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Science Networks in Cutting-edge Research Institutions: Gender Homophily and Embeddedness in Formal and Informal Networks

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Abstract

Female researchers are underrepresented in leading academic positions. Literature has referred to networks as a central factor for sex differences in scientific careers. The present study analyses the interrelations between formal and informal science networks and focuses on gender homophily as a driver for structural embeddedness. Applying QAP network correlation analysis on the principal investigators of two institutions from the German Excellence Initiative, gender homophily minorly influences the involvement in research cooperation, research support and social acquaintance networks. Other similarity variables seem to be more strongly related to integration in science networks, namely, research area, geographic dispersal and academic status.

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Keywords: cutting-edge research; Excellence Initiative; formal and informal networks; gender homophily; social network analysis

1. Introduction

The science system in Germany is, amongst others, affected by a particularly striking underrepresentation of women in leading academic positions (e.g. Engels, Ruschenburg & Zuber, 2012). Many reasons for this inequality are known and are subject to enduring discourse: socialization system, family support, career choice, evaluation practices and employment conditions, to name a few (Bennett, 2011; Feeney & Bernal, 2010). There is also broad consensus that embeddedness in academic social networks—notably informal networks—is both crucial for doing research and for achieving a career.

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Studies on gender and higher education have repeatedly referred to networks as a central factor for gender differences in scientific careers (e.g. in the context of old boys networks see Asmar, 1999). Following Etzkowitz, Kemelgor and Uzzi (2000), "[o]ne of the underlying barriers to the success of women scientists is the structure of their social networks" (p.176). Compared to their male equivalents, female researchers are supposed to have less access to beneficial network ties (Feeney & Bernal, 2010; Long, Allison & McGinnis, 1993), thus suffering from lower social capital. Bourdieu (1985) defined that sort of capital as being "the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition" (p.248). According to Seibert, Kraimer and Liden (2001), social capital is considered a key variable for the explanation of successful careers.

A fundamental assumption on the reproduction of inequality is homophily. It is a basis for social selection (Robins, Pattison, Kalish & Lusher, 2007) and describes the tendency of an actor to interact more with similar than with dissimilar others (e.g. McPherson, Smith-Lovin & Cook, 2001). In Germany, the working environment for scientists in cutting-edge research institutions is dominated by the presence of males (for more on sex segregation in work establishments see Bielby & Baron, 1986). Following the homophily-argument, same-sex ties might be the favored type of connection for investigators. The view on homophily as raising the likelihood for tie formation is central to most sociological theories, thus making a prediction about social networks (e.g. Hanneman & Riddle, 2005). Gender homophily can cause disadvantages to women by isolating them from the global network and its resource flows. This effect may still be higher, when women work in communities with a low percentage of same gender (e.g. cutting-edge research). Selection of same-sex-ties from men can thus be regarded as an access restriction to networks for women (Scheidegger & Osterloh, 2004). Exclusion from resource flow constrains accession to relevant information and/or cooperation opportunities. Bozeman and Corley (2004) for instance, found out that women have other experiences with cooperation that are oftentimes disadvantageous compared to males. Furthermore, feelings of isolation can lower motivation and thus reduce work outcomes (Feeney & Bernal, 2010). In contrast, men can scoop from an expanded pool of instrumental as well as affective network resources which may increase their academic success.

Various studies from management literature have provided indication for the different involvement of women and men in occupational contact structures (e.g. Brass, 1985). However, there is little empirical verification on research networks in general and gendered participation of investigators in formal and informal networks (exempt from e.g. Bozeman & Corley, 2004). Although the scientific community is constantly getting more intertwined, very few studies have focused on a quantitative analysis of realized social networks in the present context yet. Some articles are limited to questions of subjectively perceived networks (e.g. Sadl, 2009), while others are based on ego-centralized network data, that does not take into account the whole network and its global coherencies (Feeney & Bernal, 2010). The present study contributes to this thread of research by addressing the project-driven research question: Which relationship exists between gender homophily on the one hand, and structural embeddedness of female and male scientists in formal and informal networks on the other hand?

Like in many other European countries, Germany has established a special program for the advancement of excellent research: the Excellence Initiative[a]. One of three funding lines are Clusters of Excellence[b] (CoE) (DFG, 2011) which can be regarded as fictitious constructs, where scientists accomplish cutting-edge research. In this paper, I examine the associations between (formal) research cooperation, (informal) research support and (informal) social acquaintance networks, as well as gender homophily among the principal investigators (PIs) from two CoEs, both partaking in the German Excellence Initiative. The article is structured as follows: In the next chapter I present conceptual foundations and define the main variables for network analysis. Then, I derive

[a] The Excellence Initiative was set up by the German federal and state governments in 2005 in order to sustainably strengthen research at universities through competition. Compared to other worldwide countries, the initiative shall make Germany more visible as a place for science.

[b] In CoEs, universities, non-university research institutions and oftentimes business and industry work on promising subjects of the future.

and propose two predominant hypotheses and illustrate the research model. After this, I describe the study design, data collection and editing, and go into variable measurement. Subsequently, I test the suppositions of correlations between gender homophily and formal and informal network links. Ultimately, I present the results of the analysis and discuss them. The paper finishes by summing up the results and by limiting them. Moreover, I give considerations for future studies.

2. Theoretical Framework

2.1. Conceptual foundation

Within the past years, the network paradigm has more and more become a discourse object (Hollstein, 2010). Social networks are basically agreed to determine an individual's environment for action (Borgatti & Foster, 2003). They are further considered as enhancing or constraining accession to valued resources (Brass, 1984; Ibarra & Andrews, 1993). Networks can foster a career (Bozeman & Corley, 2004) by canalizing resource flows, regulating access to positions, providing mentoring and support as well as by enhancing influence and reputation (Scheidegger & Osterloh, 2004). They are particularly beneficial to the exchange of knowledge resources (Feeney & Bernal, 2010; Krücken, 2007).

Emergence of social capital is based on social networks that are in turn specified through actors and ties of different contents linking them (Wasserman & Faust, 1994). Burt (1997) for example, stressed the relevancy of content from exchanged resources. Network ties can contain instrumental as well as affective resources (Podolny & Baron, 1997) and hence be highly diverse. When for a given set of actors, two or more with regards to content different network relations overlap, a multi-relational network shapes up. This occurrence is also termed multiplexity (Jansen, 2006; Kapferer, 1969; Szell, Lambiotte, & Thurner, 2010; Wasserman & Faust, 1994). Multiplex relationships are used to analyze the connection between different types of relation. For one, Krackhardt (1987) investigated if managers who are friends were more likely integrated in mutual work-related support activities. Concerning gender, content specification of relations features a substantial meaning. For example, Feeney and Bernal (2010) found out that female scientists are more infrequently asked for advice on publications, but more often than men for advice on work-life-balance. Ibarra (1992) showed for an advertising agency that men held a higher degree of multiplexity in their networks than women. Multi-relational links are considered to indirectly affect careers in a positive way (Scheidegger & Osterloh, 2004).

