Raumforsch Raumordn (2014) 72:275–291
DOI 10.1007/s13147-014-0299-2

WISSENSCHAFTLICHER BEITRAG

Revealing Relevant Proximities. Knowledge Networks in the Maritime Economy in a Spatial, Functional and Relational Perspective

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Received: 1 October 2013 / Accepted: 3 June 2014 / Published online: 4 July 2014

Abstract The maritime economy as a heterogeneous innovation system has ongoing relevance to the successful spatial and functional development of regions in Europe. A strong technological knowledge base underpins the competitiveness of the maritime economy, which is grounded in distinct spatial structures and proximities. The simultaneous relevance of global and local knowledge is particularly pronounced in the maritime economy through its inherent relevance to globalization and structural change. Conventional classifications of the maritime economy embedded in the discussion of the spatialization of knowledge-intensive activities and global value chains, however, limit the analysis to certain parts of the maritime cluster. This paper examines the applicability of various discourses on interactive knowledge generation and application as a process, based on a comprehensive dataset derived from cooperative links within the maritime economy of northern Germany. It suggests a framework for analysis that is activity based and focuses on the concurrent presence of different dimensions of proximity across value-creating systems. We explore spatial patterns by means of social network analysis. These patterns are industry-specific and have the potential to inform efforts to increase functional as well as physical connectivity in regions. The empirical analysis begins with the individual firm as an actor seeking to optimize its location for the purpose of competitiveness. It proposes an approach that is rooted in the ongoing discussion on spatial and functional dispositions for innovation activity and that bridges the dichotomy of knowledge-intensive services and manufacturing activities in the maritime economy.

Keywords Maritime economy · Knowledge networks · Spatial development · Proximity · Urban system · Germany

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Die Relevanz von Nähe: Wissensvernetzung in der maritimen Wirtschaft aus räumlicher, funktionaler und relationaler Perspektive

Zusammenfassung Die maritime Wirtschaft als ein heterogenes Innovationssystem hat großen Einfluss auf die räumliche und funktionale Entwicklung von Regionen. Die stetige Weiterentwicklung der Wissensbasis in der maritimen Wirtschaft steht in enger Verbindung mit räumlichen Strukturen und deren Verflechtung. Dabei ergänzen sich Wissensressourcen auf verschiedenen Maßstäben von lokal bis zu global gegenseitig. Konventionelle Klassifizierungen der maritimen Wirtschaft auf Grundlage der Wirtschaftsbereiche reichen dazu nicht aus, um die ‚Verräumlichung' von Wissen zu verstehen. Eine relationale Perspektive auf Wissensnetzwerke im Zusammenhang mit dem realen Austausch von Gütern ist eher in der Lage, dieses Verständnis zu fördern. Dieser Beitrag versteht die Wissensproduktion als interaktiven Prozess, der eng mit der Produktion von Gütern verflochten ist, und untersucht die Anwendbarkeit verschiedener Wissenskonzepte auf die Kooperationsnetzwerke in der maritimen Wirtschaft in Deutschland. Dabei erarbeiten wir Herangehensweise, die sich mit den Funktionen und Tätigkeiten der Unternehmen und Forschungseinrichtungen auseinandersetzt und dabei Zusammenhänge von räumlicher und relationaler Nähe analysiert. Wir wenden dabei die Soziale Netzwerkanalyse im räumlichen Kontext an. Dadurch wird ersichtlich, dass das Netzwerk der maritimen Wirtschaft hauptsächlich von Dienstleistern, Schiffsbauern und Forschungseinrichtungen zusammen gehalten wird. Die Städte in Norddeutschland formen dadurch im Ansatz ein hierarchisches Netzwerk, in dem Hamburg die höchste Bedeutung hat und als *Gatekeeper* funktioniert. Jenseits dieser hierarchischen Netzwerkstruktur etablieren sich spezialisierte Standorte entlang der Ems-Achse.

Schlüsselwörter Maritime Wirtschaft · Wissensvernetzung · Raumentwicklung · Nähe · Urbane Systeme · Deutschland

1 Introduction

The spatial organization of industrial activities has undergone dramatic change in the past 50 years (Dicken 2011). Globalization and the rise of information and communication technologies (ICT) have propelled the restructuring of value chains and knowledge networks (Derudder/Witlox 2010; Brown/Derudder/Parnreiter et al. 2010). The maritime economy has been instrumental to economic change and the formation of the urban system in Germany by producing knowledge and innovations for centuries. Recently, structural change has propelled the integration of specialized services that facilitate the flow of information and goods. The locational behavior and the importance of these services for the maritime economy have been explored by Jacobs/Koster/Hall (2011) and Jacobs/Ducruet/de Langen (2010). This development process concurs with the restructuring of port activities and the rise of port city-regions (Notteboom/Rodrigue 2005) as relevant units, marking a process of *up-scaling* and phenomenological alignment with emerging Mega-City Regions (Hall 2007b: 5 ff.). The spatial configurations that drive and are being driven by changes in the industrial organization of the maritime economy, could reveal relevant interdependencies for the future development of port cities and their hinterlands.

The term 'maritime economy' encompasses economic and research activities such as shipbuilding, logistics and ports, off-shore energy supplies, shipping companies, education and specialized services. This economic field is a growth engine for a country such as Germany, in which exports and trade are fundamental for economic success. Historically, the maritime economy in Germany can be traced back to the networks of the Hanse, which reached across the Baltic Sea and to Scandinavia. This network enabled secure shipping and the trading of commodities between port cities such as Hamburg, Bremen, Danzig in Poland and Bergen in Norway. The end of the 19th and the beginning of the 20th century represented one of the most successful periods for shipping and trading activities to date. After World War II German production of aircrafts and ships was closed down, but in 1951 shipbuilding was again liberalized (Abelshauser 2004: 165). The reconstruction of Germany, increasing trade with locations abroad and the strengthening of the shipping industry were closely linked to one another. The containerization of trade fostered the position of Hamburg as one of the biggest ports in the world. Accordingly, German shipowners became powerful while managing ship fleets all around the world (Brandt 2011: 33 ff.). The German ports nowadays are characterized by a distinct division of labor. Besides Hamburg the ports in Bremen and the Jade-Weser-Port in Wilhelmshaven specialize in container shipping and act as main hubs for the German hinterland. These North Sea ports account for 80 % of the German commodity exchange. The ports in Emden and Cuxhaven specialize in the shipping of cars (Brandt 2011: 98).

By means of its logistic service, the maritime economy is the "plumbing" of globalization, as 90 %of goods are traded by ships (Rodrigue 2013: 160). On an aggregated level, the maritime economy, which is heterogeneous in terms of its knowledge bases, represents a complex innovation system in which physical flows of goods are interwoven with a non-physical dimension of knowledge in transfer. As a result, the maritime economy provides a unique opportunity to assess the spatiality of knowledge networks, which reach beyond the facilities of ports (Hesse 2010; Brandt/Dickow/Drangmeister 2010: 241). On the one hand, the literature suggests that knowledge spillovers require face-to-face contacts for economic success. This understanding was established in the field of agglomeration economies (Eriksson 2011) and evolutionary economics (Boschma/Martin 2010). However, it has been argued elsewhere that a further differentiation in terms of knowledge types is needed to explain the spatial organization of economic activities (Zillmer 2010; Growe 2012). Therefore, an industrial process-based approach seems more applicable (Amin/Cohendet 2004; Bryson/Daniels 2010). Besides the instrumental involvement of the maritime economy in the process of globalization, this economic cluster includes a broad variety of knowledge-intensive activities and thus affects spatial development in

Germany from three different perspectives: spatial, functional and relational.

