publish-Ing.

Journal of Production Systems and Logistics
Volume 3 | Article 3
Published: April 2023

Towards The Internet Of Production – How To Increase Data Sharing For Successful Supply Chain Collaboration

Anja Leckel[1], Maria Linnartz[2]

[1]Institute for Technology & Innovation Management (TIM) at *RWTH Aachen, Aachen, Germany*
[2] *Institut for Industrial Management (FIR) at RWTH Aachen, Aachen, Germany*

Abstract

Numerous start-ups and now even some major corporates are currently trying to improve visibility and foresight in the manufacturing industry through connected supply chains, or in other words, through increased data sharing. This study strives to support companies in leveraging the potential of increased data sharing in supply chain collaborations. Despite the great potential of digitizing manufacturing and automated data sharing throughout the supply chain, most companies are not yet able or willing to implement this kind of openness. The main reason for this lack of transparency in the supply chain is the high complexity and high cost of the required interfaces. In practice, instead of automated and extensive data sharing, companies exchange spreadsheets and PDFs with minimum information. This study supports companies in the pre-stage before automated data sharing is technically implemented. We find that building trustful relationships is a necessary step towards extended and automated data sharing. Moreover, we find that social capital provides a means to partially compensate for a lack of automation in terms of shortening lead times and dealing with disruptions. Introducing a supply chain collaboration typology and showcasing descriptive and qualitative results for 36 firms, we show how to navigate the frontend of the Internet of Production.

Keywords

Data Sharing; Social Capital; Supply Chain Collaboration; Internet of Production

1. Introduction

The emergence of disruptive digital technologies and new market demands are forcing manufacturing companies to change – both internally and within their ecosystem [1]. New requirements include increasing regulations (e.g., supply chain act, CO2 guidelines), increasing costs (e.g., energy) but also reacting to growing challenges from sudden disruptions. The Internet of Things promises to provide manufacturing companies with a variety of answers and enable them to benefit from real-time production data to improve transparency and productivity [2]. This internal focus on advancing connected devices and processes is the first step toward the envisioned 'Internet of Production' (IoP), that is a framework for data exchange and usage within and between manufacturing companies.

As a next step, engaging in closer collaboration with other companies in the supply chain opens up tremendous potential to respond to these demands with agility and innovation [3–5]. **Supply chain collaboration** is often defined as two or more companies working together to create a competitive advantage through sharing information, making joint decisions, and sharing benefits which result from greater profitability of satisfying end customer needs than acting alone [6]. However, to achieve the vision of true

This Paper has been reviewed by the Certified Reviewer Community of publish-Ing. – 1 review – single blind

DOI: https://doi.org/10.15488/13409
ISSN: 2702-2587

connectivity along the supply chain in practice, it is imperative to achieve a higher level and better understanding of collaboration and data sharing.

The vision of the IoP is "to enable real cross-domain and inter-company collaboration, [therefore] semantically adequate and context-aware data from production, development and usage need to be made available to interested parties in real time, at a reasonable level of granularity, and at a potentially global scale" [7]. For this, data from production machines as well as company master and transaction data must be compiled and shared with other upstream and downstream partners to achieve true interconnectivity. Potential benefits of the enhanced connectivity are superior knowledge throughout the network, reduced latencies and faster decision making, higher product quality, lower development costs, higher profit margins and reduced time-to-market. Importantly, sharing production related data reduces information deficits for supply chain members which can cause problems like the bullwhip effect, that is, the fluctuation of demand volumes along the supply chain [8].

Reacting fast and flexible in a volatile environment requires up-to-date data, which makes data sharing openness one of the most critical factors for the cross-company IoP [9]. We understand **data sharing openness** as the willingness and capability to share data that is relevant for supply chain partners in a timely, transparent, and interoperable manner. However, in practice, implementing automated data sharing often fails. Not only due to the severe financial investments necessary for implementing technical solutions such as a joint interface, but also due to a lack of mutual trust, understanding, and interaction. The existing IT infrastructure is often not designed for exchanging and integrating data from foreign systems and thus requires adapting technical solutions. Additionally, companies fear that data sharing can lead to disclosing trade secrets [7]. In addition to the highest data security standards, trustful relationships are considered key prerequisites for sharing knowledge and data in a network [10]. Hence, companies must first lay the necessary foundations for such far-reaching decisions as cross-company interconnectivity.

Therefore, we investigate **social capital**, that is the resources available to individuals and groups (e.g., employees or managers of a firm) through membership of social networks (e.g., industry roundtables, university-based innovation hubs, start-up centers, or close business relations with other companies) and the norms of reciprocity and trustworthiness that arise from these connections [11]. Valuable resources that become available can include access to talent, suppliers, or information. Based on both qualitative and quantitative data from 36 firms, we address the question whether social capital can facilitate data sharing openness to improve successful supply chain collaborations. The interrelationship of these concepts is gaining new relevance and raises new questions with the ongoing digitization and automation of both manufacturing and managing business relationships throughout the supply chain [12,13].

This paper aims at understanding the relationship between data sharing openness and social capital. The proposed framework supports companies in understanding and improving their buyer-supplier relationships. We especially focus on the differences between small and medium-sized enterprises (SME) and large companies and the challenges they face when implementing data sharing.

The remainder of this paper is organized as follows. Section 2 summarizes the conceptual background on social capital and data sharing openness. In section 3 we present our approach for analyzing the concepts and the relationship between them. We present our results in section 4 and describe limitations and further research need in section 5. Section 6 contains the conclusion of the paper.

2. Conceptual background on social capital and data sharing openness

Prior studies indicate that promoting social capital in a buyer-supplier partnership has a positive effect on knowledge sharing. Our core assumption is therefore that social capital can also help increase data sharing openness between members of the supply chain. Prior research has demonstrated benefits of promoting social

capital between firms to facilitate the implementation of collaboration processes [14], accelerate the innovation process [15,16], improve the overall supply chain performance [14,17] and significantly increase the exchange of knowledge between companies [18,19]. To break down these effects in more detail, social capital can be divided into three different dimensions: structural social capital, relational social capital and cognitive social capital [11].

