared to the previous studies. For an overview of the exact data-treatment of the third exercise, we refer to Ponds et al. (2007).

Table 3.1 Specification of regression models

Model	Scale	Period	Countries	Disciplines and types of collaborations	Regression technique
1	Countries	2004	36 countries	All scientific disciplines	Negative Binomial
2–3	NUTS3	1988–2004	EU27 Norway Switzerland	Biochemistry and molecular biology (BMB) Electrical and electronical engineering (EEE)	Zero Inflated Negative Binomial
4–11	NUTS3	1988–2004	Netherlands	Eight disciplines in life sciences and physical sciences differentiating between academic, academic-firm and academic-governmental collaborations	Negative Binomial

within the population: a group having strictly zero counts and a group having a non-zero probability of counts different than zero. Correspondingly, its estimation process consists of two parts. The first part contains a logit regression of the predictor variables on the probability that there is no collaboration between two given regions at all. The second part contains a negative binomial regression on the probability of each count for the group that has a non-zero probability of count different than zero. A good technical discussion of the zero-inflated negative binomial model is provided by Long (1997). An overview of the three data sets and estimation techniques is provided in Table 3.1.

3.4 Results

Table 3.2 shows Model 1 reporting on the estimates for collaborations between countries. The alpha-statistic turns significant indicating that the estimates of the negative binomial regression model are most reliable in this case. The fit statistics of the model suggest that the added covariates adequately fit the data. Indeed size contributes positively indicating an increase in collaboration between two countries if the actors in these countries produce a larger number of publications.

The explanatory of main interest, geographical distance, shows a statistical significant effect on the knowledge collaboration between countries too. Geographical distance yields a negative and significant effect, indicating major impediments towards collaborations over longer distance. What is more, a significant effect for research collaborations within the EU is not found, suggesting that, apart from

Table 3.2 Regressions results for international collaborations between 36 countries in the world (Eq. 3.3)

	Model 1
Constant	3.711 (0.443)**
$MASS_i$ (ln)	0.535 (0.020)**
$MASS_j$ (ln)	0.754 (0.018)**
$DISTANCE_{ij}$	−0.425 (0.039)**
EU	0.076 (0.096)
Fit statistics	
Over dispersion (α)	0.571 (0.031)**
Log-likelihood	3795.263
Mc Fadden's Adj. R^2	0.119
AIC	12.068
N	630

Note: Significance levels: ** 0.99, * 0.95, Standard error in parentheses.

advantages that accrue from shorter distances between EU member states, collaborations between these states do not occur more often than collaborations between other countries in the world.

In Table 3.3 Models 2–5 are presented. The table shows the inter-regional regression models with both models presenting successively a negative binomial part, a zero-inflated part and some general fit statistics. The latter include tests checking

Table 3.3 Regressions results for inter-regional collaborations in Europe (Eq. 3.4)

	Model 2	Model 3
	BMB	EEE
Negative binomial part		
Constant	−5.401 (0.086)**	−4.064 (0.133)**
$MASS_i$ (ln)	0.649 (0.005)**	0.533 (0.009)**
$MASS_j$ (ln)	0.636 (0.005)**	0.552 (0.010)**
$DISTANCE_{ij}$ (ln)	−0.368 (0.010)**	−0.301 (0.016)**
$COUNTRY_{ij}$	1.160 (0.022)**	0.824 (0.036)**
Zero-inflated part		
Constant	7.366 (0.165)**	6.999 (0.202)**
$MASS_i$ (ln)	−0.770 (0.009)**	−0.851 (0.013)**
$MASS_j$ (ln)	−0.779 (0.009)**	−0.832 (0.014)**
$DISTANCE_{ij}$ (ln)	0.359 (0.021)**	0.423 (0.027)**
$COUNTRY_{ij}$	−1.359 (0.048)**	−1.112 (0.059)**
Fit statistics		
Over dispersion (α)	0.881 (0.014)**	1.333 (0.034)**
Vuong-statistic	27.250**	20.410**
Log-likelihood	−99774.550	−51301.529
Mc Fadden's Adj. R^2	0.458	0.439
AIC	0.231	0.119
N	865270	865270
Non-zero observations	25589	12531

Note: Significance levels: ** 0.99, *0.95. Standard error in parentheses.

whether the choice of zero-inflated negative binomial regression models is appropriate. Overall, the likelihood ratio test of over dispersion and the Vuong-statistic are significant suggesting that the zero-inflated negative binomial regression model presents the most efficient estimates.

It is essential to keep in mind that a positive sign in the zero-inflated part indicates that with a one percent positive change in the predictor, the chance of belonging to the ‘strictly zero group’ increases, ceteris paribus. Thus, the coefficients in the zero-inflated part should be interpreted reversely in comparison to the negative binomial part: a positive value in the negative binomial part has the same meaning as a negative value in the zero-inflated part and *vice versa*.