Several studies regarding women in science have pointed to the relevance of networks, but did not really prove this proposition. Until now, research in this field has been limited to rather blanket requesting to sensed embeddedness and to supposed importance of networks. For instance, Zimmer, Krimmer and Stallmann (2007) found out that women in academia feel less integrated into informal networks than their male colleagues. However, quantitative research has revealed that scientists from both sexes utilize formal as well as informal coordination instruments for seeking to achieve their academic targets (Corley, 2005; Feeney & Bernal, 2010; Naldi & Vannini Parenti, 2002). In general, formal relations are defined to be explicit, impersonal and functionally specific. On the contrary, an informal relation is specified by being implicit, personal, unspecific and not codified (Böröcz & Southworth, 1998). The latter type is critical for transferring relevant information, exchanging ideas and support as well as for evaluation of research work (e.g. Tierney & Bensimon, 1996).

One of the most general sociological observations is that "birds of a feather flock together" (Hanneman & Riddle, 2005). Homophily (Contractor, Wasserman, & Faust, 2006; Gibbons & Olk, 2003; Lazarsfeld & Merton, 1954; McPherson et al., 2001) simplifies communication, enhances predictability of behavior and boosts trust as well as reciprocity (Brass, Galaskiewicz, Greve & Tsai, 2004). Numerous studies have supported this proposition which is a basic presumption in many theories (e.g. Blau, 1977). By way of example for gender, Ibarra (1992) found an indication for homophily, observing two extensively segregated networks. Likewise, a study from Brass (1985), investigating a newspaper publisher, arrived to the same conclusion. Moreover, the study "Women in

STEM networks", by Feeney and Bernal (2010), revealed homophile tendencies. So, women were more present in advice networks of other female scientists than in such networks of male colleagues.

2.2. Variable definitions

Formal research work includes many challenges, such as writing and publishing journal articles, registering patents or raising third-party-funds, to name a few (e.g. Katz & Martin, 1997). Intrinsic motive of researchers is the increase of scientific capital, accompanied by advancing her or his career. However, there is a tendency towards scientific teamwork compared to "solo research" (Asmar, 1999) due to positive expectations regarding knowledge production (Melin, 2000). The outcome of this is a potential for intense involvement and participation in collaborative networks (Asmar, 1999). As a matter of principle, science can be more efficiently accomplished in cooperative activities (Katz & Martin, 1997). The more intricate a research project, which compasses extensive methods and experiments, the more the need for researchers to collaborate. Therefore, cooperative action is crucial for succeeding in cutting-edge research. Cooperation as a specific type of tie is based on equal and flowing partnership as well as autonomy (Sadl, 2009). Bozeman and Corley (2004) define research cooperation as "working closely with others to produce new scientific knowledge" (p.609). I conceptualize that particular sort of collaboration to consist of formal working functions which need to be performed in order to reach the scientific purpose. Cooperation has a specific relevancy for women: It is alongside complex interactions of compliance and antagonism, another female identity (Kilduff & Mehra, 1996) and, in science, a strategy to elude from contest which means rivaling predominantly men.

There has been little systematic theorizing and empirical studying on informal structures in the context of gender differences in higher education although Kanter—already in (1977)—discovered consequences of limited access for women. Meanwhile, Feeney and Bernal (2010) uncovered underrepresentation of women in informal academic networks. But for fulfilling scientific jobs informal contacts are particularly important and an integral precondition for succeeding. Task knowledge is said to derive in large part from suchlike connections (Cross, Borgatti, & Parker, 2001). Two relationship categories can be distinguished: (1) exchange of information and transfer of knowledge as instrumental network links, as well as (2) advice and help ties which additionally incorporate a substantial affective component (e.g. Lazega & Pattison, 1999). Networks provide opportunities for support (Gilbert & Ones, 1998). It is, amongst others, critical to publish in appropriate journals. For that, a researcher may need informal help in form of annotations for her or his work (partially referred to by Feeney & Bernal, 2010). A scholar further requires up-to-date information on, for example, new releases. I argue that support relations consist of both information flows as well as of help and advice contacts. Thus, informal relations within scientific work are conceptualized as research support.

Next to informal research ties, social acquaintance (Parker & Arthur, 2000) outside of work might appear among women and men working in cutting-edge research institutions. Social acquaintance is more affective by nature. However, it also comprises an instrumental element in terms of an opportunity to attain other resources thereby (e.g. support). Social acquaintance can be understood as a footing for soft social capital that enhances self-confidence and adds development of a professional self-conception (van Emmerik, 2006). Therefore, it facilitates problem-solving activities through boosting mutual trust. Contacts out of work can deepen a relationship with respect to its strength. The stronger a tie, the less opportunistic and the more trustful a colleague is (Jansen, 2008). Information for example, is rather exchanged in confiding relationships than in loosely tied bonds (Podolny & Baron, 1997). Trust can also foster speed of resource transfers and hence promote efficient progressing in scientific work (Katz & Martin, 1997).

Homophily can for instance, refer to sex, age, status, cultural background, professional education or entry date into an organisation (Katz & Martin, 1997; McPherson et al., 2001). A theory of gender homophily in the present context would suggest that in a CoE, scientists with similar (same) sex are more likely to be connected via formal and/or informal ties than would be scientists from diverging sexes. Technically, homophily is the degree to which interacting pairs of scholars equal in their sexes. In this paper, homophily is conceptualized as similarity (equity) in the attribute gender. It is necessary, to remark that similarity is a relational concept (Brass et al., 2004). A researcher can only be similar with regard to another academic and in relation to dissimilar others. Generally, the patterns of homophily are said to be exceptionally robust (McPherson et al., 2001).