Structural social capital denotes the frequency and intensity of interaction in a network, for example the communication between buyers and suppliers across hierarchical levels and functions [14]. The more connections and interactions in a network, the denser it is. Denser networks have more potential channels for exchanging information, data and other resources [20].

Relational social capital represents the nature and quality of the relationship in a network [21]. This includes, for example, trust, norms, and expectations between buyer and supplier [22]. Trust reduces opportunistic behavior, enables open communication and promotes transparency [23,24]. Due to the more open communication and the decrease of transaction costs, companies sharing a high level of relational social capital can exchange knowledge more easily [22].

Cognitive social capital denotes the extent to which members of a network develop a common understanding and common goals. Cultural linkages such as shared language and shared narratives enhance understanding between business partners and their ability to exchange knowledge [25,26].

These three dimensions are interrelated and together they shape the potential for exchanging information and data within a supply chain [15,12].

Openness in supply chains refers to the capability of interacting with other actors of the production network [27]. It includes among others bilateral communication, information exchange and business process integration and depends on the willingness of partners to open up boundaries [4]. We focus on **data sharing openness** and analyze the dimensions transparency, interoperability and timeliness of shared data.

In a supply chain collaboration context, **transparency** means that a company's data-based decisions are fully traceable [28,29]. For a high degree of data sharing openness, data generation and data transfer between collaborating companies are automatic and provide reliable and accurate information [30,31,29]. **Interoperability** refers to the use of open, understandable, and common standards when exchanging data [28,29]. To be able to receive the exchanged data and also to work with it, appropriate technical skills must be uniformly developed [32]. **Timeliness** of data exchange refers to the frequent exchange of information between collaborating companies. This includes generating and sharing the exchanged data in a timely manner so that as much information as possible is available [33,34].

Prior research suggests that there are differences in the resources and capabilities between large and small firms when it comes to implementing data sharing openness. More precisely, large companies are likely to have a higher level of data sharing openness than smaller firms [35,36]. As large companies have greater resources to implement supporting IT infrastructure than SMEs, they achieve higher levels of data and information exchange [37,38]. Other studies indicate that SMEs, however, show greater willingness to cooperate openly. As their resources and capabilities are limited compared to the larger companies, they aim to compensate this disadvantage through collaboration [39,40].

3. Approach for analyzing the relationship between social capital and supply chain collaboration

We followed a mixed methods approach to study the above concepts in 36 firms.

We conducted and analyzed 21 semi-structured interviews with supply chain experts. All interviewees have regular contact with their company's suppliers. The use of semi-structured interviews allows to capture in-depth insights and provides flexibility to explore additional issues raised by managers [41,42]. We indicate

the industry, position, and company size of each interviewee in Table 1. Interviews were conducted with experts from different sectors and from companies of different sizes. This enables a cross-industry perspective as well as a view on SMEs and larger companies and corporations.

For the quantitative survey data, 36 respondents indicated values for the level of data sharing openness and social capital for a supply chain relationship with a specific supplier. Both constructs are measured on a scale of 1 to 7. Table 2 contains the measurement items, which we developed in several qualitative and quantitative pre-studies, and the respective reference sources. We developed a scale for data sharing openness based on an extensive literature review. We developed a scale for social capital based on established scales by selecting and adapting items to fit today's standards of digital collaboration and more regulated work ethics. The survey tool included concise definitions as well as examples for the concepts and their distinct dimensions. To validate whether respondents form a common understanding of social capital, interviewees were asked to explain in their own words and to give an example from their own business context. This helped to verify and improve the suitability of the measurement items and definitions given in the survey tool.

In Figure 1, we mapped the data along the two key dimensions: social capital and the degree of data sharing openness. Based on our measurement items and an evaluation of the average values of the responses, the data was divided into high and low degree of data sharing openness and social capital. Respondents indicated extensive background data on their own company and on the respective supplier company (e.g., firm size, spatial distance between buyer and supplier, or the respective lead time). These insights were used to identify further underlying patterns. The qualitative interview data helped us interpret the relationships between variables.