Again the estimations indicate that geographical proximity matters for collaborations. An increase in distance negatively affects the chance and intensity of collaboration between two regions. The dummy variable indicating institutional proximity (here, whether two regions belong to the same country) shows the expected positive signal and turns out to be significant. This indicates that apart from a general effect of geographical distance on research collaboration, there is also an extra effect of institutional distance on the chance and intensity of research collaboration.

In Tables 3.4, 3.5 and 3.6, Models 4–11 further zoom in and show the results for inter-regional collaborations between Dutch NUTS3-regions differentiated to institutional backgrounds. Within life sciences (Models 4–6), 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 organisations than for academic collaboration and collaboration between firms and academics. Differences are, however, relatively small. The higher coefficients for collaboration between academic and non-academic organisations suggest that geographical proximity is more important for these forms of collaboration.

In the case of the physical science-based technologies (Models 7–11), travel time has no significant effect on the intensity of academic collaborations at all. Collaborations between all other types of collaborations turn out to be significant with the exception of academic-company relations in the field of optics. Yet, in physical sciences differences between academic-governmental relations and academic-firm relations are absent with the exception of the fields of optics[8].

We thus obtain quite different results for academic collaborations when compared to all other types of collaborations. Even at the relatively small scale of the Netherlands, geographical proximity is still important for collaborations. Yet, the importance varies between forms of collaboration, and academic collaborations do not seem to be sensitive for geographical distance. The result suggests that university scholars are less sensitive for geographical distance in collaboration. One can

[8] A more explicit treatment of differences between scientific disciplines in the extent and reach of collaboration can be found in Ponds et al. (2007).

Table 3.4 Regression results for inter-regional collaborations in the Netherlands (Eq. 3.5)

Life sciences	Constant	MASS (ln)	$TRAVELTIME_{ij}$	Over dispersion	Log-likelihood	Adj. R^2	*N*
Model 4: Agriculture and food chemistry							
Total	−7.647 (0.186)**	0.857 (0.018)**	−0.008 (0.001)**	0.649 (0.053)**	−2481.06	0.297	1521
Acad	−8.363 (0.328)**	0.937 (0.030)**	−0.003 (0.001)**	0.411 (0.074)**	−713.76	0.284	324
Acad-com	−7.032 (0.308)**	0.957 (0.039)**	−0.004 (0.001)**	0.687 (0.100)**	−833.60	0.326	1024
Acad-gov	−8.177 (0.274)**	0.955 (0.028)**	−0.007 (0.001)**	0.855 (0.080)**	−1681.04	0.312	1444
Model 5: Biotechnology							
Total	−7.616 (0.184)**	0.851 (0.018)**	−0.009 (0.001)**	0.692 (0.054)**	−2598.28	0.292	1521
Acad	−8.122 (0.308)**	0.912 (0.028)**	−0.004 (0.001)**	0.338 (0.055)**	−713.90	0.299	324
Acad-com	−6.940 (0.323)**	0.956 (0.041)**	−0.005 (0.001)**	0.920 (0.119)**	−895.36	0.309	1024
Acad-gov	−8.258 (0.268)**	0.942 (0.027)**	−0.006 (0.001)**	0.919 (0.085)**	−1784.66	0.301	1444
Model 6: Organic fine chemistry							
Total	−7.417 (0.175)**	0.827 (0.017)**	−0.008 (0.001)**	0.710 (0.050)**	−2989.88	0.283	1600
Acad	−8.642 (0.281)**	0.943 (0.025)**	−0.004 (0.001)**	0.256 (0.044)**	−700.48	0.335	400
Acad-com	−7.663 (0.334)**	1.017 (0.043)**	−0.005 (0.001)**	1.142 (0.129)**	−1034.85	0.288	1089
Acad-gov	−8.769 (0.281)**	0.975 (0.028)**	−0.006 (0.001)**	1.100 (0.092)**	−1957.25	0.291	1600

Note: Significance levels: **0.99, *0.95. Standard error in parentheses.