2.3. Model and hypotheses development

I differentiated social capital of scientists into three different forms: involvement in (1) research cooperation, (2) research support and (3) social acquaintance networks. In cutting-edge research institutions, cooperation relations consist of mutual applying for funding, working together on projects as well as collaborative publishing. Moreover, it can include the jointly filling of a patent. The aim of building and maintaining formal research connections is the attainment of scientific objectives and hence academic career advancement. To achieve the scholarly goals, a researcher may need support from an academic colleague. By passing new and relevant information as well as by commentating paper drafts, support can be given (or received) among scientists in a CoE. The other way around, many scholars have agreed that cooperation often starts informally (Bozeman & Corley, 2004). Furthermore, researchers who frequently collaborate with colleagues and/or support each other informally may be more likely involved in joint outside-of-work meetings than researchers who are not linked to their colleagues via a research tie. Little work-related ties—whether formal or informal—would emerge without a trustful foundation of the relations. Confidence can be enhanced by meeting for coffee break or lunch and/or by talking about things that are not based on the job. Social acquaintance relations can, for example, increase—through fostering trust—the ability for mutual problem solving in scientific work. Emerging reliance between any two PIs may result in increased tie multiplexity, that is, the presence of one relation is interdependent with the presence of another. The first hypotheses (H1a-c) refer to these network interdependencies:

H1: a) In a cutting-edge research institution, the association between *research cooperation* and *research support* is strongly positive.
b) In a cutting-edge research institution, the association between *research cooperation* and *social acquaintance* is strongly positive.
c) In a cutting-edge research institution, the association between *research support* and *social acquaintance* is strongly positive.

Gender is an important identification base for the perception of similarity. According to the similarity-attraction-hypothesis, heterogeneity lowers interaction activity (Byrne, 1971) which is, however, essential for resource transfers. Given that cutting-edge research exhibits a demanding knowledge base and tasks are very knowledge intensive, scientists in CoEs are assumed to "network" a lot. Resource flows between the researchers in turn influence the creation of new scientific knowledge, thus fostering research success. But literature has repeatedly highlighted the importance of actor characteristics, such as sex for tie formation. Numerous studies from different areas have found an indication for a positive relationship between actor similarity and the probability of a link between them (McPherson et al., 2001). Regarded from a gender-homophily-perspective, largely separated female and male networks are likely to emerge.

The homophily-argument seems to be relevant in the context of science networks because academic environment is dominated by the presence of male researchers. Gender homophily can advantage male investigators since they may have broader accession to important network resources. On the other hand, female scientists may obtain less resources from their smaller pool of network connections. Females might be isolated from entire resource flows due to the fact that they are a minority in the academic system (Bozeman & Corley, 2004; Hirshfield & Joseph, 2012) and thus highly underrepresented in the CoEs too. Besides, women's efforts in building and maintaining ties to male scientists can fail because of men's non-existing willingness to integrate female researchers into their male-dominated networks. After all, women's homophile tendencies can compete with a preference for dealing with higher-ranked individuals (Lin, 1982) that are usually influential men. It seems that female scholars face various barriers in establishing relevant network links to (reputable) men. Consequently, power among investigators may be unequally distributed between the sexes. Gender segregation produces female networks with relatively little power[c]. Similarly, Brass (1985) showed in his previously mentioned study that women, like men, networked with their colleagues, but that the networks of women performed less influence.

A few studies have analyzed multiple types of relationships (e.g. Fischer, 1982). They show that the patterns of homophily tend to get stronger as more relations exist between two actors, revealing that homophily on each type of relationship cumulates to create greater homophily for multiplex than for uniplex network links. The other way around, homophily of networks with regard to sex and gender tends to decrease within the group of highly educated (McPherson et al., 2001). In skewed environments where men represent a big majority, for example, Ibarra (1992) found affective ties to be exceptionally gender homophilous. I suppose that both informal relations—research support as well as social acquaintance—are determined by analogue homophile tendencies pertaining to gender. Following Hagstrom (1965), cooperative action is related to various forms of actor similarity (including gender). But due to the fact that research collaboration lacks in socio-emotionality and is more instrumental by nature, the effect of homophily on the probability of a cooperation link to emerge between any two PIs is assumed to be weaker than for the informal relations. The second three hypotheses (H2a-c) refer to gender homophily and its impact on the science network variables. Hence, I hypothesize that PIs from cutting-edge research institutions that equal in their sexes are more likely to form a network tie than researchers with diverging sexes.

H2: a) In a cutting-edge research institution, the association between *gender homophily* and *research cooperation* is weakly positive.
b) In a cutting-edge research institution, the association between *gender homophily* and *research support* is moderately positive.
c) In a cutting-edge research institution, the association between *gender homophily* and *social acquaintance* is moderately positive.

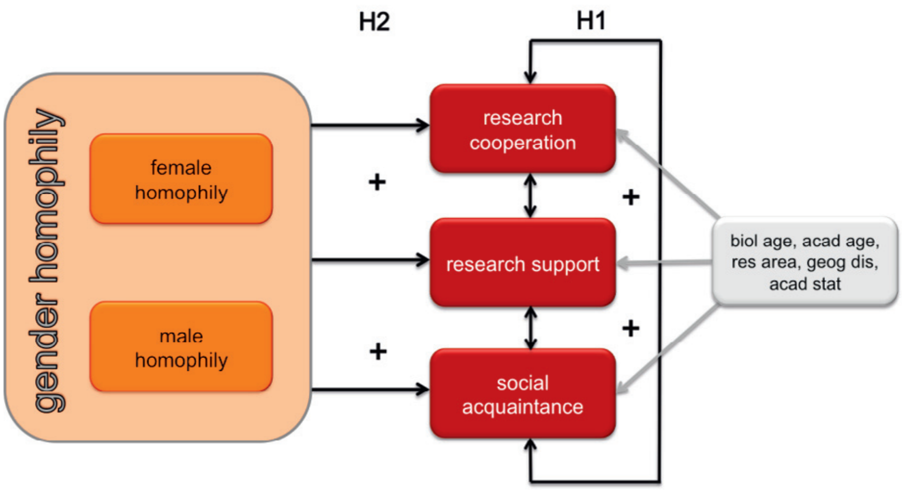

Fig. 1. Hypothesized model of gender homophily and network embeddedness

[c] Resource flow frequently functions as a central power source.

Figure 1 illustrates the hypothesized research model for empirically testing the relationships between the variables.

3. Empirical Analysis

3.1. Data

This paper uses data from the research project “Women in cutting-edge research”[d] located at Universität Hamburg and funded by the Federal Ministry of Education and Research (BMBF) (grant no.: 01FP0719) as well as European Social Fund (ESF) of the European Union[e]. The process study explores the German Excellence Initiative and focuses on aspects affecting gender (in)equality in cutting-edge research institutions. One section of investigation is social network analysis which has been conducted in selected excellence institutions. Data was collected per postal questionnaires in 2010[f]. The decision for this was made after having had longer preliminary talks with contact individuals from the excellence institutions[g]. Subjects of enquiry were the PIs which are characterized as being representatively involved in the scientific direction of their institutions. These were prevalently researchers in leading academic positions, albeit, scholars with a lower academic status also participated. All PIs of an excellence institution were regarded to constitute the respective network. Since there is no commonly accepted sampling technique for networks (Kossinets, 2006), several authors have emphasized that every actor of a delineated network shall be surveyed (Burt & Ronchi, 1994; Ibarra, 1992). So, as many individuals as possible were attempted to contact by phone in order to enhance feedback. PIs who had left their excellence institution were thereby identified and excluded from the network population. Networks have been farther reduced to PIs who had returned a complete form, even when other colleagues had cited them as a contact (e.g. Robins, Pattison & Woolcock, 2004).

