Scientific collaboration in the Danish-German border region of Southern Jutland-Schleswig

Teemu Makkonen

University of Southern Denmark, Department of Border Region Studies

Address: Alsion 2, DK-6400 Sønderborg, Denmark

telephone: +45 6550 8302 ; e-mail: teemu@sam.sdu.dk

AND

University of Surrey, School of Hospitality and Tourism Management

Address: Rik Medlik Building, GU2 7XH Guildford, UK

telephone: +44 01483 682853 ; e-mail: t.makkonen@surrey.ac.uk

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Abstract This paper investigates the geographical and organizational patterns of scientific collaboration, in terms of co-authored scientific articles, in the Danish-German border region of Southern Jutland-Schleswig. The motivation behind the approach lies in the fact that scientific collaboration in border regions, in general, and the studied region, in particular, has rarely been discussed in the academic literature. The integration model of cross-border regional innovation systems provides the conceptual framework for the task. The paper, thus, gives methodological insights for the measurement of cross-border integration of knowledge infrastructures. The analysis reveals that collaborating with partners close but on the opposite side of the border is rare. Instead, cross-border collaboration takes place with partners from more faraway international research organizations. The reasons behind this can be found in the science bases—arguably more than from historic, linguistic or ethnic reasons—of the adjacent sides of the border. The research fields that the local scientists are engaged in seem to be too different between the Danish and German sides of the border region to foster large numbers of co-authored publications and, thus, the knowledge infrastructure of the border region can be considered as weakly integrated.

Keywords co-authorships; cross-border regional innovation system; Danish-German border region; publications; scientific collaboration

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Introduction

The year 2014 remarked the 150th anniversary of the Battle of Dybbøl, the key battle of the Second War of Schleswig. As a result of the war, Denmark lost Schleswig to Germany. The northern part of Schleswig (i.e. Southern Jutland; *Danish: Sønderjylland*) was reunited with Denmark, following a referendum, after the First World War in 1920 and again occupied by Germany in the Second World War (Laculiceanu, 2007). This bellicose history of the region seems to have remained as a bottleneck for local cross-border interaction (2017 Secretariat – Municipality of Sønderborg, 2014). Still, at least the cross-border mobility flows have increased steadily in the recent decades with several hundreds of shoppers (Bygvrå, 2009) and commuters (Buch, Schmidt, & Niebuhr, 2009) crossing the border every day. Accordingly, the sheer number of European Union funded cross-border cooperation projects between Southern Jutland and Schleswig would indicate that a definite integrative process is under way in the region. However, as pointed out by Klatt and Herrmann (2011), on administrative levels the outcomes of this cross-border collaboration have remained modest. In line with this, the local Danish population has generally been described to differentiate themselves from the Germans more than the Germans do from the Danes and rather reluctant to embrace Germans as their collaboration partners, even though Germany has for long been one of the most important foreign trading partners of Denmark (Malloy, 2010; Schack, 2001). Moreover, the commuter flows have been mainly directed from Germany to Denmark, whereas the number of Danes commuting to Germany has remained at a very low level (Klatt, 2014). Thus, the economies of the opposing sides of the border have in the past been described as largely separate (Krieger-Boden, 1993). In addition, the Danish-German border region (and its western parts in particular) can be considered as peripheral: lacking behind national averages in socio-economic standards and situated far away from the economic and scientific centres of their respective national capitals (Klatt & Hermann, 2011; Nørgaard, 2011).

The geographical patterns of scientific collaboration have been investigated in a range of studies focusing on global networks of authors within some specific research fields (Suominen, 2014; Wagner & Leydesdorff, 2005) and on university-industry co-authorships (Calvert & Patel, 2003; Glänzel & Schlemmer, 2007). However, the impacts of national borders on scientific collaboration have commonly been considered through national (Mattsson, Laget, Nilsson, & Sundberg, 2011) or large NUTS-2 regional (Hoekman, Frenken, & Tijssen, 2010) scales, whereas in the (scarce) empirical literature set specifically in cross-border settings earlier studies have commonly focused–

in line with the existing macro-level evidence—their interest on (university-industry) linkages in distinct research fields (Coenen, Moodysson, & Asheim, 2004; Hansen, 2013; Hansen & Hansen, 2006). Therefore, as a point of departure, here the Danish-German border region is investigated as a whole taking into account the entire range of research areas and private-public sector specifications.