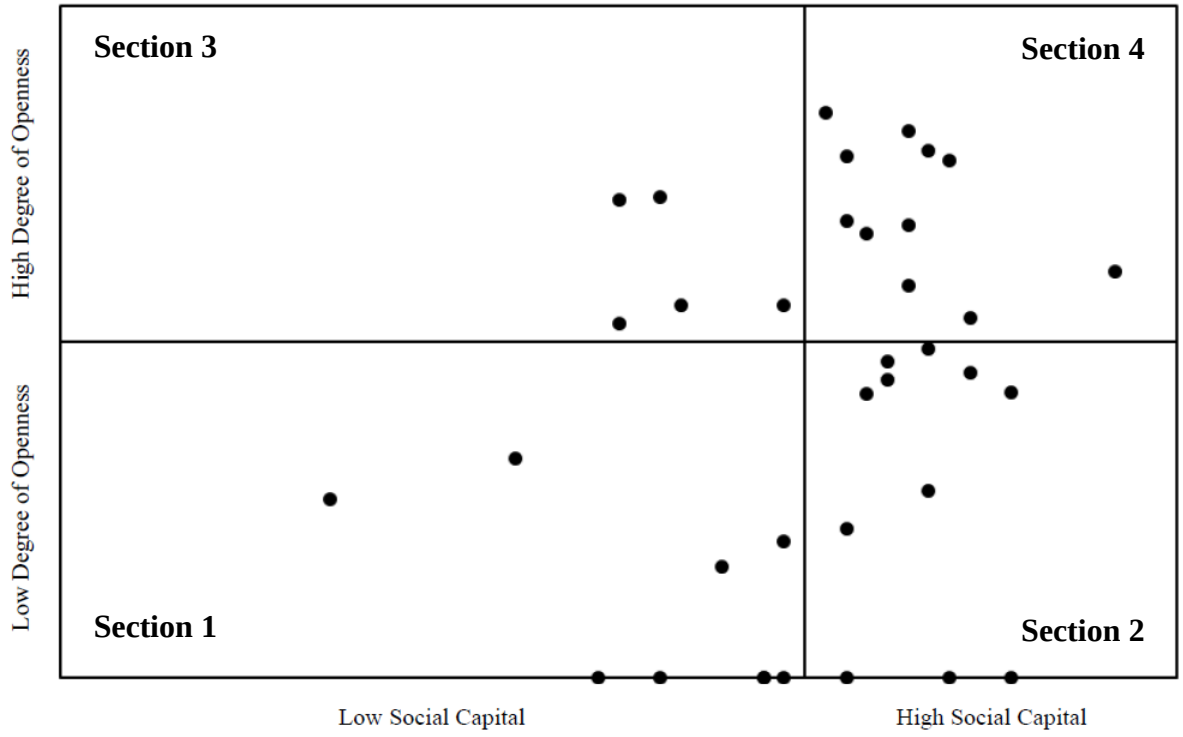

Figure 1: Mapping the degree of data sharing openness and social capital

4. Understanding and improving buyer-supplier relationships

Analyzing our interview data and performing regression analysis with our quantitative survey data, our results show that social capital has a positive effect on the degree of data sharing openness and is thus a

facilitator for supply chain collaboration within the IoP. Based on the interview data and our quantitative analysis we propose the supply chain collaboration typology as a framework for structuring buyer-supplier relationships. As part of the framework, we suggest development paths for companies and describe recommended actions. Moreover, we present a decision support tool that has been developed based on the results of the survey.

4.1 The supply chain collaboration typology

The proposed framework is based on the analysis of the degree of data sharing openness and social capital (see Figure 1). These factors represent the two key dimensions for structuring buyer-supplier relationships. The supply chain collaboration typology (see Figure 2) comprises four sections that have been derived from underlying patterns relating to variables such as firm size, geographical proximity, or contract complexity. These patterns are derived from the four sections presented in Figure 1, and further corroborated by the interview data and quantitative analyses. In the following, we present the four sections in more detail.

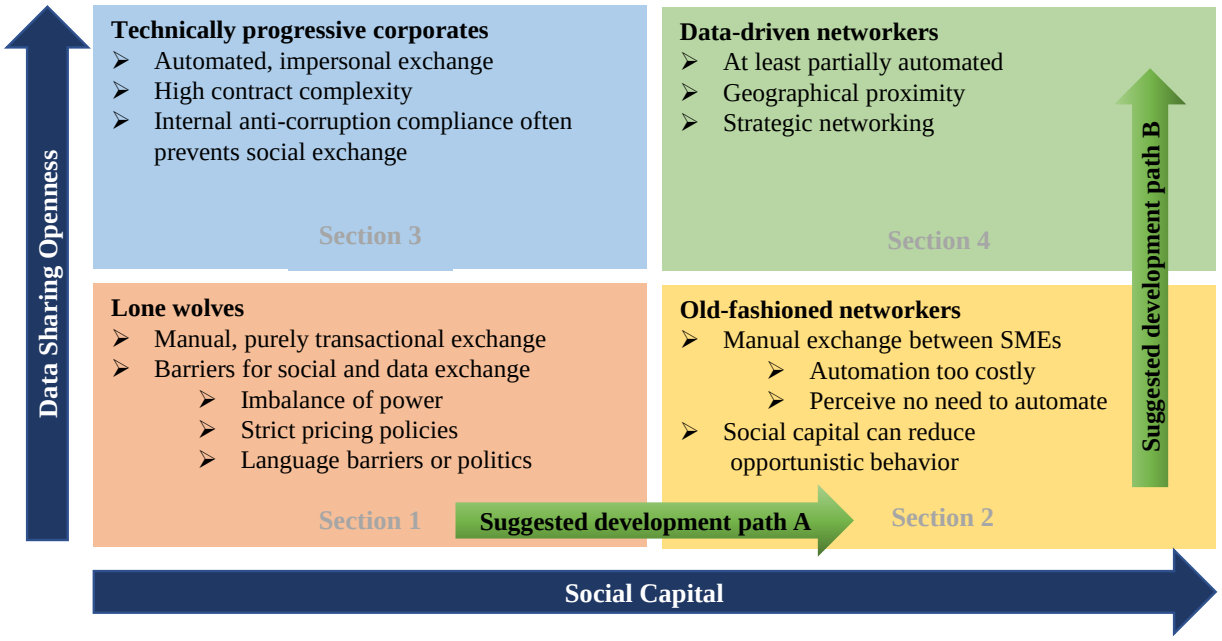

Figure 2: Supply chain collaboration typology

Section 1: This section is characterized by low levels of social capital and by far the lowest level of data sharing openness. These companies that have a purely manual and transactional exchange relationship with their suppliers can be referred to as '**lone wolves'**. Our interviews show that to date, the data exchange between many supply chain partners is reduced to the absolute minimum, often manually processed with PDFs or excel tables via email – even between different sites or subsidiaries of the same corporation. Although companies in this section do not clearly show a single unifying characteristic, the interviews reveal that critical reasons can be a strong imbalance of power, a strict pricing policy that prevents data sharing, communication barriers or suppliers being located in countries with difficult political circumstances. For example, one manager (I.12) says language barriers are a big hurdle for data sharing openness, emphasizing that "it would be impossible without an intermediary." Furthermore, I.10 describes the influence of the supplier's location as follows: "My experience teaches me that in the current context, for example, regarding data protection concerns in China, trust in an entire country can suffer: There could be simply no trust because the supplier is based in China. The question for companies is: what happens to the data that this supplier receives from us?"

Section 2: Buyer-supplier relationships in this section are characterized by low levels of data sharing openness but the highest levels of social capital. Strikingly, this cluster consists mainly of supply chain collaborations between SMEs (see Figure 3).