From a spatial perspective, the maritime economy shapes the interrelation of cities and ports. Innovations and new technologies have fundamentally restructured this relationship. The ongoing extension of commodity chains has led to an increased integration of ports in global production networks (Hall/Jacobs 2010; Hall/Jacobs 2012). At the same time, global trade demands accessibility for large vessels and new port facilities, reshaping coastlines. This process is accompanied by expansions of the hinterlands of ports (Hall/Jacobs 2012), underpinning the ports' functionality. Recent urban transformation at the waterfront of cities such as Hamburg and Bremen is mainly driven by the reorganization of port activities and the rise of service activities. However, the physical presence of the maritime economy not only revolves around port facilities but also includes activities in financial centers or places remote to coastal areas where further actors such as research institutions or logistic partners are located (Brandt/Dickow/Drangmeister 2010: 238). Thus, the multiplicity of the maritime economy affects spatial development through a number of parallel processes and historical events.

The functional perspective considers the maritime economy as a heterogeneous innovation system that transcends the sectors around transport, services and manufacturing, and involves private and public actors. Furthermore, the maritime economy is strongly affected by structural change, which fosters the importance of advanced producer services as intermediates in the production process, the relocation of labor intensive elements and new development paths such as wind energy (Fornahl/Hassink/Klaerding et al. 2012). These developments fundamentally affect the functional interfaces within the maritime economy.

The relational perspective emphasizes the knowledge networks of the actors of the maritime economy and considers knowledge creation as an interactive process. The value chains of this part of the economy range from low-tech manufacturing to knowledge intensive industries, where knowledge production is a complex process that is strongly interlinked with the transformation and exchange of goods (Hall/Hesse 2013; Hesse 2013). Moreover, the nature of knowledge calls for a differentiated approach which takes into account that proximity is key for the transfer, application and generation of knowledge (Vissers/Dankbaar 2013). The more knowledge is based on experience and learning by doing, the more likely it is that actors seek personal contacts and geographical closeness. Relational proximity is then used to complement these geographically bounded knowledge resources. In this regard geographical and relational proximity are counterbalanced in order to sustain learning processes and the influx of new information (Malmberg/Maskell 2006: 8 f.). Transferring this process of knowledge creation in the maritime economy to spatial development, the question arises as to how different types of knowledge evolve in different patterns of proximity between urban centers in northern Germany.

By studying the activities contained within the maritime economy, we aim to improve understanding of the ongoing differentiation of spaces initiated by the creation of knowledge in a highly complex economic field, which is deeply engrained in the identity of port cities. The question, therefore, arises as to how the different types of knowledge networks involve cities and regions in northern Germany in an urban system and ultimately affect spatial development in places even beyond port cities. Transformation of port cities, waterfront regeneration, logistic poles, port expansion, infrastructure planning and urban expansion create a disparate image of European port cities in terms of economic success (Hall 2007c; Schubert 2009; Hein 2011). This research requires an analytical approach, which takes the heterogeneity of the maritime economy into account and further reflects on innovation-oriented cooperation in value-added relations. We apply a closer and inductive look at the composition of, and relationships within, the maritime economy in order to evaluate the role of knowledge transfer for spatial development, the interdependence of activity fields and interaction of spatial co-location and distant collaboration.

Our research approaches the question of the spatial organization of the maritime economy from a spatial, functional and relational perspective. Firstly, we analyze the entire network of the maritime industry and how it devolves into certain sub-networks that rely on sectoral composition and spatial qualities on a regional scale. Secondly, we investigate the functional engagement of actors and how the different fields of activities are interrelated within the maritime economy. Thirdly, due to the fact that knowledge production is interlinked with the exchange and transformation of material goods, we include value-added characteristics in order to investigate the spatial range of knowledge relations.

To gain insight into the character of activities and relationships within the maritime economy Section Two elaborates the theoretical background of the analysis, discusses knowledge generation with regard to differences in the nature of knowledge and patterns of proximity, and introduces the research hypotheses. Section Three sketches the relationships among the activity fields involved in the maritime economy and introduces the set-up of analysis and the data used. Section Four presents the empirical findings which demonstrate the validity of this differentiated approach, applying network analysis to study how knowledge interaction and spatial proximity are interrelated. Finally, the conclusion in Section Five summarizes our findings with regard to the urban system in northern Germany.

2 Theoretical Background: Knowledge Creation and Proximity

Our understanding of the maritime economy, in which knowledge production is interwoven with the trade and production of goods, and its relevance for spatial development processes is based on three constituent parts. Firstly, the nature of its knowledge base and the catalytic effect of spatial and relational proximity. Secondly, the social process of knowledge creation, as it is interwoven with the production and trading of material goods. Thirdly, innovation as the valorization of generated knowledge in the form of a tradable product or service, driving economic development. This process of interactive knowledge generation evokes a complex interplay between spatial and relational proximity on different scales. The innovation system contains "the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge" (Lundvall 1992). Therefore, we derive an understanding in which the intersection of manufacturing, research and development and advanced services is emphasized.

2.1 The Nature of Knowledge

Knowledge is a production factor for both the input and the output side of value generation (Amin/Cohendet 2004: 15). In order to transform knowledge into value, firms or people apply specific competencies. Knowledge as an output is provided, for instance, by scientific research. In order to study the spatial consequences of knowledge application and creation, as well as collective learning, further differentiation is required.

Ever since the publication of Polanyi's "The tacit dimension" in 1966, it has been acknowledged that knowledge has a strong spatial relation, and that codified and tacit knowledge are mutually dependent (see Kujath/Schmidt 2010). Whereas codified knowledge may be transmitted via ICT without any *friction losses*, tacit knowledge is considered as geographically located or socially embedded (Amin/Roberts 2008). Gertler (2003: 78 f.) provides three arguments for the spatial foundation of tacit knowledge. Firstly, tacit knowledge is difficult to exchange over long distances since it is rooted in experiences made during learning processes. Secondly, it is context specific in terms of language, shared values or culture. Finally, the innovation process turns into social action in which learning structures become relevant and, thus, it involves institutions and organizations enabling access to learning. Gertler (2008) suggests further distinguishing between analytic, synthetic and symbolic knowledge to capture systematic differences in knowledge bases and innovation processes across industries.