Table 3.5 Regression results for inter-regional collaborations in the Netherlands (Eq. 3.5)

Physical sciences	Constant	MASS (ln)	$TRAVELTIME_{ij}$	Over dispersion	Log-likelihood	Adj. R^2	N
Model 7: Information technology							
Total	−7.047 (0.289)**	0.927 (0.034)**	−0.006 (0.001)**	0.841 (0.110)**	−991.23	0.312	1089
Acad	−6.838 (0.516)**	0.953 (0.066)**	−0.002 (0.001)	0.798 (0.123)**	−481.66	0.246	289
Acad-com	−5.874 (0.343)**	0.927 (0.049)**	−0.006 (0.001)**	0.683 (0.142)**	−434.24	0.372	784
Acad-gov	−5.381 (0.448)**	0.894 (0.071)**	−0.006 (0.001)**	0.777 (0.143)**	−494.71	0.242	441
Model 8: Optics							
Total	−7.890 (0.271)**	0.955 (0.030)**	−0.003 (0.001)**	0.581 (0.079)**	−1076.16	0.322	1024
Acad	−8.124 (0.501)**	1.043 (0.061)**	−0.000 (0.001)	0.420 (0.081)**	−447.97	0.256	225
Acad-com	−6.831 (0.335)**	0.935 (0.046)**	−0.002 (0.001)	1.030 (0.152)**	−667.01	0.325	900
Acad-gov	−5.517 (0.445)**	0.881 (0.065)**	−0.005 (0.001)**	0.686 (0.123)**	−411.03	0.290	361
Model 9: Semiconductor technology							
Total	−7.612 (0.291)**	0.954 (0.033)**	−0.005 (0.001)**	0.518 (0.077)**	−815.79	0.3522	784
Acad	−7.477 (0.475)**	0.974 (0.057)**	−0.001 (0.001)	0.312 (0.061)**	−377.47	0.310	196
Acad-com	−6.113 (0.398)**	0.902 (0.060)**	−0.004 (0.020)*	1.557 (0.248)**	−480.78	0.270	529
Acad-gov	−5.487 (0.504)**	0.882 (0.077)**	−0.005 (0.001)**	0.932 (0.156)**	−413.58	0.261	324

Note: Significance levels: **0.99, *0.95. Standard error in parentheses.

Table 3.6 Regression results for inter-regional collaborations in the Netherlands (Eq. 3.5)

Physical sciences	Constant	MASS (ln)	$TRAVELTIME_{ij}$	Over dispersion	Log-likelihood	Adj. R^2	N
Model 10: Telecommunication technology							
Total	−7.722 (0.278)**	0.964 (0.032)**	−0.004 (0.001)**	0.588 (0.083)**	−975.47	0.344	1089
Acad	−7.326 (0.469)**	0.989 (0.060)**	−0.002 (0.001)	0.558 (0.096)**	−488.21	0.267	289
Acad-com	−6.611 (0.363)**	0.960 (0.049)**	−0.004 (0.001)**	0.883 (0.159)**	−497.37	0.354	784
Acad-gov	−5.688 (0.410)**	0.908 (0.063)**	−0.004 (0.001)**	0.513 (0.111)**	−456.64	0.279	441
Model 11: Analysis, control & measurement technology							
Total	−8.107 (0.224)**	0.911 (0.022)**	−0.005 (0.001)**	0.637 (0.064)**	−1746.27	0.332	1521
Acad	−7.695 (0.420)**	0.914 (0.043)**	−0.002 (0.001)	0.583 (0.087)**	−685.66	0.236	289
Acad-com	−6.736 (0.301)**	0.932 (0.039)**	−0.006 (0.001)**	0.868 (0.103)**	−975.01	0.319	1089
Acad-gov	−6.333 (0.289)**	0.855 (0.033)**	−0.007 (0.001)**	0.734 (0.101)**	−958.93	0.340	1156

Note: Significance levels: **0.99, *0.95. Standard error in parentheses.

assume that academic collaborations involve the production of knowledge that is more codified than the knowledge produced in collaborations in which a firm or government agency participates. In this light, our results are in line with the idea that collective production of codified knowledge is less dependent on face-to-face contact, and thus less sensitive to geographical distance.

3.5 Conclusions

In this contribution, we tested the 'death of distance' hypothesis for research collaboration using data on publications with multiple addresses. In contrast with previous studies focusing on collaborations between nation states, this study also analysed inter-regional collaboration both within countries and between countries. We tested the effect of geographical proximity and institutional proximity using the gravity equation and found strong evidence that geographical distance and national borders still hamper research collaboration. However, by distinguishing between different types of collaborations for the Netherlands, we find that geographical proximity matters significantly less in establishing collaboration between academic organisations than in case of all other types of collaborations.

In light of research policy, our analysis proves that policies to enhance the propensity of collaboration over long distances and across national borders remain necessary. We found evidence that the effect of geographical proximity exists independently of national borders, suggesting that the process of integration between as well as within countries is incomplete. This means that in further integrating research systems there is a role for actors at several spatial scales. Thus, in light of European policy the efforts to create a European Research Area seem well justified but also need to be complemented by efforts of its member states.[9]

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[9] For an in-depth discussion of EU research policies in this context, see Frenken et al. (2007).

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