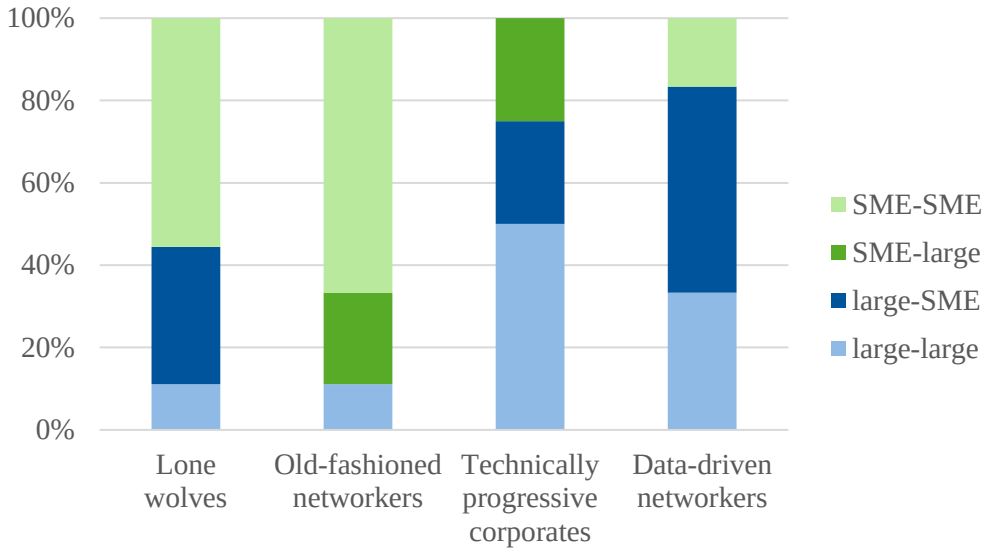

Figure 3: Firm sizes in the four section

These companies have a high degree of social capital but no means or perceive no need for an automated data sharing solution, as the interview data shows. In such situations, SMEs can benefit from social capital instead of complex contracts. A manager from one SME (I.12) explains that knowing each other well can make a contract needless: "There is no supplier contract. (...) They were happy that they were able to manufacture for someone else and it didn't make any sense to draw up a contract now. (...) We know from experience that they really make a massive effort." Moreover, the interviews demonstrated the positive influence of social capital on reducing the lead time. As one manager (I.2) recapitulates on the link between trustful relationships and receiving products faster: "I think we were able to anticipate our mutual behavior well. I was able to anticipate reactions. (...) I think if you translate 'trust' with 'helping each other out' or 'jumping into the breach for the other', of course, there were such situations." In sum, companies in this section can be described as '**old-fashioned networkers'**.

Section 3: The supply chain collaborations in this section are characterized by low social capital and a high degree of data sharing openness, mostly between large companies or between large companies and SMEs as illustrated in Figure 3. In this context, one manager (I.10) says about a global supply chain collaboration between two large corporations: "I can assure you that social capital does not matter to them at all. In the end it's all about reliability and price and quality. (...) We communicate what we want and when we want it. We get relatively little information from the other side about production capacities and planned production in general. The whole process runs automatically via a request in our SAP software." Another manager (I.16) summarizes the decreasing importance of social capital between large firms as follows: "With large companies, this can get lost because you no longer know who is in contact with whom." Another shared feature of these '**technically progressive corporates**' is the high contractual complexity of the business relationships between firms and their suppliers (see Figure 4).

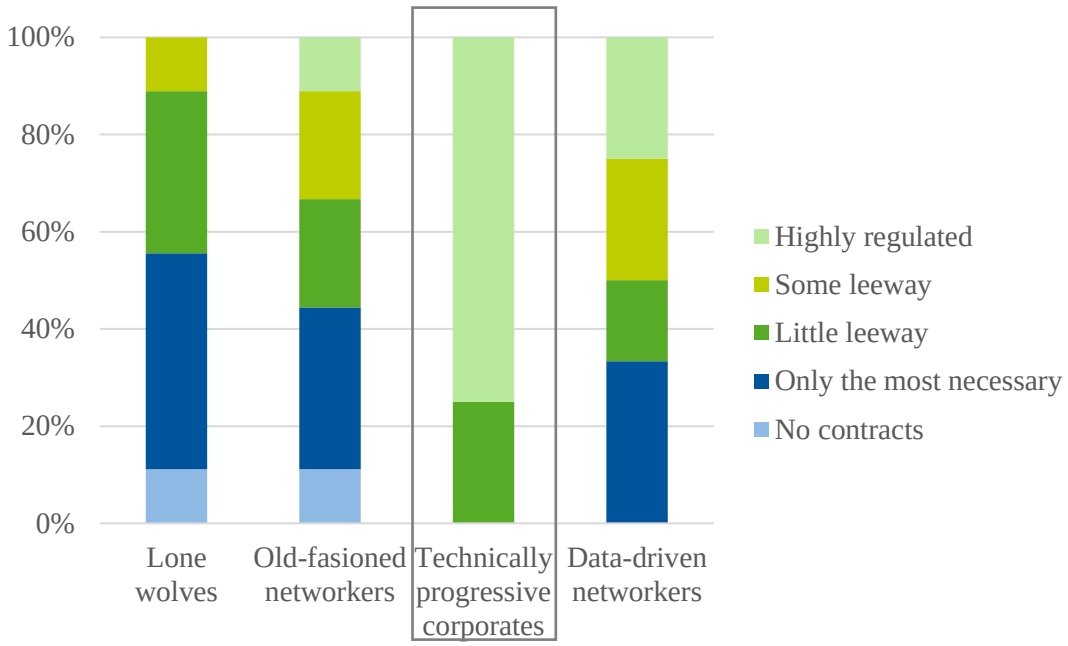

Figure 4: Contractual complexity in the four sections

More than 70 % of buyer-supplier relationships in this section are highly regulated. The results demonstrate that the more large companies are involved, the more complex the contracts are. One manager (I.21) confirms that "especially with the larger suppliers it was quite strongly regulated by contracts". Strict contracts can even prevent the formation of social capital as there is no more room for individual actors to build a relationship with the counterpart. Especially large companies have compliance regulations in place which suppress and sometimes even prohibit the formation of social capital. Managers implied that particularly the relational social capital decreases under very strict contracts as they make it increasingly difficult for individual actors within a supply chain to build relationships of trust.