2.2 Relevant Proximities for Knowledge Creation

The literature on knowledge generation and innovation is closely related to Schumpeter's work on economic development (Schumpeter 1934). From a spatial perspective, the ability to produce and absorb knowledge is considered key to innovation and sustainable economic success. Moreover, the 'right' configuration of spatial and relational proximity is crucial for the success of firms (Nooteboom 2000; Schamp/Rentmeister/Lo 2004; de Jong/Freel 2010). As knowledge can be of various forms and types, knowledge transaction depends on a variety of factors. Most critically, tacit knowledge transfer is catalyzed by proximity between actors (Boschma 2005). Physical proximity is given by short geographical distance and considered to catalyze knowledge transfer by increasing the likelihood of interaction (Storper/Venables 2004; Eriksson 2011). Other forms of proximity such as cognitive, institutional and organizational proximity are based on the relations of actors and are considered to broaden the bandwidth of communication by shared systems of reference (Gertler 1995; Torre/Rallet 2005; Boschma 2005). Cognitive proximity exists when actors share the same knowledge or technological base. Institutional proximity is realized by being a formal member of a club or association. Finally, organizational proximity is defined by being part of an overarching framework within which the same rules or strategies are followed, as is the case with the subsidiaries of a company (Boschma 2005). Hall and Jacobs (2010) employed these different forms of proximity to the global system of ports and observed a shift in cognitive and organizational proximity between seaports. Their conclusion makes clear that the increase in external linkages of seaports is counterbalanced by strengthening of the importance of proximity to institutions and other partners within the local environment (Hall/Jacobs 2010: 1113). However, the relevance of proximity is not revealed by considering a dichotomy of local and global resources, but requires rather a multi-scalar perspective that illustrates how knowledge-intensive firms and institutions make use of different forms of proximity to increase their knowledge base. With regard to the maritime economy, we consider knowledge to be a multiplex subject including both advanced skills and standardized procedures with strong interrelations to physical goods and transportation. This perception is in line with a definition of innovation that sees economic growth as being realized by new products, new processes or the exploitation of new markets.

Relational proximity by means of organizational, institutional and cognitive proximity is complementary to physical proximity in that it reduces barriers to the exchange of knowledge within a shared value creation process, knowledge base and competitive and regulatory environment (Pavitt 1984; Malerba 2005). Furthermore, continuous interaction in the value-added process potentially creates a shared understanding and common interpretative schemes (Lam 2005) as well as knowledge sources, which are complementary for the actors involved (Broekel/Boschma 2010). Moreover, these different forms of proximity catalyze the exchange of knowledge by providing an environment of trust and reciprocity (Granovetter 1985), which facilitates innovation in a heterogeneous field of specialized actors. Knowledge transfer between firms can be distinguished from transfer within firms as it bears particular potential in the context of industrial change, which is highly relevant to the maritime industry. Moreover, industrial dynamics and globalization have spurred the dependence of trans-organizational collaboration and new forms of integration in the maritime economy. Hence, complementarity in innovation capability can be described as the temporary alignment of economic interest or the completion of previously existing knowledge in the form of a product in order to gain competitive advantage and increased returns. The multitude of interactions between private actors, institutions and public authorities constitutes the innovation system of the maritime economy.

The concept of related variety further refines the meaning of cognitive proximity in the context of knowledge creation. Related variety is defined as "sectors that are related in terms of shared or complementary competences" (Boschma/Iammarino 2009: 292 f.). Therefore, cognitive proximity between such sectors plays a crucial role. "Information is useless if it is not new, but it is also useless if it is so new that it cannot be understood" (Nooteboom 2000: 72). However, absorptive capacity is also constantly in flux. The number of employees and their knowledge base heavily affect a firm's capability to broker knowledge (Cohen/Levinthal 1990). The concept of related variety focuses primarily on technological development within manufacturing sectors. Service sectors are not explicitly taken into account in this concept. However, they are relevant in the maritime economy due to its constitution, in that shipping companies are a prime example of an actor linking the sector of transport and logistics, manufacturing and high tech, by commissioning the construction of vessels to certain specifications and then inserting those vessels directly or indirectly in the system of maritime transportation. Moreover, this parallel activity within two value chains makes the shipping companies and their trade organizations centers of gravity for related services such as insurance, the acquisition of labor, standards and rules, making manifest the cognitive proximity between manufacturing and service sectors.

2.3 Knowledge in Interaction and Value-Added Relations

Conceiving knowledge creation as a process implies interwoven and coinciding patterns of development and production, and the application thereof in products and services. The synthesis is an evolving innovation system which, in the case of the maritime economy, is affected by technological change and the restructuring of value chains.

To analyze this innovation system we focus on patterns of proximity between the actors of the maritime economy and their functional role in the process of innovation. Zillmer (2010) suggests an approach that enables the analysis of knowledge in transfer. In her comprehensive analysis of different service activities she summarizes four different types of generic activity related to industrial clusters: high-tech, transformation services, transaction services and media/information services (Zillmer 2010: 113 ff.). Her approach focuses on the relations between single actors as the active parts in the network rather than on the inherent knowledge stock or the aggregated level of technological regimes. It assumes a non-arbitrary selection of partners and distinguishes product- and process-related services, making it particularly useful for the analysis of the maritime economy. Furthermore, it considers services and manufacturing activities as complementary in value production (Bryson/Daniels 2010: 83 ff.). This approach is intrinsically relational since it centers around collaboration between actors for the purpose of knowledge generation.

Transaction services are defined as actors delivering input into the value chain process that revolves around the amalgamation of different knowledge spheres. It focuses on the organization and management of economic transactions (Kujath/Schmidt 2010: 46) and includes advanced producer services such as insurance, finance or law, which are the backbone of the global economy.

Transformation services are provided by those actors that deliver their non-material input into material-focused parts of the industry and thereby shape the product as such. This includes research and development facilities as much as consultants delivering input into, for instance, the high-tech industry. The focus is on the transformation of existing knowledge into new knowledge for the benefit of a different economic application (Kujath/Schmidt 2010: 46). The processing of materials such as metal is strongly dependent on the research carried out by engineers. For example, the shape and consistency of ship hulls has developed significantly due to new production processes in metal works and new materials. The results are plans or templates for wider series of production.

As a functional group high-tech actors are concerned with the production of material goods. The value added to the system rests firmly thereon. In contrast to the former two groups, the material input is valued at cost rather than in conjunction with non-material components. It revolves around the production of knowledge-intensive material goods by integrating new knowledge in products and processes (Kujath/Schmidt 2010: 45). A typical high-tech product is the computer chip, which enables complex control techniques within maritime navigation or supply chain management. Since high-tech activities are defined by the invention of new products, transformation processes tend to refine these materials accordingly.

Finally, relations based on media and information services contain activities that transform knowledge into a standardized knowledge good. These are predominantly educational relations where guidance and instructions for action are provided. This type of knowledge lays the basis for future interactive knowledge processes. For example, masters and skippers of ships train their skills in simulators before employing them in reality.

These four roles are embedded in the value-chain relations of the maritime economy and are inherent to the innovation system. In order to explore distinct patterns of spatial organization, we formulate three hypotheses based on the theoretical insight into the interdependence of relevant geographical and relational proximities. To inform our empirical network analysis we use the following three hypotheses.

Hypothesis 1: While transformation processes are based on explicit knowledge, transaction processes revolve around implicit knowledge sources. We expect that the spatial range of networks in the maritime economy is clearly differentiated according to the relevance of spatial and relational proximity. We then surmise that spatial proximity is more important for experience-based knowledge interaction albeit in potentially remote locations. Therefore, transaction- based exchange is concentrated in geographical proximity.

Hypothesis 2: Cognitive proximity is a binding link for all actors within the maritime economy. We therefore expect cognitive proximity to shape the subdivisions of the maritime economy by means of underlying knowledge bases.

Hypothesis 3: The complementary nature of geographical and relational proximity forms an urban system. Whereas transformation links yield a higher proportion of explicit knowledge, networks of this knowledge type tend to spread out further spatially. Transaction links, however, tend to concentrate at certain locations within an urbanized environment. We therefore expect distinct patterns of spatial organization in networks that include this type of knowledge.