The empirical topic of this paper is, thus, to investigate the level of integration—in terms of their regional orientation in scientific collaboration—between Danish and German research organizations in the border region. In other words this paper will provide evidence on whether the local researchers have looked elsewhere when choosing partners for scientific collaboration or whether the Danish-German border region has evolved towards a more integrated cross-border regional innovation system. The paper will proceed by introducing a (short) review of the relevant literature on cross-border scientific collaboration and cross-border innovation systems followed by the methodological considerations of this paper. Next the results of the paper—including statistics on the volumes of scientific co-publications in the border region and a description of the similarities and/or dissimilarities of the science bases on opposing sides of the border—will be presented and discussed. Finally, concluding remarks will sum up the paper.

Cross-border scientific collaboration and cross-border innovation systems

In the literature there is a lively debate on the importance of geographical proximity for regionalized knowledge flows. According to the empirical evidence it seems that geographical proximity is, indeed, important for scientific and innovation cooperation, since it facilitates overcoming possible institutional differences between universities, public research institutes and private firms (Arundel & Geuna, 2004; Ponds, van Oort, & Frenken, 2007). However, although due to the process of European integration the impacts of national borders seem to be diminishing inside the European Union (Scherngell & Lata, 2013), they still hamper the volume of knowledge spillovers and flows (even) between adjacent border regions (Fischer, Scherngell, & Jansenberger, 2006; Thompson, 2006). Thus, geographical proximity is not the only dimension of “closeness” that matters for scientific and innovation cooperation (Balland, Boschma, & Frenken, 2014; Boschma, 2005). Earlier research has proposed that also for example cognitive (e.g. shared areas of scientific expertise), cultural (e.g. shared language or ethnical background) and organizational (e.g. shared organizational contexts) proximities make a significant contribution to the intensity and

successfulness of cross-border collaboration (Knoben & Oerlemans, 2006; Lundquist & Trippel, 2013).

Recently the discussion on cross-border technological, scientific and innovation cooperation has gained increasingly more attention in the academic and political circles of the European Union (OECD, 2013). The heightened importance given to the systemic relationships between cross-border actors has lead Trippel (2010) to coin the concept of “cross-border regional innovation systems” to discuss the levels of integration of innovative activities in cross-border settings in various dimensions including business, relational, socio-institutional and governance dimensions. However, here the concept is used, particularly, to refer to the similarities of science bases (i.e. knowledge infrastructure dimension) in the adjacent border regions and to the nature of the knowledge linkages between them. In a highly integrated cross-border regional innovation system there would be complementarities in a wide range of scientific fields supported by intensive cross-border knowledge flows and exchange. Contrarily, a weakly integrated cross-border regional innovation system would be characterised by strong differences in specialization of the science bases and a general lack of cross-border knowledge flows (Lundquist & Trippel, 2013). The reasoning behind the approach lies in the proposition that achieving a more integrated system should lead to positive synergies resulting in heightened innovativeness and economic success of the region as a whole (Lundquist & Trippel, 2013; Trippel, 2010). However, despite some refreshing case study examples (Hansen, 2013; Kiryushin, Mulloth, & Iakovleva, 2013; van den Broek, & Smulders, 2014), the concept has not yet been evaluated or validated with extensive empirical evidence. Therefore, here the integration levels of cross-border innovation systems are used as a backdrop in the evaluation of the intensity of scientific collaboration in the Danish-German border region. The aim is to offer methodological insights into the ways that the integration of the knowledge infrastructure dimension of cross-border regional innovation systems could be analysed. It can be expected that cross-border regional innovation systems are likely to exhibit varying stages of integration, but it has also been assumed that, even globally, only a few border regions—which actually belong to and have been integrated with their respective national centres and innovation systems (Lundquist & Winther, 2006; Prokkola, 2008)—have favourable conditions for achieving a strongly integrated cross-border regional innovation system (Trippel, 2010).