Section 4: This section is characterized by a high degree of social capital and the highest degree of data sharing openness. This cluster comprises mostly large companies, but also SMEs, whose partners are often located within the same country or even in the same region (see Figure 5).

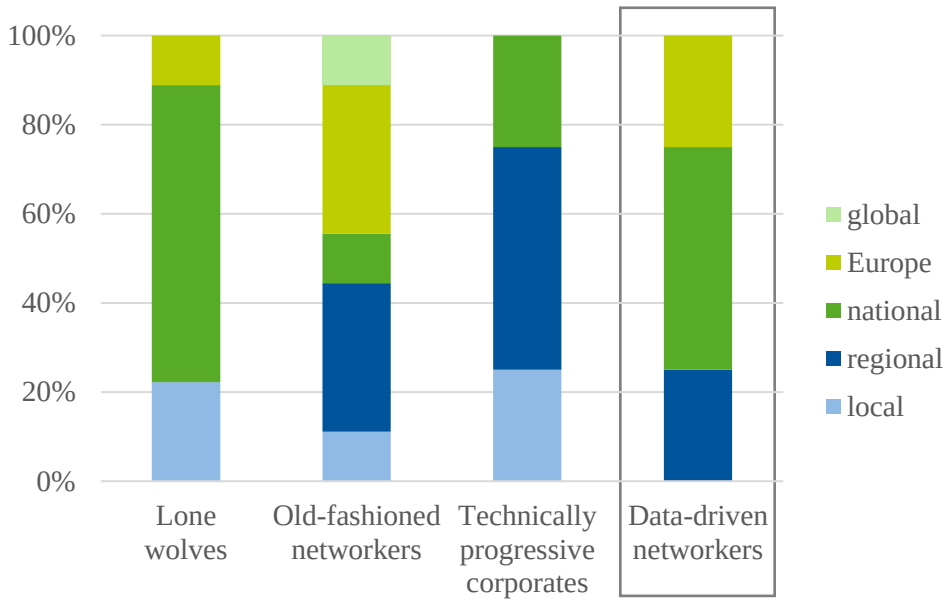

Figure 5: Geographical proximity in the four sections

Nearly 80 % of the buyer-supplier relationships in this section are national or regional. Thus, geographical proximity regarding the companies' locations seems to play an important role for '**data-driven networkers**'. In line with prior research, our findings show that the relationship between buyer and supplier is stronger when they are geographically close to each other, fostering collaboration and information sharing [43,44]. As one manager (I.18) recaps with regard to a local supply chain collaboration between two SMEs: "There must be a high level of trust, and you can't do it [automated data sharing] with everyone." Moreover, our data shows that high levels of social capital and data sharing openness come along with shorter lead time, higher satisfaction with the delivered products and a more reliable supply safety. Lead time refers to the period of time between triggering an order and receiving the product, that is production time plus delivery time. It is striking to see that the data-driven networkers indicate by far the shortest lead time, the highest satisfaction with delivered products and the most reliable supply safety, while the lone wolves in Section 1 indicate exactly the opposite (see Figure 6).

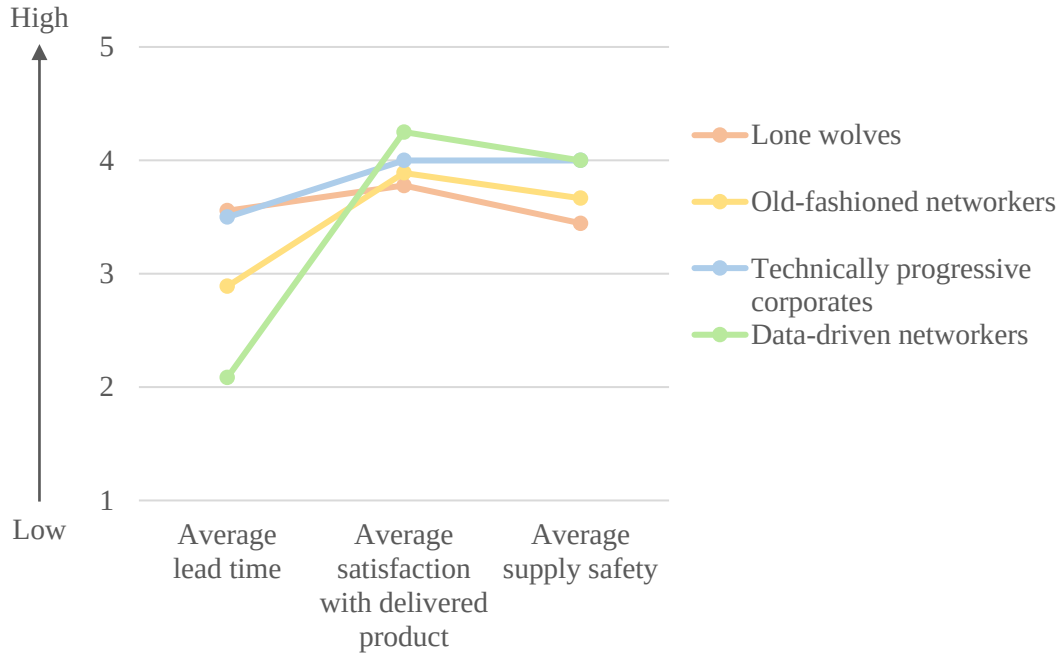

Figure 6: Lead time, product satisfaction and supply safety in the four sections

Our study provides further contributions to management research focused on the impact of social capital on knowledge sharing in innovation ecosystems and a firm's innovation capability (e.g., [45,46]). Prior research found that short lead times are mainly realized in supply chains that are characterized by a high level of data sharing and the use of information systems [47], making it the main driver for sharing information between buyer and supplier [48]. Our findings add another important factor. Our regression analyses reveal that not only data sharing openness has a positive effect on reducing lead time. In fact, social capital has a positive effect on both data sharing openness and reducing lead time, indicating that data sharing openness mediates the effect of social capital on reducing lead time. In sum, social capital can positively impact supply chain collaborations, contributing to increased data sharing openness and, hence, to reducing lead time. Our findings also show that especially for SMEs, it is difficult to implement automated data sharing and the respective interface management. Yet, we find that social capital provides a means to partially compensate for a lack of automation. Smaller companies often cannot achieve the same level of frequent data exchange as large corporations, but a strong buyer-supplier relationship enables them to effectively manage manual data exchange and thus reduce lead time. Hence, companies can practically approach the vision of the IoP in a deliberate pre-stage before they are willing or able to implement the technical solution of automated data exchange. Social capital forms the basis for creating the necessary conditions to enable automated data