3 Methodology

3.1 The Maritime Economy as a Conglomerate of Sectors

The concept of the maritime economy combines the production, delivery, servicing and trading of maritime vessels and components in one input-output system. A general definition of this field does not exist in the literature. Approaches differ clearly in terms of what the research subject is. Several studies focus on the exchange of commodities, the role of logistics firms and the organization of ports (Hall/Jacobs 2010; Lee/Song 2010; Ducruet/Zaidi 2012). The shipbuilding industry as the high-tech part of the maritime economy is the subject of studies concerned with the inter-industrial exchange of information flows and innovation capabilities (Fei 2011; Fornahl/Hassink/Klaerding et al. 2012). The bearing of the maritime economy on spatial development is discussed within the context of the renewal of cities and ports. Hall and Jacobs (2012) show clearly that the reorganization of port activities intensively affects urban development. Actually, the biggest ports in the world coincide with populous agglomerations (Hall/Jacobs 2012: 190). Equally, headquarter functions of global firms and specialized services tend to locate in urban environments, whereas logistics remain at the port facilities. Finally, the maritime economy contains specialized service activities, which reveal distinct locational patterns that differ from those of other advanced producer services (Jacobs/Koster/Hall 2011). A review of these studies reiterates the heterogeneous character of the maritime economy, which includes manufacturing, services, transportation and energy, all with their individual location strategies. This results in a multitude of drivers influencing spatial development in places where the maritime economy retains a strong economic position.

For the purpose of this study, our definition of the maritime economy transcends the economic sectors of Manufacturing (NACE Section C), Professional, Scientific and Technical Activities (NACE Section M), Transportation and Storage (NACE Section H), Education (NACE Section P), Administrative and Support Service Activities (NACE Section N). Other sectors, which may be of relevance in certain activity fields, are Construction (NACE Section F) and Financial and Insurance Activities (NACE Section K). The NACE classification draws on economic activities that use common resources: “capital goods, labor, manufacturing techniques or intermediary products are combined to produce specific goods or services” (Eurostat 2008: 15). Thus, it is a framework that focuses on input-output relations and a common production base.

As a heterogeneous cluster of activities, the inner logic of cooperation and innovation in the maritime economy is critically affected by the flow of knowledge within and

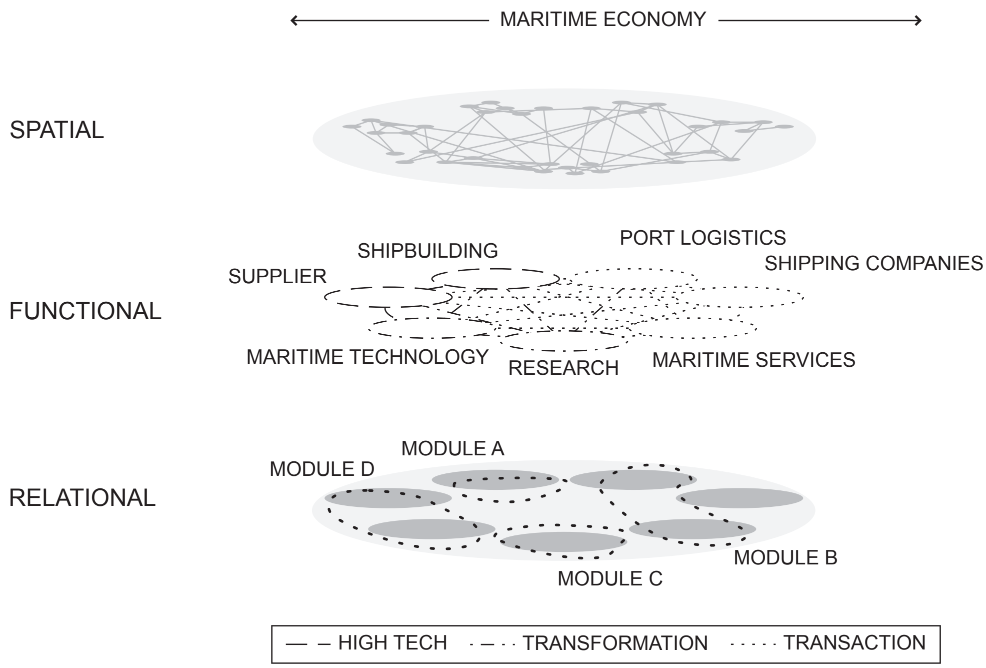


Fig. 1 Set-up of the analysis as layered applications

across activity fields (Brandt/Dickow/Drangmeister 2010). According to these considerations we have defined 13 different activity fields that are part of the maritime economy. These comprise: boat building, port corporations, port logistics, maritime services, maritime education and professional development, maritime science, marine engineering, marine engineering science, shipping companies, shipbuilding, shipping suppliers and other economic and science actors. Knowledge intensity varies across and within these activities. Therefore, we adopt a definition which is applicable to cross-sectoral activities and different functional profiles. Hall (2007a) considers activities to be knowledge intensive when the ratio of highly qualified personnel is above the average of all services (Hall 2007a: 49). More specifically, Legler and Frietsch (2006: 22) define shipbuilding and shipping as knowledge-intensive branches.

However, what is more important for the assessment of knowledge flows is the interrelation of the aforementioned activities and the interlinkage with non-market relations within the industrial cluster. In regards to innovation activity, the exchange of knowledge is not only critical for the development of new products and services but also for the brokering of uncertainty involved in such a process. Podolny (2001: 41 f.) argues that in order to successfully develop and place an innovation, firms draw on resources and information from their network but also need to gain visibility, which enables them to find or be found by exchange partners. We argue that this dichotomy of transformation- and transaction-based activities is of particular relevance to the maritime economy.

3.2 Set-up of the Analysis

A multifaceted methodology is required in order to assess heterogeneity in the maritime economy. This approach explores the composition of and relationships within the maritime economy. We evaluate the relevance of different forms of proximity for knowledge transfer and its effects on spatial development in the specific context of the maritime economy of Northern Germany. Furthermore, we analyze the functional interdependence of activity fields in relation to their spatial configuration, which varies from geographically distant to close.

Figure 1 shows the set-up of the analysis as layered applications of a spatial, functional and relational perspective. The geographical distribution of actors of the maritime economy forms the starting point of the analysis. Firstly, we investigate the interrelations of actors in different fields of activity and focus on their functional means. Secondly, we show that the entire network of the maritime industry devolves into certain sub-networks, which relate to sectoral patterns and different types of knowledge, suggesting that cognitive proximities are of importance. Thirdly, due to the fact that knowledge production is interlinked with the exchange and transformation of material goods in this sample, we include value-added characteristics in order to investigate the spatial range of actors in terms of organizational proximities. Thereby, the characteristics of value-added relations are being attributed to the network links. In other words, we consider the cooperation as being interlinked either with the transformation of goods or services, the transaction or the production and development of high-tech products.