Overall, network data from seven Graduate Schools and four CoEs was collected. The entire return run lay at 72%. For this analysis, I picked CoEs due to a higher level of research intensity, thus raising the potential for collaborative research activities. Furthermore, I selected more than one cluster in order to slightly enhance generalisability. Case studies are—and this is what the investigation of previously defined networks is—better grounded if a pattern from one data set is affirmed by the directions of another (Eisenhardt, 1989). Two of the four CoEs needed to be sorted out a priori because they contained less than two female PIs and therefore did not fulfill the essential precondition for homophily analysis. The other two clusters exhibited proportions of 16.4% (CoE A) respectively 15.2% (CoE B) women in their PI networks. Shares of women across the 27 studied excellence institutions within the project ranged between 0% and 31%. The percentage of females among all German professorships amounted to 17.4% at the time of data collection (Ruschenburg, Zuber, Engels, & Beaufays, 2011). In CoE A, the original relation between women and men was 14.5% which means that proportionately a few more women answered the form. In cluster B, the portion of 15.2% equals the ratio between female and male investigators to whom we had sent the questionnaires. For these reasons, response biases in terms of systematic differences seem rather improbable.

The two CoEs further differ with respect to their main research foci and their PI network sizes. They also discern in regard to their geographic dispersals. Given that data privacy statement does not allow for revealing detailed information about the institutions and their PIs, I need to pass an in-depth explanation of the studied CoEs. In brief, cluster network A consists of 61 PIs (response rate 80%) and is assigned to the field of life sciences. Network B is composed of 33 PIs (response rate 72%) and belongs to the field of natural sciences.

[d] At the beginning, 35 (later 27) Graduate Schools and CoEs as well as 5 universities with Institutional Strategies participated in the whole investigation.

[e] Any opinions expressed here are those of the author.

[f] Data collection was conducted by the former project associate Tina Ruschenburg.

[g] Subsequently, the alternative of an online survey was being excluded due to an expected significantly lower return rate.

Despite the assignment to a particular research field, PIs from various disciplines took part in the excellence institutions. The average number of PIs across all studied institutions was 55 researchers. Concerning geographic dispersal, two greater institutions that are spatially separated representatively participate in CoE A.

The network survey form collected relational as well as attributive data. The former accounted for a good portion of the questionnaire and compassed network questions on, for instance, research, teaching, committee work and social acquaintance which reflect diverse contacts from academic workaday life. Part two of the questionnaire contained personal questions on, for example, sex and biological age as well as queries on professional development such as academic age and affiliation to research area. A personalized form was sent out to each participant. For every relation, identical rosters with the names of all institutional PIs, excluding the name of the respective respondent, were provided. Informants were asked to mark those PIs, with whom they had accomplished certain collective activities within the past 12 months. They were free to cite as many colleagues as appropriate for suitably reflecting their relationship activities. According to Holland and Leinhardt (1973), fixing the number of response possibilities, tends to impose measurement error into network data. Also in this study, it seemed improbable that every PI would have exactly the same number of contacts.

3.2. Measures

According to the number of analyzable PIs in each excellence institution, network data from CoE A was organized in 61x61 binary adjacency matrices, whereas for cluster B, data was arranged in suchlike 33x33 matrices. Research cooperation, research support and social acquaintance represent relational variables, where cell x_{ij} refers to i's relation of a particular type to actor j (Hennig, Brandes, Pfeffer & Mergel, 2012). Since the questionnaire only asked (for the different relations), whether a contact between any two PIs was realized within the past 12 months, irrespective of the strength of relationship, cell entries were coded 1 for an existing and 0 for a non-existing tie (Kilduff & Mehra, 1996).

The cooperation matrices have been merged by the publication, the patent, the project work, the third-party- and the intern-fund networks. The results were multiplex matrices with possible cell occurrences between 0 and 5. Due to simplification and better comparability with the other aggregated networks, the matrices were firstly dichotomized. All cell values that equaled or were greater than 1, were coded 1. The rest kept noted a 0. Then, I symmetrized the cooperation matrices. It was believed that contacts might have been forgotten, but unlikely forged. According to Lincoln and Miller (1979), an indication from one actor is adequate to suppose an existing tie. Thus, unilaterally specified links were also assumed a reciprocal connection. The symmetrization procedure compared all cells right above the zero-diagonal with the respective cells left below and added the higher values in the corresponding cells (Hanneman & Riddle, 2005). After all, uniplex and undirected matrices have arisen which depict the existence (or non-existence) of a research cooperation link between any two researchers of the respective PI network.

The support matrices have been aggregated by the information transfer and the collegial help networks. Originally, the data set consisted of four matrices, respectively. Two questions asked for receiving on the one hand, and forwarding relevant news on the other hand. Two other questions sought for annotating on drafts on the one hand, and for getting drafts commented on the other hand. The informal research sub-matrices were in contrast, to the sub-matrices of the formal contacts, asymmetric. For verification of comparableness between formal and informal research networks, the latter were firstly summed up to multiplex matrices by addition of the partial nets. Since both directions of draft annotating as well as on news transferring were requested, summation involved both—giving and receiving—perspectives of the informal research networks. Likewise for cooperation, the aggregated matrices containing all four sub-networks were dichotomized. One might argue that dichotomizing leads to loss of information. However, in the case of research support, matrix cells could comprise values between 0 and 4. A 2, for instance, could have indicated either a bilateral connection of one particular sort or a mix of two different types of tie. As this could not be discerned within the multiplex research support matrices, simplification through dichotomization appeared to be inevitable. Together with the followed symmetrization, uniplex and undirected support matrices have been produced. The matrices reflect to what extent informal research contacts generally existed but do no longer reveal the direction of ties or if they occurred reciprocally.

Ultimately, the social acquaintance matrices have been merged by the appointment for coffee break and/or lunchtime as well as by the conversation on non-professional issues networks. Multi-variate matrices with value ranges between 0 and 2 had been the result of matrix summation, before dichotomization led to uniplex matrices. Just as data preparation of the forewent relational variables, symmetrization was operated on both social acquaintance matrices. The outcomes are informal social acquaintance matrices that are both uniplex and undirected, giving rise to an (unvalued) distinction between realized and unrealized PI network ties.