exchange in a future step. Our results provide an essential prerequisite for the development of a decision support tool that assist managers in the design and enhancement of their relationships with suppliers, indicating actionable advice when disturbances impair the supply chain.

Finally, the effect of social capital can be narrowed down to the three dimensions of the construct. As illustrated in Figure 7, we find that the structural social capital is the weakest, relational social capital shows medium values, and cognitive social capital is by far strongest pronounced for all supply chain collaboration types and firm sizes in our sample.

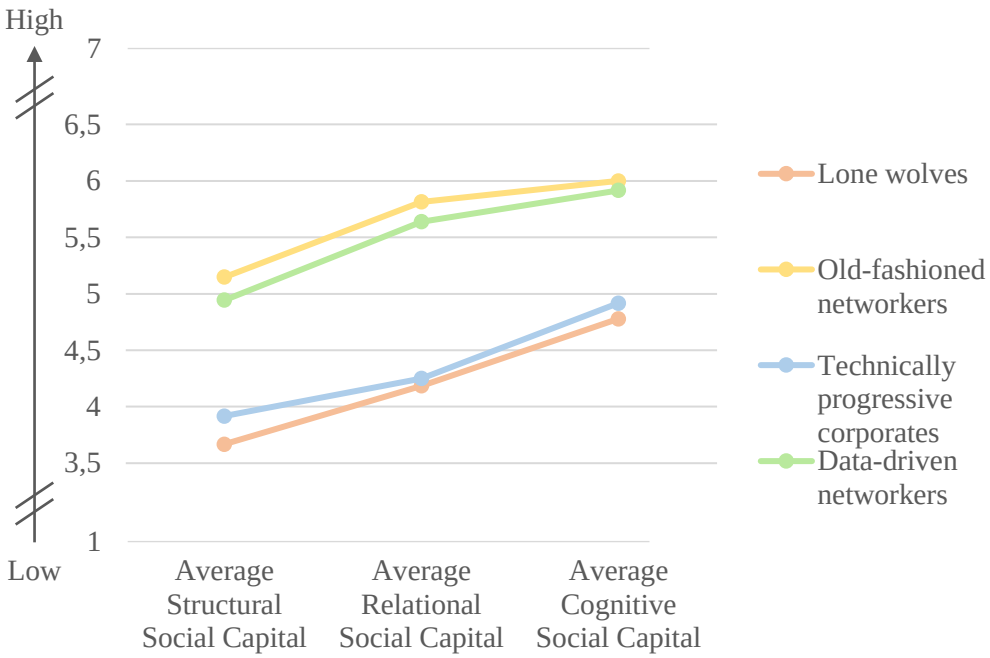

Figure 7: Dimensions of social capital in the four sections and for large companies and SMEs

This is of particular importance, as the results of the regression analyses indicate that only structural and relational social capital have a significantly positive impact on data sharing openness, whereas the effect of cognitive social capital is not significant. This suggests that investing into increasing the level of interaction and trust with the supply chain partner is an important prerequisite for frequent information and data exchange (in line with [12]). While many studies use a proxy for the intensity of interaction as a measure for social capital, we contribute to prior research in showing more detailed which aspects are important, that is, not only the intensity of interaction (structural social capital) but also the nature of the relationship (relational social capital). This clearly indicates which aspects of the business relationship should be systematically improved, guiding our recommendations for action in the following chapter.

4.2 Recommendations for actions

Based on the supply chain collaboration typology we derive recommendations for managers to increase social capital and data sharing openness in their buyer-supplier relationships according to their position in the supply chain collaboration typology. We suggest two development paths (see Figure 2). To increase the benefits that arise from sharing data, we provide recommendations for **old-fashioned networkers** to become data-driven networkers – the ideal quadrant in the upper right corner. For **lone wolves** it is recommended to first focus on increasing social capital (Path A) before increasing data sharing openness (Path B). A high level of data sharing openness, such as automated data sharing of real-time production machine data, remains a risky investment and would not be implemented without a pre-existing relationship. The need for a foundation of trust, mutual understanding and effective communication underscores a causal effect and the respective temporal sequence between building social capital and increasing data sharing openness.

However, the benefits of *automated* data sharing in many cases do not exceed the costs for smaller companies. Building and sustaining social capital is of major importance to still achieve data sharing openness. Companies located in the lone wolves section should aim at implementing a *manual* data exchange in a first step. Our findings highlight the importance to promote the structural and relational dimension of social capital for this. **Technically progressive corporates** are very rare in their positioning of exerting high data sharing while having lower levels of social capital. These large corporates try to replace trustful relationships with high contract complexity. However, to deepen their existing relationships, for example to not only exchange money for supplies, but to source or jointly develop innovations with suppliers, building social capital is a strategically important decision to open the communication channel for such sensitive matters in the first place.