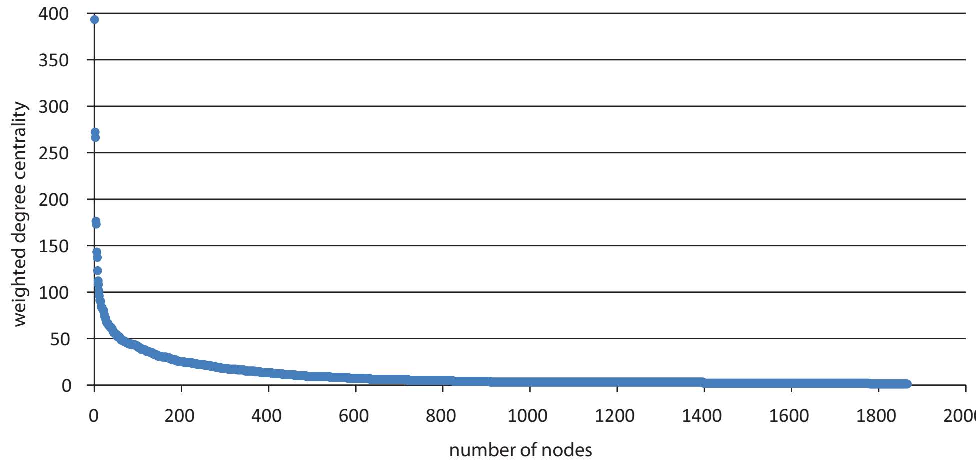


Fig. 2 Weighted degree centrality distribution. n: 1,873 actors and 4,174 network links, own calculation

The dataset used here results from large-scale surveys in the maritime economy carried out by the Norddeutsche Landesbank—Regionalwirtschaft (Brandt/Dickow/Drangmeister 2010: 241 f.). Data access was exclusively provided by the project leaders of studies in the field of the maritime economy in Germany at Norddeutsche Landesbank—Regionalwirtschaft. Detailed reports on this analysis are provided by Nord/LB (2009a and 2009b) .

In an initial phase the database was built by gathering information from commercial resources, associations and networks, business directories and the internet. In a second step the actors were asked to name the partners they cooperate with for the purpose of (1) education and qualification, (2) temporal co-working on innovation-oriented projects and (3) long-term strategic cooperation. In addition, the data contains structural indicators such as firm size, employment, turnover, innovation activities and expenditures and aims in research and development. All in all, the network contains 1,873 actors and 4,174 network links. The database provides insight into the ties between individual firms and organizations that sustain innovation capabilities.

We apply social network analysis to assess the relations between different functions and knowledge types within the maritime economy. Social network analysis allows us to assess the importance and relations of individual actors with regard to their functions and activity fields. This bundle of methods is framed by a perception that "the structure of relations among actors and the location of individual actors in the network have important behavioral, perceptual, and attitudinal consequences both for the individual units and for the system as a whole" (Knoke/Kuklinski 1982: 13). With regard to economic geography and spatial development, Ter Wal and Boschma (2009: 740) suggest that "networks are an appropriate conceptualization of inter-organizational interaction and knowledge flows". This paper applies this relational approach in the context of knowledge networks in the maritime economy.

The multi-facetted set-up of the analysis, involving visualization and quantitative methods of network analysis, enables us to understand the heterogeneous cluster of the maritime economy. To be successful, network analysis requires a clear definition of the boundaries of the system. Although our approach is promising in the sense that the actors of the maritime economy are captured by scanning the aforementioned registers of business circles and public associations, the involved actors may also have links to other economic fields. For example, producers of pistons might supply shipbuilders and car producers at the same time and thus be part of the maritime economy and the mobility sector. Hence, the data of our analysis represents only part of the economy and the reference to urban systems is not complete, given that other economic sectors might reveal different network structures.

4 Results

The maritime economy displays an innovation system that inheres a strong link of knowledge flows and the production and exchange of material goods. In this section we explore the maritime economy with a spatial, functional approach.

4.1 The Maritime Economy as an Innovation System

The network of the maritime economy revolves around a limited number of actors as central nodes. Figure 2 shows the distribution of weighted degree centrality. This measure is calculated by the sum of links of an actor multiplied by the weights of network links (Freeman 1979: 219 ff.). In our data these weights differ between 1 and 3. Hence an actor with one triple weighted link is as important as an actor with three single linkages. Thus high values of weighted degree centrality could either be the result of a large number of lowly rated links or a smaller number of highly rated links.

Fig. 3 The entire network of the maritime economy from a relational perspective. Circle size = degree centrality

The actors are ranked according to their weighted degree centrality. The slope begins at the value of 393 and decreases steeply. The second most connected actor has a weighted degree centrality of 272 followed by 266. Therefore, the slope is similar to a power decay function and may provide a scale-free network (Barabási 2009: 412), which indicates that network structure is independent of size.

Interestingly, among the top ten actors in terms of weighted degree centrality are five actors classified as marine engineering science, and which therefore act as public institutions. The most connected actor—Germanische Lloyd AG—provides maritime services in various fields. This company has merged with the Norwegian shipping company Det Norske Veritas (DNV) since the data was gathered. The Meyer Werft, which operates in the field of shipbuilding, is ranked in sixth position and is followed by Hamburgische Schiffbau-Versuchsanstalt GmbH, providing expertise in marine engineering, and Briese Schiffahrts GmbH & Co. KG, operating as a shipping company. The Hamburger Hafen und Logistik AG, which organizes and manages port activities within Hamburg—the biggest port in Germany—reaches the thirteenth highest value.

Figure 3 shows the entire network of the maritime economy from a relational perspective. The graph was calculated in Gephi and the OpenOrd Algorithm was applied. This algorithm is based on the Frutcherman-Reingold algorithm, which has two guiding principles: vertices connected by an edge should be drawn near each other and vertices should not be drawn too close to one another (Fruchterman/Reingold 1991: 1131). Consequently, the link between two nodes functions as an attraction force, whereas nodes without links repel each other. Since OrpenOrd displays a relational approach it highlights the subdivisions of the network by separating them visually, thus allowing a community structure of the network to be obtained.

The network of the maritime economy constitutes a scale-free network. According to network theory such networks yield the character of preferential attachment (Glückler 2007: 624). This means that it is more likely that actors link to those actors in the network that already have the most connections. Structural change or diversification of production processes is strongly linked to these central actors (Fornahl/Hassink/Klaerding et al. 2012). Consequently, economic change within the maritime economy is potentially driven by research institutions and a few other actors in maritime services and shipbuilding. Based on their high connectivity and dominance within this network, we assume a higher capability for innovation and economic change. Furthermore, these actors bridge different fields of activity and combine different knowledge bases.

4.2 Knowledge in Interaction

The second step of the analysis considers the knowledge types ‘in interaction’. The maritime economy transcends the sectors transport and storage, services and manufacturing. Therefore, by their very nature, value chains in the maritime economy integrate labor- and material- intensive processes as well non-physical processes that draw exclusively on the skills and knowledge of workers. Thus, the application and generation of knowledge combines different activities ranging from practical experience to formalized and standardized procedures.

The most prominent knowledge types in the maritime economy are transaction and transformation processes, representing 1,260 and 1,609 cooperations respectively. Furthermore, the network contains 626 high-tech relations and 301 information links. While transformation processes are based on explicit knowledge, transaction processes revolve around implicit knowledge sources. We expect the spatial range of these networks to be clearly different and spatial proximity to be more important for experience-based knowledge interaction. Figure 4a and b depict the spatial reach of transaction and transformation.

The actors involved in transaction processes form three observable triangles. The first is located between the cities of Hamburg, Bremen and Bremerhaven. To a large extent the Alfred-Wegener-Institut, which carries out research in the fields of oceans, the atmosphere and climate change, constitutes this triangle. With a weighted degree centrality of 176 this research institute is the fourth best interlinked actor of all.