Empirical literature on cooperation on a firm level suggests that—due to the barriers they impose—national borders significantly hamper the knowledge flows between border regions as firms look for collaboration partners mainly inside their home countries. Moreover, border regions are in fact frequently bypassed in cross-border cooperation which mostly occurs (if and when it occurs) with firms located in the economic centres of foreign countries (Hassink, Dankbaar, & Corvers, 1995; Koschatzky, 2000; Krätke & Borst, 2007). In the case of scientific cross-border collaboration one of the most commonly studied example region has been that of the Danish-Swedish border region of Øresund—in total, the region is considered to belong to the top 25 scientific centres of the world (Anderson, Anderson, & Mathiessen, 2013)—and in particular its biotech cluster of Medicon Valley. A study by Hansen and Hansen (2006) reported a positive growth trend in co-publishing between the Swedish and Danish parts of the region. Contrarily, a study by Hansen (2013) has concluded that the scientific integration between the two parts belonging to different nation states has been relatively weak when compared to the development in co-authorships of papers with the major research hubs of the world. A similar trend had been observed already by Coenen et al. (2004): according to the co-publication patterns of biotechnology firms in the region the observed level of integration has remained limited. Other border regions (and the case of the Danish-German border region of Southern Jutland-Schleswig) have, however, less often been studied from this perspective i.e. despite the evident importance and interest on the topic, the issue of scientific cross-border collaboration has rarely been studied as an integrative process together with time-series data.

Data and study design

Generally, the absolute numbers of scientific publications and co-publishing have increased steadily (Puuska, Muhonen, & Leino, 2014), due to several reasons including the establishment of new academic journals, changes in the way that universities are evaluated according to their scientific production and the globalization of the scientific arena where more and more countries have developed lively scientific communities that take part in international scientific publishing. Therefore, a mere increase in the number of co-authored scientific publications is a poor measure for the level of integration within border regions. Thus, comparing the development of co-authorships in the Danish-German border region with the development between the border region and other parts of Denmark, Germany and the rest of the world, will give a better indication of the possible integration progress of scientific collaboration within the border region.

The data on the article publications from the years 1991–2012 were gathered from the Web of Science (WoS) database (during May-June 2014). In relation to the reliability of the results presented below, it has to be noted that focusing on scientific publications in journals indexed in WoS leaves a number of other forms of scientific collaboration (for example the Universities of Flensburg and Southern Denmark offer joint courses for students on both sides of the border) and a multitude of non-WoS-indexed scientific journals outside the scope of this paper, not to mention the bias imposed by the varying publishing traditions between different disciplines (Laudel, 2002). One possible (alternative or complementary) measure to overcome some of the limitations of using scientific publications would be to look at joint projects, for example cross-border projects funded by the European Union (Scherngell & Lata, 2013), in order to get a more precise picture of the possible collaboration that does not show (as publications) in the WoS database. Still, scientific article publications are arguably among the best and the most commonly applied indicators of (international) scientific output and collaboration (Moed, Glänzel, & Schmoch, 2005) and WoS among the best databases to access this kind of information (for detailed discussions on the advantages, limitations and comparisons of various publication databases see Bar-Ilan, 2008; Franceschet, 2010; Mingers, Evangelia, & Lipitakis, 2010; Torres-Salinas, Lopez-Cózar, & Jiménez-Contreras, 2009; Vieira & Gomez, 2009). Nonetheless, since the data gathering and processing phases include a number of different steps and copious amount of handiwork, the use of co-authored scientific publications as statistical indicators is error-prone (Luukkonen, Tijssen, Persson, & Silvertsen, 1993). Thus, proper care must be taken when collecting the data by using search procedures and when analysing it with statistical software packages.