Unlike the network variables, the gender and "control" variables are actor attributes and for methodological reasons, needed to be recoded to relational data too. Hence, I converted the original 2-mode data sets to 1-mode sets (cf. the procedure in Rank & Tuschke, 2010). The outcomes are actor-by-actor matrices for each variable where cell x_{ij} was coded 1 if both PIs had, for example, the same academic status. If they did not have the same status, the corresponding cell was coded 0 (e.g. Burris, 2005). The resulting matrices can be considered similarity, or rather for gender, homophily matrices.

The introduced variables are relational as well as recoded attributive matrices. Five "control" variables have been included into the analysis: biological age, academic age, research area, geographic dispersal and academic status (Feeney & Bernal, 2010). Similarity in biological age was believed if two PIs were aged up to 30, between 31 and 40, between 41 and 50, between 51 and 60 and if both were over 60 years old. Biological ages ranged between 34 and 63 in CoE A and between 35 and 69 in CoE B. Given that the academic age—measured as years since conferral of a doctorate—is much lower than the biological, steps were made a bit different. Two PIs were regarded similar if both did their doctorate within the past 5 years, between 6 and 15 years ago, between 16 and 25 years ago, between 26 and 35 years ago and if two PIs received a doctorate's degree 36 or more years ago. Academic ages ranged between 3 and 33 in cluster A and between 6 and 41 in institution B. Both CoEs exhibited activities in different areas of research, to which the PIs had classed themselves. Similarity was presumed if two PIs did research within the same area of expertise. In CoE A, the PIs had assigned themselves to 5 different disciplines. Cluster B was with 7 different areas of research more interdisciplinarily oriented. The forth variable, geographic dispersal, has been included into the analysis because the PIs from excellence institution A were spatially dispersed. Hence, a 0 was coded in a cell x_{ij} if two PIs worked at different places. Finally, similarity in academic status—measured as current scientific position—has been assessed. Respondents could check for professor, junior professor, junior research group leader, postdoc or other position. In CoE A, four additional groups were generated, whereas three extra groups were built for excellence institution B, thus forming similarity matrices out of eight, respectively, seven status categories. Likewise the other variables, similarity in status caused a 1-coding.

3.3. Method

To study the associations between the different network relations—in terms of a "deepening multiplexity analysis"—and gender homophily while additionally including other variables (similarity in biological and academic age, research area, location, status) into the investigation, I applied the Quadratic Assignment Procedure (QAP) (Hubert & Schultz, 1976) network correlation analysis on the PIs of two CoEs. I selected this methodological approach because the unit of analysis is the relational dyad which cannot be assumed independent from other dyads. QAP is a popular approach for comparing matrices (Robins & Pattison, 2006) and seems to be able to overcome the problem of tie interdependency (Krackhardt, 1987). Furthermore, not always could a causal direction be assumed. Several matrices are supposed to be mutually contingent upon each other (relational variables).

QAP is a non-parametric test that is based on permutations (Krackhardt, 1987). It seeks to find out if two network structures are significantly related to each other (e.g. Baker & Hubert, 1981)[h]. The extent of association between any two relations can be assessed by correlating the corresponding adjacency matrices (Hanneman & Riddle, 2005). For instance, the following question shall be answered: If an acquaintance link between two PIs exists, is it likely that a cooperation tie also connects them? The QAP algorithm proceeds in two steps: Firstly, data—originally in matrix form—is vectorised and a standard Pearson correlation coefficient between corresponding cells of two matrices is calculated (the observed correlation). Secondly, a null-hypothesis distribution is generated with which the observed correlation coefficients can be compared in order to investigate statistical significance. A reference distribution is created by randomly permuting all rows and columns (synchronically) of one matrix—with the other one kept fix—and recalculating the correlation coefficients. This procedure is repeated very often to calculate the proportion of how often a random measure greater or equal to the observed measure occurs[i]. The obtained coefficients are then used to assess the probability of the original coefficient having resulted by chance (Rank, 2008; Robins & Pattison, 2006).

3.4. Results

I tested, on the network level, the earlier proposed hypotheses (H1) that research cooperation, research support and social acquaintance links are highly correlated among each other as well as that there is a tendency for scientists to build and maintain relationships with institutional colleagues from the same sex (H2). Tables 1 and 2 depict the QAP results for the two analyzed CoEs. They show the correlations between all main as well as other variables and—if existing—the corresponding significance levels.

Table 1: QAP network correlation results for Cluster of Excellence A

A	Biol Age	Acad Age	Res Area	Geog Dis	Acad Stat	Gend Homo	*Fem Homo*	*Mal Homo*	Res Coop	Res Sup	Soc Acqu
Biological Age											
Academic Age	.31***										
Research Area	.02	-.01									
Geographic Dispersal	.01	-.03*	-.02								
Academic Status	.20***	.06*	.06*	.00							
Gender Homophily	.02	-.00	.01	-.03	.09						
Female Homophily	.02	.04	-.03	.03	-.06*	.10					
Male Homophily	-.01	-.02	.02	-.04	-.10	.94***	-.24***				
Research Cooperation	-.04*	.00	.02	.36***	.07*	-.05	.06*	-.07*			
Research Support	.04*	-.03	.02	.31***	.15***	.03	-.01	.03	.61***		
Social Acquaintance	.05*	.02	.03	.31***	.14***	.04	.03	.03	.53***	.54***	

***: p<.001, **:p<.01, *:p<.1
5.000 permutations

[h] The QAP test retains integrity of the observed structures (e.g. explicit preservation of interdependencies between dyads).
[i] The more permutations that are performed, the better the estimates of standard errors and „significance“ sample out.

Table 2: QAP network correlation results for Cluster of Excellence B

B	Biol Age	Acad Age	Res Area	Geog Dis	Acad Stat	Gend Homo	*Fem Homo*	*Mal Hom*	Res Coop	Res Sup	Soc Acq
Biological Age											
Academic Age	-.03										
Research Area	-.10*	-.10									
Geographic Dispersal	-.09	-.01	.03								
Academic Status	.30**	.06	-.12*	-.08							
Gender Homophily	.17*	-.15	.10	-.06	.09						
Female Homophily	-.05	.12	-.00	-.04	-.05	.08					
Male Homophily	.19*	-.19	.09	-.07	.11	.95***	-.22***				
Research Cooperation	.02	.07	.11*	-.01	.12*	.02	.12*	-.02			
Research Support	.06	.13*	.15**	.04	.14**	.08*	.00	.08	.58***		
Social Acquaintance	.06	.07	.19**	-.04	.23***	.09*	.13*	.05	.48***	.52***	

***: p<.001, **:p<.01, *:p<.1
5.000 permutations

QAP correlations have been computed with the program UCINET (Borgatti, Everett, & Freeman, 2002). The prediction from the network interdependency notion was that all three network variables are strongly interrelated (H1). For both CoEs, the results confirm the assumed highly positive correlations between the cooperation, the support and the social acquaintance network. Coefficients around and beyond 0.50 have emerged between all relational variables of the respective excellence institutions. The observed values are all significant at the 0.001-level against the null-hypothesis of random correlation which means that the observed values had only a 0.1% chance to have been assigned at random (Krackhardt, 1987). At 5,000 random permutations, only five produced a correlation of for example, 0.52 (B: SocAcqu/ResSup) or higher. The outcomes can be interpreted as “matching” between pairs of relations.