The second triangle draws on links between Hamburg, Leer and Papenburg. In this sub-network the Meyer Werft GmbH is dominant. Based on the number of links it has a degree centrality of 173. The Meyer Werft, therefore, is ranked fifth and establishes mostly transaction links to actors such as port authorities and port logistics and maritime services. These actors tend to be concentrated in Hamburg around port facilities. Furthermore, shipowners are located in Leer and maintain cooperations with the Meyer Werft as well.

The third triangle is less striking in form. Its actors are located in Hamburg, Papenburg and Emden. Emden hosts a high share of employment in high-tech branches (BBR 2011) and is therefore strongly specialized in knowledge-intensive manufacturing.

Interestingly, Hamburg functions as an anchor point for all these triangles, since it lies at the point of superimposition of the most intense edges. There are only a few cross-links between these triangles. This spatial pattern indicates an emerging hierarchy in which Hamburg captures the highest rank and acts as a hub. Bremen is a second-tier city in this system. Actors located there tend to form links predominantly to Hamburg, but also to a lesser extent to the aforementioned edges of the triangles.

When compared to the network of transformation processes spatial differences are evident. The amount of links in both cases is almost equal. However, actors operating with transactional knowledge tend to be more concentrated in a discrete number of cities. Above all, Hamburg retains the most central position in this sub-network. The recurring triangle formed by Hamburg, Bremen and Bremerhaven suggests that these cities form an urban system with a hierarchical tendency.

4.3 From Knowledge Types to Community Structures

The network of the maritime economy represents a complex economic field in which different knowledge types are employed. Since knowledge is produced in interaction, the network of the maritime economy may dissolve into smaller groups of actors that have strong relations with one another. Various approaches exist that enable the identification of communities within an entire network (Newman 2004), thus contributing to the better understanding of the structure and inner life of a complex network. In our approach we detect these small-worlds or sub-networks by applying Newman’s modularity algorithm (2006). Therefore, the third part of our analysis investigates the interrelatedness of certain sub-networks based on the dominant form of knowledge.

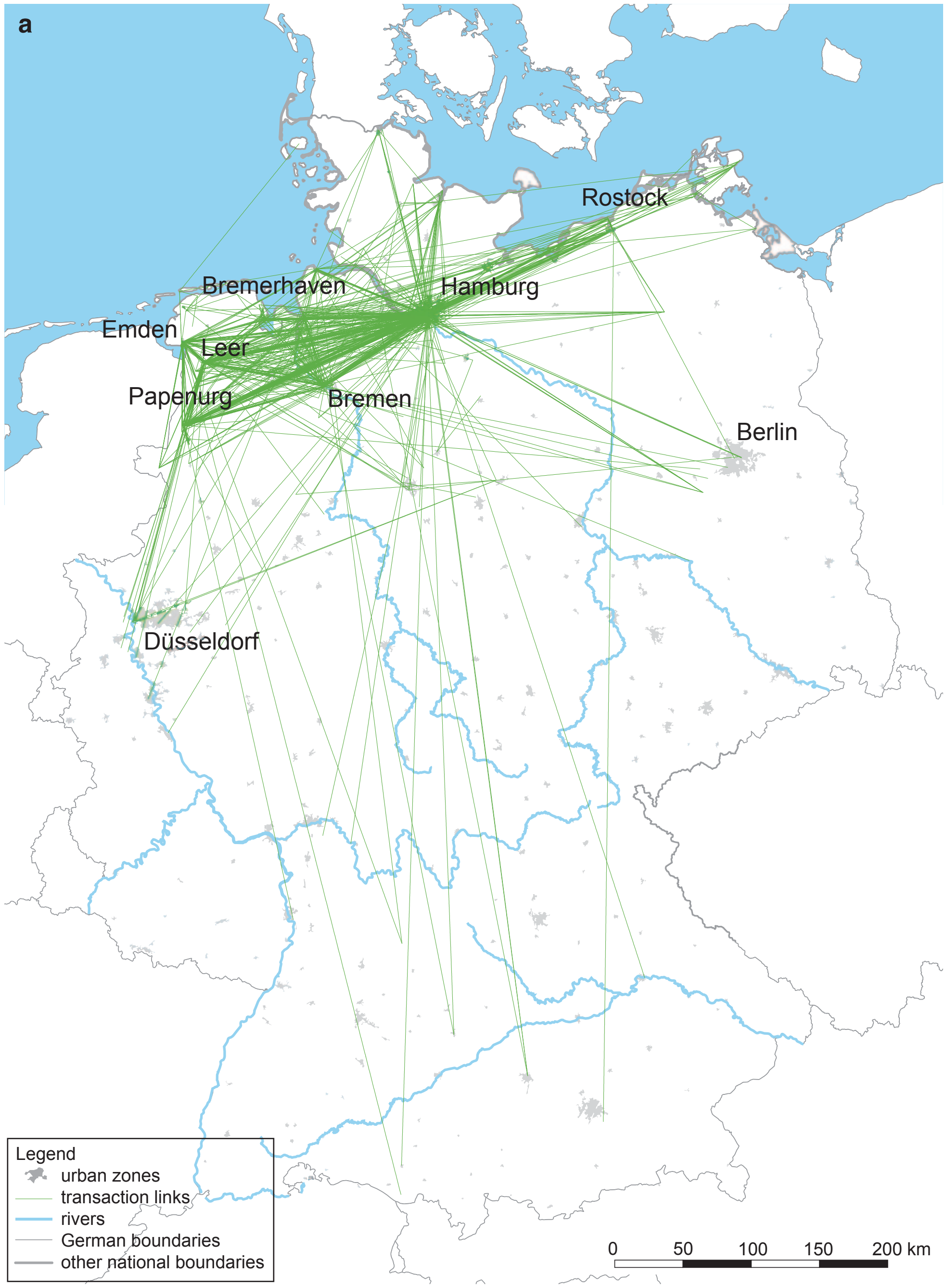
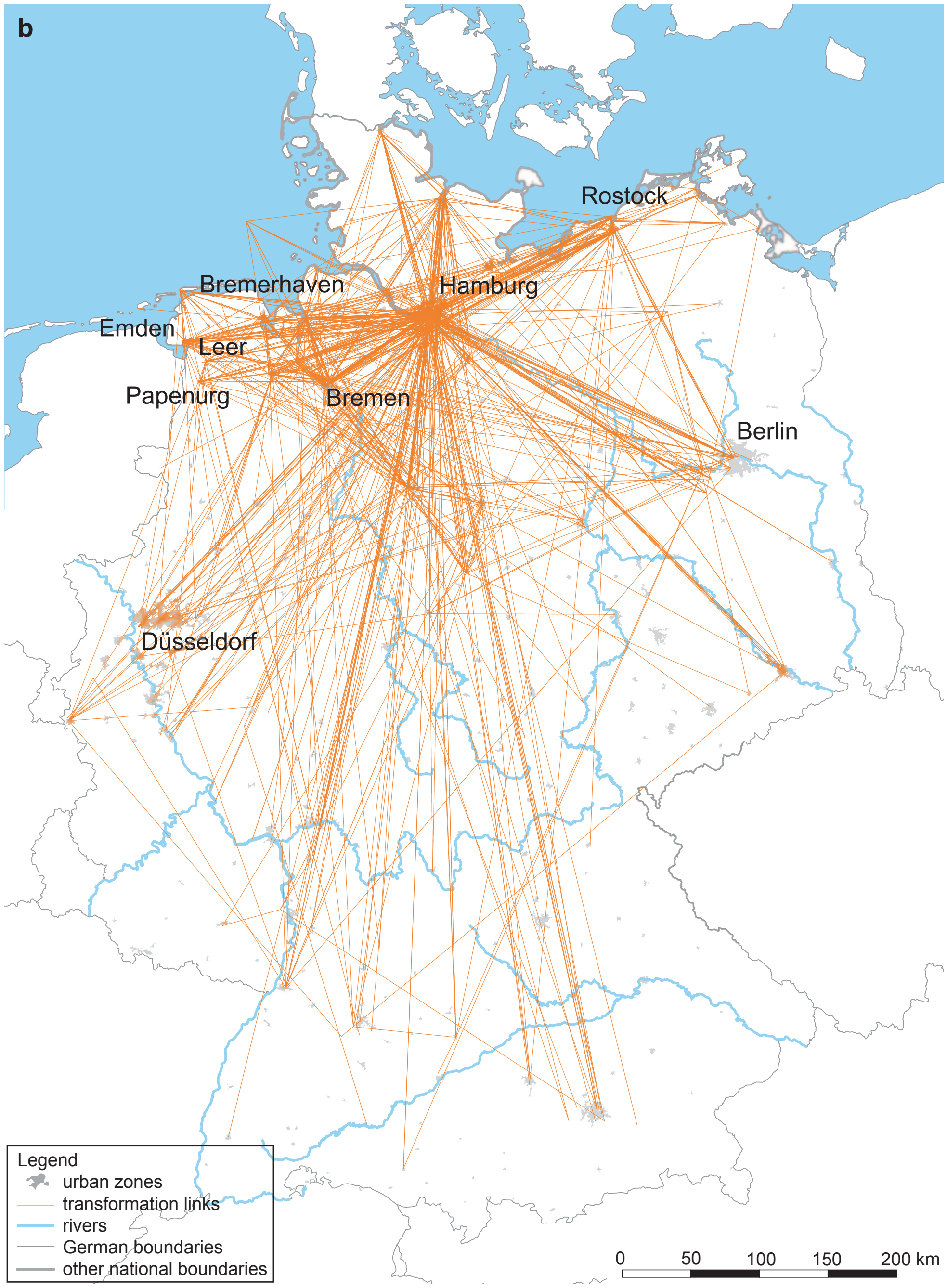