Here, the Danish-German border region of Southern Jutland-Schleswig was delineated according to the description by the Association of European Border Regions (2014). The search procedures offered by WoS were taken advantage of by using the address field as an initial identifier of the hometowns of the organizations belonging to Southern Jutland and the border municipalities of Schleswig (Figure 1): the total picture of the regional collaboration patterns was accomplished by individually searching for scientific publications by names of the municipalities, towns, former municipalities and sub-regions in the study area (see Table 1 for a full list) and comparing them to postal codes when possible. Thus, with a modest amount of uncertainty, it can be stated that the dataset constructed here covers local publications in WoS to a high degree of accuracy and, thus, gives a truthful overall picture of the situation. However, it has to be noted that the fact that some

smaller localities (e.g. districts or neighbourhoods) might have been overlooked and that it is near to impossible to take into account all the possibilities for potential misspellings of the town names in the database, even though the most obvious ones were taken into account (e.g. the writing out of ø had been done in some occasions as oe and in others as o), remain a (minor) limitations of this study.

<Figure 1 about here>

<Table 1 about here>

The researcher marked down the following details on each individual article separately for publications stemming from the Danish and German sides of the border region: 1) year published, 2) name of home town, 3) name of home organization, 4) collaboration with domestic partners (yes/no), 5) collaboration with international, excluding German/Danish, partners (yes/no), 6) collaboration with German/Danish, excluding the German border municipalities/Southern Jutland, partners (yes/no), 7) collaboration with partners from the German border municipalities/Southern Jutland (yes/no), 8) name of collaboration organization and home town of partners from the German border municipalities/Southern Jutland. The home organizations were carefully grouped together including possible name variants in German or Danish to indicate the most prolific organizations (in terms of numbers of scientific articles) in the region. The data was then processed and analysed with the aid of standard statistical software packages. Additionally, the research area(s) of the publication were marked down to investigate the similarities and differences between the science bases of the adjacent regions. A total of 132 research areas were identified in either side of the border. Based on this data, a separation measure—Cognitive Separation Measure (CSM)—was constructed by creating a discipline vector describing the similarities/dissimilarities of numbers of publications in each of these research areas. Following Jaffe (1986), Hoekman et al. (2010) and Acosta, Coronado, Ferrándiz and León (2011) a correlation measure ($Corr_{ij}$), cosine similarity (or un-centered correlation), was calculated (cf. McNamee, 2013, p. 858) as follows (Equation 1):

$$Corr_{ij} = \frac{\sum_{r(1)}^{r(n)}(tf_{ir})(tf_{jr})}{\sqrt{\sum_{r(1)}^{r(n)}(tf_{ir})^2} \sqrt{\sum_{r(1)}^{r(n)}(tf_{jr})^2}} \quad (1)$$

, where tf_{ir} (“term” frequency) is the number of times a classification r is assigned to the region i . Thus, if two regions (i and j) publish exactly in the same proportion in each research area r ($= 1, 2 \dots 132$), the measure would equal to one and if they publish precisely in different research areas the measure would equal to zero. As in Peri (2005, p. 315), CSM was then obtained by subcontracting this measure from one (Equation 2):

$$CSM_{ij} = 1 - Corr_{ij} \quad (2)$$

Finally, the information on the most common collaboration partners (organizations) outside the study area were gathered by using the organizations enhanced field of inquiry in WoS. However, not all organizations or name variants have been included in the database. Thus, the results related to the collaborating organizations have to be interpreted with some caution.