Pursuant to hypothesis 2a, the association between gender homophily and a research cooperation tie was assumed to be weakly positive. Once again, the homophily variables have been recoded from their original actor-by-attribute form to the methodologically required 1-mode matrices. Hence, they present similarity matrices with each cell x_{ij} coded 1 if a pair of scientists had the same sex (no matter which). A 0 was then coded if two researchers differed in their sexes. Looking at the results from CoE A, gender homophily indicates a very weak and negative correlation with research cooperation which is insignificant. No evidence can be derived from the empirical results that the scientists in that cutting-edge research institution are more likely to form a cooperation tie with a colleague from the same sex than with somebody from the other sex. Yet, a negative relationship (-0.05) has emerged which would have, if significant (and higher in value), indicated that a researcher would be more likely to cooperate with a co-worker from the other sex. The result from CoE B differs with regard to prefix of the coefficient. It is very weakly positive (0.02), but insignificant as well. Therefore, I cannot find support for H2a.

Hypothesis 2b suggested gender homophily to have a moderately positive effect on the likelihood of a research support tie to emerge between two PIs. Certainly, no significant association (0.03) can be found in CoE A. However, in excellence institution B, there is a slight tendency (0.08) identifiable that scientists with the same sex are more likely to be connected via a support tie than would be scholars from diverging sexes. This relationship is lightly significant[j]. Given that the latter coefficient—although slightly significant—is too low for calling the association between gender homophily and research support "moderate", H2b also needs to be rejected.

The second informal network variable, social acquaintance, reveals no significant relationship (0.04) with gender homophily in CoE A. On the contrary, cluster network B exhibits a lightly significant tendency (0.09) for scientists to communicate and/or interact outside of their cutting-edge research work with peers from the same sex[k]. Anyway, like for hypothesis 2b, the very neap correlation coefficients lead to the conclusion that the hypothesized association between gender similarity and social acquaintance is not denoted for scientist who act in a CoE. With QAP correlation analysis, H2c cannot be supported as well.

4. Discussion

4.1. Main variables

Just as claimed by Krackhardt (1987), the correlations between the network matrices on hand have revealed strongly positive connections. This points to tie multiplexity of the formal and informal science networks. More precisely, the QAP correlation results constitute quantitative measures of multidimensionality of human relationships (Szell et al., 2010). In both cases, the highest values were achieved for the relationship between the cooperation and the support network (A: 0.61; B: 0.58). In cutting-edge research institutions, collaborative activities between two scientists are likely to occur together with supportive actions. While working together on a project or collectively writing a paper, scholars may also help each other by annotating other paper drafts or by passing her or him relevant news. It can be the other way around as well. If researchers support each other then it may be more likely that they will initiate and run a research cooperation too. These results are in line with Bozeman and Corley (2004) who state that cooperative activities often begin with informal contacts.

A very important factor is trust that may strongly evolve from joint outside-of-work meetings and/or conversations on non-professional issues. Both CoEs showed highly significant correlation coefficients for the relationship between research support and social acquaintance (A: 0.54; B: 0.52). It seems that when two scientists are tied via a social acquaintance link then reliance is created that in turn increases the likelihood for research support. The other possible way around, researchers who help each other by annotating papers or forwarding relevant news may be more likely to, for example, meet for lunch than they would without being linked via a support tie.

The third coefficient suggests a high association between social acquaintance and research cooperation (A: 0.53; B: 0.48). As for the previous relationship, if scientists in cutting-edge research institutions cooperate with colleagues they may be more likely to also be involved in mutual social activities that have nothing directly to do with their work. This may be simply due to the fact that they get to know each other better when cooperating. On the other hand, trust gained through social acquaintance may make it more likely for a pair of researchers to set and accomplish cooperative work.

Having a look at gender homophily, it seems—unlike the common assumption of homophily in work settings (Bielby & Baron, 1986; Brass, 1985; Ibarra, 1992)—that sex does not play a considerable role in joint activities of scientists in cutting-edge research institutions. Anyway, the results could to some extent be explained by the low proportion of women which amount to approximately 16% in both clusters. Insofar, the gender similarity matrix exhibits a very high number of 1s since many PIs (men) have the same attribute (sex). Assuming, for A, a

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[j] Usually, a significance level of 0.05 is chosen. But when the sample is quite small, reaching significant results can be difficult. In this case, the level of significance can be reduced to 0.1.

[k] Two correlation coefficients in cluster B indicate slight tendencies towards homophily. This leads to the question if that CoE differed from the other, e.g. in potentially offering incentives for collaboration. We do not have any information on that and as the coefficients are not very high, searching for great differences in the clusters does not seem to make sense.

male researcher tends to form ties with co-workers from the same sex, he might maintain up to 50 ties per relation (cf. the following formula):

$$F = n - 1 - g \quad (1)$$

Place holder n stands for the number of all PIs, g represents the number of members of the other sex (in this case: women) in the network. However, humans only possess limited capacities of time and attentiveness, wherewith they are only able to form and look after a certain quantity of (multiplex) relationships. It seems obvious that not as many ties as would be needed to match all the 1s in the gender homophily matrix, could be kept by the male scientists.

To check for potential bias and to enlarge exploration, I calculated individual gender homophily using the formula applied by Mehra and Kilduff (1996) which corrects for availability bias:

$$H = \frac{ad - bc}{\sqrt{(a+c)(b+d)(a+b)(c+d)}} \quad (2)$$

In the formula is a the number of cites to PIs of the same sex, b the number of cites to PIs of the other sex, c the number of PIs of the same sex the respondent could have cited but did not and d the number of PIs of the other sex the respondent could have cited but omitted (see also the empirical example from Ibarra, 1992). Calculations of homophily measures on the individual level revealed similar results as the QAP correlation analysis. In CoE A, a slight tendency towards heterophily, on average, was found within the cooperation network (-0.09)[1]. Also, alike the QAP result, a lightly positive averaged value was detected within the social acquaintance relation (0.03), showing a very low tendency for homophily. The averaged homophily value of the third network variable—research support—quasi indicated a non-effect (-0.01). Cluster B is characterized by very base homophily within all three relations (ResCoop: 0.04; ResSup: 0.06; SocAcqu: 0.08). All these ordinary values are in line with the findings from the QAP analyses. Exploring gender homophily on the individual level allows for a more detailed investigation compared to comprehensive examinations on the network level.