Fig. 4 **a** and **b** Knowledge types in transfer: transaction (*left*) and transformation (*right*) links and their geographical range

The modularity of a complex network represents an index for community structure between the network nodes, which may have quite different characteristics to the overall network. Not least the modularity provides insights into common activities revolving around the functional characteristics of an actor and type of knowledge. Newman (2006: 8578) defines modularity as "the number of edges falling within groups minus the expected number in an equivalent network with edges placed at random". The technique focuses on the links between the actors. Belonging to a module consequently represents intense linkages within this sub-network. This internal interaction is more intense than the connectivity to external nodes. It informs our understanding of the production of knowledge as a complex process in which services, manufacturing and qualification activities are interwoven. Moreover, we hypothesize that cognitive proximity is an important mechanism shaping such subdivisions of networks and, therefore, that modularity may concur with communality between actors, providing additional explanatory power to the aforementioned value relations and different knowledge types.

Fig. 4 (Continued)



The modularity calculation indicates reliable results with a value of 0.584. The closer the value is to 1, the more clearly the communities are differentiated (see Blondel/Guillaume/Lambiotte et al. 2008; Lambiotte/Delvenne/Barahona 2009). The entire network of the maritime economy dissolves into 48 different modules, which starkly differ in terms of size and composition.

In the following section, we focus on the five biggest modules in our data set. In total, these contain 1,055 of 1,871 actors. These modules have more than 150 nodes each and clearly differ in terms of functional composition and spatial range. Firstly, we discuss their functional composition, which is marked by the fields of activity the actors belong to. In the second part of the analysis we look at the geographical range of the modules.

Table 1 shows the quotient of specialization of each module according to Glaeser/Kallal/Scheinkman et al (1992). This measure is defined by:

$$\text{Quotient of specialization} = \frac{\frac{m}{M}}{\frac{n}{N}}$$

Table 1 The five biggest modules and the quotient of specialization within fields of activity

Module and main activities	1 Shipbuilding and suppliers	2 Engineering and science	3 Ports and education	4 Ports and shipping	5 Services and shipping
Boat building	0.29	0.00	0.81	0.44	0.00
Port corporation	0.10	0.63	**1.61**	**1.60**	0.56
Port logistics	0.42	0.25	**2.88**	**1.77**	0.19
Maritime services	0.82	0.26	**1.41**	**1.06**	**2.21**
Maritime education and professional development	**1.10**	0.00	**3.12**	0.00	**1.99**
Maritime science	**1.53**	**2.48**	0.96	0.52	0.31
Marine engineering	0.73	**1.95**	0.19	0.55	0.15
Marine engineering science	**1.03**	**2.51**	0.22	0.31	0.07
Shipping companies	0.88	0.33	**1.20**	**1.31**	**1.96**
Shipbuilding	**2.16**	0.16	**1.15**	0.84	**1.95**
Shipping supplier	**2.53**	0.27	0.63	0.88	0.86
Other economic actors	0.55	**1.39**	**1.03**	**1.40**	0.89
Other science actors	0.97	**1.61**	0.49	0.96	0.63

Own calculation

Table 2 The five biggest modules and the type of knowledge involved

Module and main activities	1 Shipbuilding and suppliers	2 Engineering and science	3 Ports and education	4 Ports and shipping	5 Services and shipping
Types of knowledge relations within a module					
High-tech	16.0%	29.7%	1.6%	11.2%	1.3%
Transaction	30.0%	10.0%	65.6%	67.9%	87.9%
Transformation	53.1%	58.8%	17.0%	16.5%	6.0%
Information	0.8%	1.6%	15.8%	4.5%	4.7%
Number of links	*636*	*320*	*247*	*224*	*232*

Own calculation

with m the number of actors within an activity field of a module, M the number of actors of a module, n the number of actors within an activity field of the entire network and N the total number of actors within the entire network. Values above 1 indicate that the module has a higher share in an activity field than the overall share of the whole sample. A value below 1 indicates that the share of a field of activity is below average (Glaeser/Kallal/Scheinkman et al. 1992: 1141). For instance, Module 1 (shipbuilding and suppliers) reaches a value of specialization in the field of shipping suppliers of 2.53 followed by shipbuilding with a value of 2.16 and maritime science with a value of 1.53. It therefore contains a higher share of actors from these fields than the overall sample. Finally, the values for maritime education, professional development and marine engineering science are slightly above 1. Module 1 is strongly oriented towards manufacturing combined with engineering and qualifying tasks. In other words, this module represents the core of the cluster revolving around the production of ships in the maritime economy.

Module 2 (engineering and science) displays high values in the fields of maritime science, marine engineering and marine engineering science. In contrast to Module 1, cooperation in Module 2 is underpinned by research and development activities and is less production oriented. Module 3 (ports and education) is strongly specialized in maritime education and professional development and port logistics. Module 4 (ports and shipping) represents a community in which port corporation, port logistics and shipping companies maintain intense corporate networks. These fields of activity are supposed to require access to port facilities. Whether this holds true for the shipping companies will be investigated in a spatial assessment of these modules. Finally, Module 5 (services and shipping) is strongly specialized in service activities ranging from education to maritime services, and displays high shares of shipbuilding and shipbuilding suppliers. Thus this module is placed at the intersection of the services and the manufacturing parts of the maritime economy.