Results

The science base of the Danish-German border region of Southern Jutland-Schleswig

The most prolific actors on the Danish side of the border region (Table 2), in terms of numbers of scientific articles ($N=841$)¹, include the University of Southern Denmark (Syddansk Universitet – SDU) formed in 1998 (the figures include its regional predecessors: Southern Denmark School of Business and Engineering and Danish Institute of Border Region Studies), the Hospital of Southern Jutland (with local hospitals in the municipalities of the Danish side of the border region), the Nordborg-based Danfoss AS—global producer of components and solutions for e.g. air conditioning and heating—and the King Christian X's Hospital for Rheumatic Diseases in Gråsten. SDU is a multi-campus university and, thus, the publications stemming from other campuses than the campus located in Sønderborg were not counted here, as the other campuses of SDU are situated significantly farther away from the Danish-German border. Logically, most of the scientific activities in the region seem to be centred in the regional economic “capital” of Sønderborg (Table 2). Other towns stand out due to strong individual organizations such as Danfoss AS (Nordborg) and the King Christian X's Hospital for Rheumatic Diseases (Gråsten).

<Table 2 about here>

¹ The corresponding figure for Denmark as a whole was 189 311 scientific articles.

On the German side of the border region, the most prolific organization (Table 3), in terms of numbers of scientific articles ($N=968$)², has been that of the Alfred Wegener Institute for Polar and Marine Research (AWI)—its Wadden Sea Station Sylt in List to be precise. The figures also include those papers from the researchers at Helgoland Research Station—part of AWI since 1998—that have listed List in the address field, whereas those including only Helgoland in the address field were excluded, since Helgoland is not part of the municipalities under study here. Other major scientific players in the border region are the University of Flensburg (and its predecessor Pädagogischen Hochschule) established in 1994, the Diakonissen Hospital (DIAKO) in Flensburg as well as the Schleswig-based Pig Improvement Company (PIC) Germany—a biotechnology company engaged with genetic improvements for pig industries—and the Foundation of Schleswig-Holstein State Museums—its museums in Schleswig to be precise. Flensburg also hosts the Flensburg University of Applied Sciences (FUAS). On the German side of the border the scientific activities are centred to three individual towns (Table 3), those of Flensburg (the largest town in the border region), List and Schleswig, which coincide with the home locations of the most prolific, in terms of numbers of scientific articles, organizations.

<Table 3 about here>

The science base of the Danish side of the border region is dominated by life sciences and biomedicine, physical sciences and technology (Figure 2): taking into account the departments found in the campus of Sønderborg of SDU, the headquarters of the technologically-oriented Danfoss AS situated in the region and the strong publication track record of the local hospitals, this comes as no surprise. In particular, the strong impact that the Mads Clausen Institute (MCI) for Mechatronics (at SDU) and Danfoss AS together make is visible in the high share of article publications in the fields of physics, engineering and materials science (Figure 3). Accordingly, the impacts of the King Christian X's Hospital for Rheumatic Diseases and the Department of Border Region Studies (at SDU) are shown by the high shares of publications in the field of rheumatology and business and economics respectively. In contrast, due to the diverse research area coverage of the publications stemming from the branches of the Hospital of Southern Jutland the other fields inside the category of life sciences and biomedicine do not stand out as evidently. Still, local

² The corresponding figure for Germany as a whole was 1 494 276 scientific articles.

researchers and doctors have published (relatively) intensively for example in the research areas of neurosciences and neurology and immunology.

<Figure 2 about here>

<Figure 3 about here>

On the German side of the border region, the science base is monopolized by life sciences and biomedicine together with physical sciences (Figure 2). Additionally, the social scientists in the region make a significant contribution with a relatively high number of article publications. Again, taking into account the impact of AWI and DIAKO as well as the departments of the University of Flensburg the results are in line with what one could expect. When taking a closer look at the most common research areas the strong impact of AWI becomes even more evident through the high shares of the subject areas of marine and freshwater biology, oceanography, environmental sciences and ecology as well as plant sciences (Figure 3). Particularly due to PIC, agriculture is also a prominent research field in the region. The local hospitals seem to be mostly concentrated on cancer research (oncology) and on neurosciences and neurology, whereas due to FUAS and the Foundation of Schleswig-Holstein State Museums also engineering and archaeology, respectively, are relatively prominent fields of research in the region.