Development Path A – How to Increase Social Capital: Relational social capital is a key prerequisite to engage in data sharing. Trust can be established through meetings in which common goals and values are defined, and through frequent interaction with mutual feedback loops, purposefully aligning mutual expectations. Structural social capital can be fostered by establishing fast and uncomplicated communication channels, for example, by defining dedicated counterparts with a personal direct line. This is also essential for frequent and smooth manual exchanges and in case of problems. Furthermore, geographical proximity can facilitate mutual understanding (cognitive social capital) and interaction (structural social capital). Misunderstandings with regard to technical language and cultural differences can be reduced [25], preventing problems that can disrupt the exchange processes. Except for considering the location of suppliers when selecting a partner for increased collaboration, further tools to build or increase cognitive social capital can be shared Wikis to establish a common technical language as well as intercultural communication training, if companies are characterized by different cultures (e.g., to manage communication with different understandings of power distance or uncertainty avoidance).

Development Path B – How to Increase Data Sharing Openness: As soon as there is a high level of social capital and manual data exchange within the supply chain, steps can be taken towards more automated data sharing to achieve continuous data sharing openness. One prerequisite is the implementation of joint processes, which allows the identification of required data and the frequency of data sharing. Additionally, the format of shared data and its compatibility needs to be discussed. Using data standards (e.g., EDIFACT) and standardized interfaces supports the compatibility of information systems. In order to save costs and remain flexible in the connection, a so-called integrator can be implemented within the exchange network. Via this third-party provider, only one connection to this provider has to be realized, which in turn enables the connection to all other possible systems. This means that not every connection to all members of the supply chain must be made individually, but only one to the integrator.

Overall, our key conclusion is that, as long as no automated data exchange of master data (e.g., through connected ERP systems) is established, social capital is a key facilitator for rapid data exchange between supply chain partners in a *manual* fashion. Because SMEs often have difficulties implementing automated data exchange, this insight is particularly important for them in order to reduce lead time – even without complex contracts.

4.3 Decision support tool for improving buyer-supplier relationships

The overarching goal of this research project is to develop an industry-applicable decision support tool to improve buyer-supplier relationships. The tool shall provide companies with an immediate overview on the current level of data sharing openness and social capital with a specific supply chain partner and give recommendations for improving the relationship. With the goal of developing such a decision support tool, we first took an exploratory approach and identified current problems in companies regarding data sharing openness. As a result, we first focused on providing guidance in the pre-stage of the IoP instead of focusing on a purely technical solution. The above-described results of our empirical research provide the foundation

for developing the decision support tool. To do so, we collected and analyzed data from different contexts, validated supply chain experts' understanding of the underlying concepts and discussed their relevance, to iteratively derive and validate the suggested development paths.

The decision support tool contains a self-assessment for evaluating a specific buyer-supplier relationship regarding data sharing openness and social capital. The self-assessment is based on the measurement scale that we also used in our study (see Table 2). After answering the questions, the tool provides a visual and textual classification of the results including performance indicators. In a next step, managers receive results-based recommendations for action as outlined in the Development Paths above.

5. Limitations and need for further research

The limitations of our study demonstrate valuable opportunities for future research. A longitudinal study will be most insightful to further validate our recommendations for action beyond our interview data. In addition to gaining a larger sample size for quantitative analyses to increase limited generalizability of our results, another promising approach to gain more practically relevant insights on how to improve a company's data sharing openness and the meaning of social capital in this context, is through in-depth case studies on companies of each quadrant. There are also further potentially important antecedents of data sharing openness, that have not been explored in this study. Other types of capital include for example human capital, psychological capital and of course financial capital. The latter is evidently vital for the necessary investments into automated data sharing as discussed above. Relevant human capital includes soft skills training and building technical know-how within a company, while organizational psychological capital refers to the employees' mindset of optimism, self-efficacy and resilience in the face of challenging tasks [49]. These aspects are key for embracing innovations like Industry 4.0 technologies to boost collaboration and data sharing in buyer-supplier relationships [13].

Moreover, there are further research opportunities, concepts and technologies that should be taken into account for designing automated data exchange. The question on how information systems can be linked to one another has to be answered from a technological perspective. In this context, using different database schemas across multiple companies poses challenges. Important fields for future research include standardized interfaces and connectors. Challenges that arise due to limited data control can be approached through technological innovations like blockchain technology for example, that offers decentral and tamper-proof data exchange. Ensuring data sovereignty is also a major research topic in initiatives like 'Industrial Data Spaces' or 'GAIA-X'.

Future research also needs to differentiate between technological solutions that provide connectivity within one supply chain (i.e., from OEM to Tier N) and platform-based solutions that can host and link data from different supply chains across industries. Whereas the first type of solution already exists (many start-ups and established players like SupplyOn, E2Open, Supply Dynamics, etc.), platform-based solutions are just being developed (e.g., Manufacturing-X or Forward Sensing). While the first type of solution is usually sponsored by the OEM at the top of the supply chain – facilitating and forcing its suppliers to adapt to required interfaces – platform-based solutions are more complex. In order to achieve a truly collaborative platform that provides more value than inflicting cost, they need to provide low barriers to entry, that is, providing interfaces with low data complexity. In the case of Forward Sensing, this implies using existing transactional data (i.e., sales and purchase order) instead of more complex master data. Although these platform-based solutions will face critical challenges in terms of scaling, data sovereignty and competition law, they will offer a whole new level of transparency (e.g., in terms of foreseeing disruptions), compliance (e.g., tracking CO2 footprint along the supply chain and fulfilling regulatory requirements) and collaboration (e.g., second sourcing).

Besides sharing data in the context of production planning, there are other important fields for further investigating data sharing openness and social capital throughout the supply chain. Future research should focus on SMEs as suppliers in the innovation process of larger companies. There is still little research on integrating suppliers into the innovation process compared to the integration of other external sources, such as customers or start-ups. Establishing a relationship of trust and commitment to innovation through joint development efforts are key prerequisites for involving the supplier in the innovation process.