A closer look at the types of knowledge interaction reveals important characteristics in terms of shared knowledge bases. As mentioned above, knowledge production is a continuous process in which previous knowledge is expanded and complemented by new knowledge. Each actor is embedded in a professional context of knowledge that determines the form in which knowledge is appreciated and accepted, i.e. absorbed, and made available for further development. For instance, scientific knowledge production is expressed in journal articles. These reflect previous literature and highlight original and novel contributions to research. In contrast, knowledge production in engineering results in patents or plans. Knowledge generation in services tends to initiate new processes, which would not have been possible without it.

The analysis of modules indicates that there is a relation between the relational proximity of actors and their shared knowledge typologies in the sample. Each module shown in Table 2 revolves around a distinct type of knowledge relation.

Module 1 (shipbuilding and suppliers) displays intense manufacturing activities. Knowledge here is predominantly produced by the transformation process, since the share of transformation links within the module accounts for 53.1 %. Knowledge production correlates with the exchange of material goods. Furthermore, transaction links reach a share of 30.0 % as a result of intense knowledge relations between maritime sciences and shipbuilders and their suppliers. In other words, actors within this module potentially complement explicit knowledge applied in transformation processes with experience-based knowledge in order to control and implement these transformation tasks (see Niehues/Nissen/Reinhart 2012).

Module 2 (engineering and science) also specializes in manufacturing activities. Predominantly, the actors carry out engineering and science activities, but in contrast to Module 1 there is a stronger focus on the development of new products, since high-tech relations with a share of 29.8 % are very significant. Modules 3 (ports and education) and 4 (ports and shipping) are mainly formed by transaction links revolving around the functions of port facilities. Moreover, links within Module 3 are characterized by information relations and reach a share of 19.0 %. Contrastingly, Module 4 is less specialized within port logistics and has a higher share of high-tech links than the former module. Both modules thus have broad activities in services in common but differ clearly in terms of second-tier activities. Whereas Module 3 is oriented towards education and qualifications, Module 4 links services with high-tech activities. Finally, Module 5 (services and shipping) is clearly defined by transaction links between maritime services, maritime education and professional development, shipping companies and shipbuilding. Thus tacit knowledge plays an important role and is applied in a heterogeneous value chain ranging from education activities and services to shipbuilding.

Finally, complementary specialized clusters tend to be organized in geographical proximity and capture a functional position within the urban system. This, in particular, holds true for modules revolving around transaction relations. Contrastingly, transformation-based interrelations stretch across the rest of Germany with a strong anchor point in the city of Hamburg. This result sheds light on spatial development options.

5 Conclusion

The conceptualization of the maritime economy as an innovation system enriches the discussion of technological and structural change and focuses it on those instances where the port and city retain synergies both functionally and geographically. The transcendence of the sectors transportation and storage, manufacturing and services implies interaction between actors drawing on knowledge as a key resource and actors relying on physical labor and land as production factors, with production factors shifting gradually between these poles. In certain cases, a strong physical relation and interdependence with port facilities remains the critical factor for location choice. Overall spatial development is highly intertwined with the evolution of transportation networks on both land and sea and thereby needs to be embedded in a global context. This is not merely a development away from traditional maritime trade and the manufacturing of vessels, but also a qualitative change within the entire economy. New actors have developed competencies and oriented themselves towards the modern maritime economy. This, particularly, holds true for service firms, as they provide services not only for the maritime economy but also for other subsystems of the economy.

The analysis shows three important findings for the maritime economy and its impact on spatial restructuring. Firstly, the network of the maritime economy is predominantly held together by actors of the maritime services, shipbuilders and research institutions. Thus, the network centers on advanced producer services, manufacturing and research institutions. This involves knowledge from transaction, high-tech and information and requires mediation between tacit and codified knowledge. Additionally, modules with a distinct specialization in shipbuilding or engineering tasks emerge. Shipping companies have particularly high betweenness centralities and act as bridging actors between certain subdivisions.

Secondly, conceiving knowledge as an interactive process in which transaction, transformation, high-tech and information processes are carried out, deepens our understanding of cognitive and spatial proximity. Whereas spatial proximity is still crucial for experience-based learning, cognitive proximity becomes even more crucial in the context of globalization, since actors are able to expand their absorptive capacity. This interplay is important for the sustainable development of the maritime economy. Our empirical results reveal that the maritime economy revolves around certain knowledge bases and cognitive proximity between the actors. A common sense of understanding and a shared language drives specialization in engineering and high-tech activities with strong tendencies towards local clustering and services spreading their networks in a regional spatial range. Moreover, the higher the share of implicit knowledge the more the networks are centered on a core activity.

Thirdly, reflecting on these findings with regard to the urban system in the northern part of Germany allows three constituting elements to be identified. Firstly, a centralization of maritime services in main cities, particularly in Hamburg, can be seen. These services are assumed to be attracted to urban environments, which facilitate face-to-face contacts and high accessibility. Secondly, certain activities in manufacturing, such as shipbuilding and ship suppliers are concentrated in remote areas along the Ems axis. These actors strongly depend on the availability of highly qualified personnel. Since these actors are located in less dense areas, geographical proximity seems to be less important to enable knowledge spillover. However, geographical proximity between shipbuilders and their suppliers is still necessary. This might be an attempt to lower the risk of delays in just-in-time production or ad-hoc problem solving. Finally, as a third element of this urban system, bridging services such as shipping companies and research institutions emerge as actors connecting the production-centered and the service-oriented activities of the maritime economy.

The ongoing structural change may induce changes in the power and control structures of the maritime economy and thereby interlink spatial development strategies in Germany with the globally operating system of the maritime industry. This points towards the relevance of spatial policy since the reorganization of economic networks is strongly connected to a relocation of activities in the maritime economy and the potential for aligning private and public location strategies. The merging of the shipping companies Germanische Lloyd and the Norwegian competitor DNV represents an example of such a change. The headquarters of the DNV GL Group is located in Oslo, while activities related to ship classification remain in Hamburg. Equally, the planned merger of Hapag Lloyd and Hamburg Süd could change the current situation as it is aimed at establishing a competitive logistics enterprise in terms of size and market shares. The main shareholders of Hapag Lloyd are the City of Hamburg, the logistics provider Kühne & Nagel and the travel agency TUI. This merger has not yet been realized. The debate about the floatation on the stock market of this new enterprise is still in progress, but it is proof that the maritime economy in Germany faces competition from other powerful global actors such as Maersk, MSC and CMA CGM. Besides this ongoing reorganization of corporate structures, public-private initiatives in education contribute to the qualification of the maritime economy as an innovation system. The Kühne Logistics University in Hamburg was established in 2003 as a cooperation between the Technische Universität Hamburg and the Kühne foundation. Its Focus on subjects related to logistics and management aims to secure the provision of young human capital in Hamburg.

Our study has limitations. Further research is required to triangulate these findings with more qualitative methods in the context of the maritime industry. Also the specific role of shipping companies is worth exploring, as they are situated at the intersection of manufacturing and transport-related value-added processes. Furthermore, it would be worth applying this analysis to another industrial cluster in order to establish the extent to which the findings are transferable. Lastly, the existence and typology of distinct patterns of organization within the maritime economy traced here need to be reflected upon in regards to the governance of value chains and territories.

Acknowledgement We would like to thank the reviewers for their helpful advice.

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