Cross-border scientific collaboration in the Danish-German border region of Southern Jutland-Schleswig

As expected the total numbers of scientific article publications and the number of domestic and international collaborations have increased during the time period analysed here (Figure 4). The trend lines of domestic and international co-publications follow (at least loosely) the overall trend. However, collaborating with co-authors from organizations from the neighbouring countries under study here seems to be a more infrequent, but not totally uncommon, phenomenon.

<Figure 4 about here>

Of the article publications on the Danish side of the border region (N=841, of which in 659 cases there is at least one co-author from an outside organization) in 56% of the papers there is at least one co-author from another Danish organization, in 33% of the papers there is at least one co-author

from an international (excluding German) organization and in 10% of the papers there is at least one co-author from a German organization. The most common collaboration partners for organizations on the Danish side of the border (excluding other campuses of SDU) include Danish universities and hospitals, but also North American technical universities (Table 4). The first German university—the Humboldt University of Berlin—is ranked eleventh in the list. Other German organizations with several collaborations with organizations in Southern Jutland include the Charité University Medicine Berlin, the University of Bonn, the Free University of Berlin and the University of Kiel.

<Table 4 about here>

The corresponding figures for the German side of the border region are (N=968, of which in 664 cases there is at least one co-author from an outside organization): in 50% of the papers there is at least one co-author from another German organization, in 32% of the papers there is at least one co-author from an international (excluding Danish) organization and in 4% of the papers there is at least one co-author from a Danish organization. The most common collaboration partners for organizations on the German side of the border (excluding other locations and research stations of AWI) include German universities, in particular the geographically close universities in Kiel and Hamburg (Table 5), and other German research centres such as the Max Planck Society and the Centre for Materials and Coastal Research. The first foreign collaboration partner in the list is that of Aarhus University (Denmark) closely tailed by the Scottish Agricultural College (UK) and the University of South Carolina (USA). The German side of the border region has lower (than the Danish side with German organizations) numbers of co-authored articles with other Danish organizations including the second and third most common Danish partners of SDU with eight and the University of Copenhagen with only six co-authored scientific articles.

<Table 5 about here>

There are only three papers with local (meaning within the border region) cross-border collaboration in the dataset: the two collaborations (Gretzinger, Hinz, & Matiaske, 2011; Royer, Simons, Boyd, & Rafferty, 2008) in the research area of business and economics between the Department of Border Region Studies (at SDU) and the Institute of International Management (at

the University of Flensburg) and the List-Tønder link (Strasser et al., 2003) in the research areas of marine and freshwater biology and oceanography.

Synthesis and discussion

In the Danish-German border region of Southern Jutland-Schleswig the local universities and hospitals, supported by other research institutes and few notable high-tech companies, are the most prolific organizations in terms of numbers of scientific articles. The local economic centres (largest towns) act as the research hubs in the region. On the Danish side of the border the science base is constructed mainly from techno-scientific research fields of physics, engineering and materials science, whereas on the German side the most prominent research fields come within life and physical sciences, namely marine and freshwater biology, oceanography and environmental sciences and ecology. The only coinciding notable research areas are those of engineering and neurosciences and neurology. Thus, local hospitals might gain from looking at the opposite side of the border when searching for partners and co-authors in the field of neurosciences and neurology. Similarly, MDI (at SDU), Danfoss AS and FUAS could complement each other's research outputs through cross-border collaboration in engineering sciences. However, the local organizations mainly collaborate with domestic or more faraway international partners with similar research fields. The only already existing link across the border in the region with (some) potential for future collaborations seems to be the connection between the Department of Border Region Studies (at SDU) and the Institute of International Management (at the University of Flensburg). A schematic overview of the situation has been summarized in Figure 5—a stylized picture of the scientific collaboration linkages in the Danish-German border region (drawn according to the results presented in this paper). However, the limitations of WoS have to be stated again: the data used here covers only one aspect of scientific collaboration (i.e. co-authorships) and only a limited set of journals. Therefore, the possible scientific collaboration across the border in the region might take place in other forms not covered by scientific articles or the results might be published in scientific journals not covered by WoS. Still, the methods described here offer one plausible way into looking at the levels of integration of the knowledge infrastructure dimension of cross-border innovation systems in different geographical settings.