An in-depth analysis of gender differences pertaining to homophily partially uncovered antithetic outcomes. So the findings from cluster B were again more linear in contrast to those of institution A. Precisely, female PIs from CoE B constantly excelled their male counterparts regarding homophile contacting. The greatest difference could be discovered in social acquaintance with averaged values of 0.30 (women) and 0.04 (men), followed by formal research contacts with averaged values of 0.22 (women) and 0.01 (men). The difference in the relation type research support was marginal with 0.08 (women) and 0.06 (men). Nonetheless, women in the excellence institution with a focus on natural sciences seem to prefer establishing relationships with co-workers from the same sex to a higher extent than their male colleagues. A probable explanation could be that women in that field of research do not “feel at home” yet and that an own group of (female) researchers has been formed which confides in each other but is isolated from the (male) majority.

CoE A exhibited more diverse results, though the differences in values were smaller. Female PIs slightly tended to cooperate with investigators from their own sex (0.09), whereas men very lightly tended to maintain cooperation ties with researchers from the other sex (-0.04). The other way around, the averaged values within the support network revealed a very low tendency towards heterophily for women (-0.02) and towards homophily for men (0.04). Finally, social acquaintance is characterized by homophile tendencies of female (0.09)

[1] The homophily index ranges between -1 and +1. Negative values show a heterophile tendency while a positive value reports a tendency to cite a colleague from the same sex.

as well as male (0.03) PIs. Except for research support, female PIs from the institution focused on life sciences, like in CoE B, seem to prefer maintaining ties with associates from the same sex to a higher extent than their male co-workers. However, both homophily and heterophily occurred on a very base level, oscillating around zero. A possibility why women in CoE A were not strongly segregated from their male colleagues could be again the institutional research focus. Life sciences consist of disciplines, where women are numerically stronger represented (e.g. biology) compared to areas of research from natural sciences (e.g. physics) (Feeney & Bernal, 2010). Their higher proportion among researchers may help increase their general standing, in turn raising the probability to be chosen as a network partner by—besides other women—men.

4.2. Other variables

The results from the correlation matrices may lead to the assumption that investigators in cutting-edge research institutions are more heterogeneous in their characteristics and that other types of homophily contribute more strongly to the understanding of scientist's embeddedness in formal and informal academic network structures. Looking at the QAP correlation matrices, we can see other, hitherto unmentioned, significant relationships between the network variables on the one hand, and the similarity variables geographical dispersal as well as academic status for CoE A and research area as well as academic status for cluster B on the other hand.

CoE A was settled in two bigger institutions in which most of the PIs performed their work. The correlations between the three network variables and geographic dispersal reveal moderate associations (ResCoop: 0.36; ResSup: 0.31; SocAcqu: 0.31) at a highly significant level, indicating that proximate researchers are more likely to build and maintain a tie than are scholarly persons who work in geographically distant places. Figure 2 displays the informal research network of CoE A. It was prepared with the aid of the program NETDRAW (Borgatti, 2002). As we can see, there is no gender-specific clustering among the PIs identifiable (cf. the result from the QAP correlation procedure: 0.03). However, there exists an apparent clustering towards geographic location. On the left side of the illustration there are primarily scientists from one greater institution clustered together (spheres). The right side is dominated by researchers from the other bigger institution (squares). The triangles indicate PIs who are not located at one of the two main places. Three missing values with regard to geographic position are shown as things.

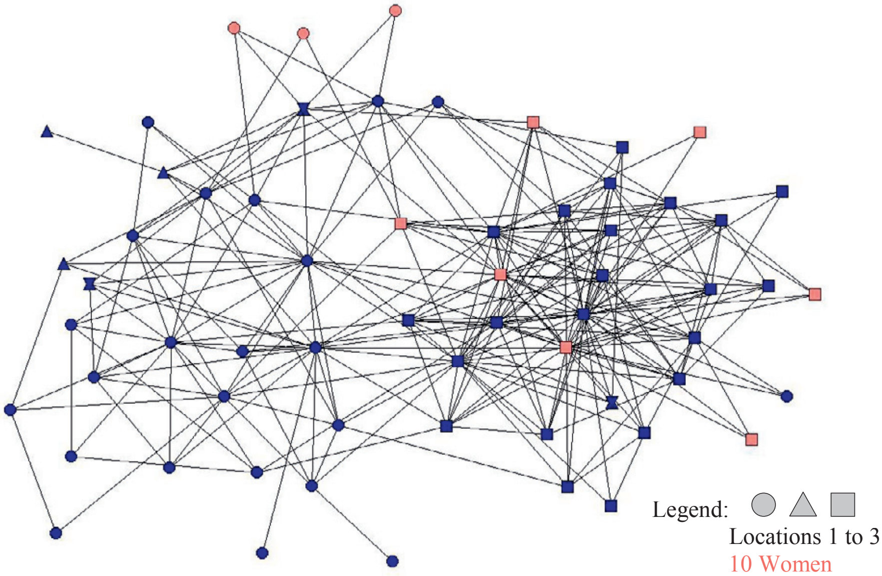

Fig. 2. Realized research support network of Cluster of Excellence A

According to McPherson, Smith-Lovin and Cook (2001), "perhaps the most basic source of homophily is space" (p.429). It seems that local concentration plays a role in forming social norms which in turn facilitate trust (Krücken, 2007), again fostering formal as well as informal linking due to reliance that exchanged resources will not be appropriated or misused. Other than in cluster A, no proximity effect can be found for CoE B. This was not unexpected, given that the PIs were almost all settled at the same location.

However, CoE B features rather moderate correlation coefficients between all network variables and the attributive variable research area (ResCoop: 0.11; ResSup: 0.15; SocAcqu: 0.19), whereof the informal relations hold higher levels of significance than research cooperation. Scholars can differ in their affiliation to area of expertise. Working in the same field of research makes it more likely for a formal or an informal network tie to emerge. Even though interdisciplinary plays an important role in the Excellence Initiative (Sondermann, Simon, Scholz, & Hornbostel, 2008), scientists may particularly seek to interact with colleagues coming from the same research area so as to master complexity. Following McCain, O'Reilly, and Pfeffer (1983), homogenous groups more easily coordinate their activities, in contrast to diverse ones. Another explanation could be that scientists from an even area act together in a specific faculty culture which might facilitate network involvement as well. Investigators may also prefer having informal relationships with colleagues, they already knew before having entered the CoE rather than with researchers from different fields, they met in the cluster for the first time. The longer two scientists have known each other, the more likely formal and informal contacts may occur.