<Figure 5 about here>

According to the earlier literature a certain degree of related variety in the science bases could be considered as an advantage (Lundquist & Trippl, 2013)—this discussion closely resembles the statements linked to Jacobian clusters (Cooke, 2008), where the innovative advantage of regions is considered to stem from the combination of technologically close but still distinct industrial sectors—but in the Danish-German border region—unlike, for example, in the Øresund region, where there are complementarities between the science bases of the adjacent sides of the border (Hansen, 2013)—the research fields that the local scientists are pursuing vary to a significant degree from one side to another (Cognitive Separation Measure = 0.749). Moreover, due to the peripheral nature of the Danish-German border region the overall local scientific output is rather small compared to metropolitan border regions (such as Øresund) and the scientific collaboration between the adjacent sides of the border in terms of co-authored scientific articles is almost non-existent. In addition, many regional universities play (and are expected to play) an important local role: a substantial part of their research funding is directed at addressing local challenges, which might also be a (likely) reason for explaining the lack of cross-border collaboration in the border region under study here. Therefore, the Danish-German border region can be described as a weakly integrated system (at best) in the dimension of knowledge infrastructure. As proposed by Trippl (2010), this is likely to be the case also in many other border regions.

Thus, the results indicate that, whereas other types of proximities certainly exert some weight, for scientific collaboration cognitive proximity is of utmost importance. Most of the collaboration takes place inside the confines of national borders, but—despite geographical distance—collaboration with more faraway international partners is commonplace: as in the case of firm-level cooperation (Krätke & Borst, 2007), the adjacent side of the border is (often) bypassed. In short, instead of finding the closest potential partner, scientists (might) opt on finding the most suitable one irrespective of geographical (or cultural) distance. In addition, organizational distance seems to play a role, since the region's top collaborating organizations are similar to those found in the region, that is, for example doctors (hospitals) collaborate mostly with other doctors and academics (universities) mostly with other academics.

Conclusions

Cross-border co-authorships between the Danish-German sides of the border region are rare. This is suggested to be caused by the peripheral nature of the border region (i.e. low scientific output

compared to metropolitan border regions such as Øresund) and due to the fact that the science bases of the adjacent sides of the border vary to a significant degree (as shown also by the Cognitive Separation Measure). Therefore, the adjacent region is, or rather has to be, bypassed when searching for collaboration partners. Instead, collaboration in co-authoring scientific articles mainly occurs with domestic and more faraway international research organizations engaged in the same scientific field. Thus, cognitive (and organizational) proximity seems to play a heightened role in the geographical patterns of academic collaboration. In the light of the evidence provided here (keeping in mind the limitations of the data used) the cross-border regional innovation system of the Danish-German border region can be described as weakly integrated system (at best) in the dimension of knowledge infrastructure. According to the literature on cross-border innovation systems, achieving a more integrated system should lead to positive innovative and economic results for the region as a whole. Therefore, to become a more integrated system the border region should intensify scientific collaboration across the border in fields where complementarities and existing traditions for cooperation can be found, that is, in the common research areas of neurosciences and neurology, engineering and business and economics. The results presented here are likely to resemble the situation in many other peripheral border regions. From a methodological point of view the present study offers a way to depict the level of integration of the knowledge infrastructure dimension of border regions in other geographical settings in an informative and precise way. Finally, further studies could add to the debate by looking into the location history of the co-authorships to examine whether cross-border co-authorships are more common among locally embedded researchers compared to new (international) recruitments.

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Tables

Table 1: List of towns and municipalities in the study area with at least one publication.