The third remarkable similarity variable is academic status. Both CoE A as well as B exhibit significant relationships between status similarity and all three network variables. The results differ in exact value and level of significance. In A and B, weak to quite moderate associations (A: 0.07; B: 0.12) between similarity in scientific position and research cooperation can be found in the QAP correlation tables. The coefficients are slightly significant at the 0.1-level. The relationship with research support is highly significant with 0.15 in cluster A and moderately significant with a value of 0.14 in CoE B. Finally, social acquaintance ties are in both

CoEs related to academic status (A: 0.14; B: 0.23). The variables are indeed significantly correlated at the 0.001-level, revealing a huge probability that the results have not occurred by chance. Therefore, similarity in academic status increases the likelihood of a link to emerge between two PIs. We can further read from the QAP correlation matrix of network A that biological age and the studied network variables are weakly correlated (ResCoop: -0.04; ResSup: 0.04; SocAcqu: 0.05) at the 0.1-level. But since firstly, similarity in biological age is highly associated with status similarity (this holds true for both excellence institutions), and secondly, the latter variable seems to be the more critical determinant of network embeddedness, and thirdly, the correlations between biological age and the network relations are very weak and at a low level of significance, a detailed discussion on age does not seem needful in this context.

Jansen (2007) stated that beside rise of visibility and reputation that can be gained through network ties, the status of a colleague is an important factor for a connecting decision. However, given that status goes beyond mere instrumentality, as it can create power disparity, informal networks are more strongly associated with status similarity than are formal research bonds. Postdocs may ask other postdocs for help concerning a paper annotation. Professors may prefer discussing non-vocational matters with other professors. Although lower status researchers may want to form an informal tie with a higher-ranked PI, there seems to exist a certain status barrier between scientists in both excellence institutions that hampers inter-status connecting[m].

5. Conclusion

Aim of the analysis was to empirically test (1), whether research cooperation, research support, and social acquaintance are correlated and thus exhibit tendencies towards multiplexity as well as (2) to what extent gender homophily in the context of cutting-edge research has an impact on scientist's involvement in formal and informal networks. The chosen network-analytical approach represents a substantial novelty in gender and higher education research, as empirical evidence on gender-specific network integration in academe is still rare.

Scholars have recurrently claimed that underrepresentation of women in leading academic positions is, amongst others, affected by women not having network access to the same extent as their male colleagues (Etzkowitz et al., 2000). The other way around, it has been supposed that female researchers with minority status have less access to advantageous net contacts than their male vis-à-vis (Feeney & Bernal, 2010). This points to a vicious circle. For a stronger establishment within top research, women ought to be better involved in formal as well as informal scientific nets. However, due to potential excluding mechanisms such as homophily, access to diverse network resources may stay refused. In a different way from tokenism theory (Kanter, 1977), Feeney and Bernal (2010) claimed that increase of percentage of woman in individual fields does not present a sufficient instrument for improving their network access. This hopelessness raises the question for which reason some women hold advanced academic positions, though they still might remain partially excluded from science networks.

The results of the two studied CoEs supported the network-interdependency-hypotheses (H1) by revealing quite strong tendencies towards multiplexity between the network matrices. The findings are in line with Krackhardt (1987) who argued that "[n]etworks are frequently multiplex by nature" (p.171). On the other hand, neither the relationship between gender homophily and cooperation (H2a) nor between homophily and support (H2b) nor between homophily and social acquaintance (H2c) pointed significantly to the proposed effects. However, two relations from cluster B very slightly and significantly correlated with gender homophily. These outcomes are to the greatest possible extent alike McPherson, Smith-Lovin and Cook (2001) and alike van Emmerik (2006), who stated that higher education or higher status lower the difference between the sexes. Anyway, deeper homophily analyses on the individual level uncovered differences between female and male PIs. Women tended to network with associates from the same sex to a higher extant than men. This was especially the

[m] Over a longer period, network embeddedness—especially informal links—can the other way around have an effect on academic status.

case in CoE B, where moderate female homophily was detected at cooperative and socializing activities. The results from the more detailed analyses are—other than research support in CoE A—opposed to existing findings from management literature which discovered stronger homophily among the majority (men) (Brass, 1985; Ibarra, 1992).

For all that, three other similarity variables exhibited moderate relationships with the network variables. In CoE A, geographic dispersal as well as academic status were significantly related to research cooperation, research support and social acquaintance. Cluster B held significant associations between similarity in research area as well as in academic status and network embeddedness into all three relations. Both CoEs indicated similar results concerning the correlations between gender homophily and the network variables that help making a vague assumption as to generalisability in the context of cutting-edge research.

However, A and B consisted of only about 16% women. Those who were at the time of data collection PIs in the respective excellence institution were accepted, but more women had not been let in. Still, women were considerably underrepresented in the excellence institutions. The data did not reveal anything about—if applicable—systematic upstream access mechanisms that had potentially excluded women from becoming a PI. Already at the time of PI composition, mechanisms of exclusion due to old boys networks could have taken effect. Those researchers who indeed managed to come to the top, whether women or men, seem to be quite akin concerning their scientific self-conception. That leads to speculations about a decreased tipping point (Kanter estimated the point near 35%)—the percentage from where negative effects of tokenism diminish. Yet, the danger of gender discriminating practices is covertly present and accordingly, should be taken seriously. At the project, we also have other data (e.g. attributive data from an online survey) and use other analyzing methods. We found for instance, a gender effect on the level of PhD students.

To enhance quality of the present outcomes, more research needs to be undertaken. The analysis on hand represents a first approach to look for multiplex and homophile tendencies in scientific networks. Future research within and outside of the project "Women in cutting-edge research" shall focus on examinations of gender-specific embeddedness into formal and informal networks at other levels of analysis. Efforts in studying the different participation of women and men in scientific net structures at the micro level as well as the determinants of integration have already been made. First results from a broader sample of excellence institutions will be presented at the closing conference of the project within this year. Furthermore, I want to investigate if any PIs are "cliqued" together in cohesive sub-groups. Are female scientists differently integrated into potential sub-groups from formal and informal networks than men? To look into the relations between different intra-network groups, I further want to conduct block model analysis. Moreover, we have additional qualitative network data from selected PIs[n] that can add subjective interpretations to the results of quantitative analyses (Hollstein, 2008)[o]. Thus, will a more detailed exploration of PIs' network embeddedness then reveal the consistently arising assertion about the unfavorable network integration of women? Or do academics from cutting-edge research institutions represent an exceptional case so that homophily theory is not fully applicable to them?

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[n] Interviews were conducted by the former project associate Sandra Beaufaÿs.

[o] First findings from a mixed-method-design have been presented at the conference "Gender Equality in a Changing Academic World" in August 2012. The presentation bore the title "Informal networks in science: Differences between perceived and realized embeddedness of female and male researchers" and is available on https://www.uib.no/gender2012/programme/presentations.

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