Denmark	Germany	
Aabenraa	Bergenhusen	Leck
Augustenborg	Bredstedt	List
Bevtoft	Breklum	Lürschau
Egersund	Flensburg	Meyn
Gram	Freienwill	Nebel
Gråsten	Friedrichstadt	Neukirchen
Haderslev	Glücksburg	Niebüll
Højer	Grundhof	Sankt Peter-Ording
Løgumkloster	Hockensbüll	Schaalby
Nordborg	Hörnum	Schleswig
Skærbæk	Husum	Sylt
Sønderborg	Hüsby	Tating
Sundeved	Kampen	Tönning
Sydals	Keitum	Treia
Tinglev	Kropp	Westerland
Tønder	Langballig	Wrixum
Vojens	Langstedt	Wyk auf Föhr

Table 2: Top organizations (A) and towns (B) measured by numbers of scientific articles on the Danish side of the border region.

A: Organization	Articles	B: Town	Articles
Univ So Denmark	320	Sønderborg	544
Mads Clausen Ins	250	Gråsten	82
Dept Border Reg Studies	31	Nordborg	75
Dept Business Commun & Informat Sci	10	Haderslev	67
Others/Unspecified	29	Aabenraa	34
Hosp So Jutland	278		
Sønderborg Hosp	198		
Haderslev Hosp	56		
Aabenraa Hosp	22		
Tønder Hosp	2		
Danfoss	113		
King Christian X Rheumatol Hosp	55		

Table 3: Top organizations (A) and towns (B) measured by numbers of scientific articles on the German side of the border region.

A: Organization	Articles	B: Town	Articles
AWI Polar & Marine Res	297	Flensburg	343
Univ Flensburg	126	List	314
Inst Movement Sci & Sport	12	Schleswig	157
Inst Int Management	11	Westerland	41
Inst Math & Its Didact	9	Husum	33
Others/Unspecified	94		
Diakonissen Hosp	78		
PIC Germany	50		
Foundation of Schleswig-Holstein			
State Museums	47		
Flensburg Univ Appl Sci	37		

Table 4: Top Danish, international and German collaboration organizations, measured in counts in the dataset, for organizations on the Danish side of the border region.

Organization	Counts
Univ Copenhagen	188
Aarhus Univ	145
Odense Univ Hos	102
Technical Univ Denmark	57
Aalborg Univ	43
Vejle Hosp	27
Gentofte Hosp	26
Esbjerg Gen Hosp	21
Wilfrid Laurier Univ (Canada)	21
Worcester Polytechnic Inst (USA)	19
Humboldt Univ Berlin (Germany)	17
...	
Charité Univ Medicine Berlin (Germany)	14
Univ Bonn (Germany)	13
Free Univ Berlin (Germany)	12
Univ Kiel (Germany)	11

Table 5: Top German, international and Danish collaboration organizations, measured in counts in the dataset, for organizations on the German side of the border region.

Organization	Counts
Univ Kiel	109
Univ Hamburg	37
Martin Luther Univ Halle Wittenberg	33
Max Planck Society	24
Ruprecht Karl Univ Heidelberg	23
Univ Ulm	23
Centre Materials Coastal Research	21
Aarhus Univ (Denmark)	19
Scottish Agr Coll (UK)	18
Univ South Carolina (USA)	18
...	
Univ So Denmark (Denmark)	8
Univ Copenhagen (Denmark)	6

Figure captions

Figure 1: Map of the Danish-German border region of Southern Jutland-Schleswig (study area highlighted in grey).

Figure 2: The share of publication on the Danish (left; N=841) and the German (right; N=968) side of the border region broken down into main categories of research areas.

Figure 3: The share of publications on the Danish (top; N=841) and the German (bottom; N=968) side of the border region broken down into detailed categories of research areas.

Figure 4: The total number of publications on the Danish (left; N=841) and the German (right; N=968) side of the border region and the number of co-published papers with other Danish, German or international organizations involved.

Figure 5: A schematic overview of the geographical patterns of scientific collaboration of organizations in cross-border settings according to the case (Southern Jutland-Schleswig) and results (the thickness of the arrows indicate the numbers of co-authored scientific articles) presented in this paper; global indicates other countries than Denmark and Germany.

FIGURES

Figure 1

Figure 2

Figure 3

Figure 4

Figure5