6. Conclusion

We investigate how companies can improve long-term production planning through increased data sharing openness in their supply chain collaborations, particularly focusing on the positive impact on reducing lead time and dealing with sudden disruptions. Building a high level of structural and relational social capital is the foundation for data sharing openness in a business relationship. Without it, data is deliberately withheld due to the fear of opportunistic behavior. In a next step, maintaining or increasing social capital is also important in deciding to establish *automated* data exchange. Since such a connection is in most cases a long-term commitment to one partner, it is important to have confidence that the partner will not misuse the data at any point in the business relationship. This research contributes to better understanding the effect of social capital on the degree of data sharing openness, not only by demonstrating the importance of social capital as enabler and facilitator, but also by highlighting the role of trust for engaging in data sharing. Particularly for smaller companies it is often difficult to adapt to the current digital transformation, leading to limited data exchange between supply chain partners compared to the level of frequent and automated data exchange of large corporations. However, we find that social capital between supply chain partners provides a means to partially compensate for a lack of automation. A strong buyer-supplier relationship enables smaller companies to effectively manage *manual* data exchange and still reduce lead time and increase transparency regarding sudden disruptions and delays. Large corporations, on the other hand, can trade social capital for high contract complexity. In conclusion, while some large corporations are able to reach high levels of data sharing openness without close relationships to their suppliers, smaller companies can boost data sharing through building social capital in order to successfully navigate the frontend of the IoP.

Acknowledgements

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2023 Internet of Production – 390621612.

The authors like to thank Dustin Siek who contributed to this study as part of his master's thesis and Daniel Kühn who contributed to this study as part of his bachelor's thesis at RWTH Aachen University. Finally, we want to thank our colleagues for their support in the data collection phase and their feedback on the manuscript.

Appendix

Table 1: Interview Sample Details

#	Industry	Position	Firm Size (Employees)	Duration
1	Laser Technology	General Manager	3	68 min
2	Automotive	Disposition and Procurement	300	65 min
3	Mechanical Engineering	General Manager	20	56 min
4	Automotive	Disposition and Procurement	500	60 min

5	Maritime	Head of Production	>1.000	30 min
6	Automotive	Quality Management and Procurement	113.000	50 min
7	Textile Industry	General Manager	210	45 min
8	Mechanical Engineering	Data Management	85.000	25 min
9	Textile Industry	General Manager	n/a	28 min
10	Construction materials	Head of Operations	35.000	74 min
11	Construction materials	Sales Director	800	42 min
12	Construction materials	General Manager	50	73 min
13	Food Industry	Logistic and Supply Chain Manager	2.500	50 min
14	Construction materials	Head of Operations	>1.000	32 min
15	Construction materials	Procurement	50	35 min
16	Construction materials	Head of Business Unit Profiles	200	30 min
17	Construction materials	Head of Procurement Logistics	>1.000	25 min
18	Food Industry	Head of Procurement	270	36 min
19	Automotive	Head of Logistic and Supply Chain digitalization	290.000	42 min
20	Construction materials	Strategic Procurement	>1.000	45 min
21	Aviation	Strategic Procurement	600	50 min

Table 2: Measures for Data Sharing Openness and Social Capital

Construct	**Dimensions**	**Measurement items**	**Scale**
Data sharing openness *(based on [50,32,28,34,51,29])*	**Transparency**	The provided data is complete and understandable.	1-7: Strongly agree - Strongly disagree
		Processes for generating data are fully automated.	
		Processes for transferring data are fully automated.	
	Interoperability	The standards used for sharing data are common and understandable.	1-7: Strongly agree - Strongly disagree
		There is a high level of connectivity between us.	1-7: Strongly agree: fully connected, e.g. connected ERP systems. Strongly disagree: manual data transfer, e.g. excel sheets, PDF.
	Timeliness	The data is generated far enough in advance.	1-7: Strongly agree - Strongly disagree
		The data is shared far enough in advance.	
Social Capital	**Structural Social Capital**	Both sides, *[name of supplier]* and us, frequently and easily get into direct contact with each other.	1-7: Strongly agree - Strongly disagree

(based on [52–54])		We regularly interact with *[name of supplier]* in a non-project specific context (e.g., networking events, research projects, conferences, social media).	
		During a project, our supply chain management/procurement and *[name of supplier]* get to know each other very well.	
	Relational Social Capital	We trust in each other's decisions.	1-7: Strongly agree - Strongly disagree
		We are confident that both our interests are fully valued and protected.	
		With *[name of supplier]*, we work towards the same objectives.	
	Cognitive Social Capital	We use the same technical language or terminologies	1-7: Strongly agree - Strongly disagree
		We are very familiar with the technologies, ideas, solutions provided by *[name of supplier]*.	
		We are aware that occurring problems within our business partnerships are a joint responsibility of both parties.	

References

[1] Rauter, R., Globocnik, D., Perl-Vorbach, E., Baumgartner, R.J., 2019. Open innovation and its effects on economic and sustainability innovation performance. Journal of Innovation & Knowledge 4 (4), 226–233.

[2] Euchner, J., 2018. The Internet of Things. Research-Technology Management 61 (5), 10–11.

[3] Cao, M., Zhang, Q., 2010. Supply chain collaborative advantage: A firm's perspective. International Journal of Production Economics 128 (1), 358–367.

[4] Fantazy, K.A., Tipu, S.A.A., Kumar, V., 2016. Conceptualizing the relative openness of supply chain and its impact on organizational performance. Benchmarking 23 (5), 1264–1285.

[5] Fawcett, S.E., Fawcett, Amylee M., Watson, B. J., Magnan, G.M., 2012. Peeking inside the black box: toward an understanding of supply chain collaboration dynamics. Journal of Supply Chain Management 48 (1), 44–72.

[6] Simatupang, T.M., Sridharan, R., 2002. The Collaborative Supply Chain. Emerald Group Publishing Limited.

[7] Pennekamp, J., Glebke, R., Henze, M., Meisen, T., Quix, C., Hai, R., Gleim, L., Niemietz, P., Rudack, M., Knape, S., Epple, A., Trauth, D., Vroomen, U., Bergs, T., Brecher, C., Buhrig-Polaczek, A., Jarke, M., Wehrle, K., 2019. Towards an Infrastructure Enabling the Internet of Production, in: 2019 IEEE International Conference on Industrial Cyber Physical Systems (ICPS 2019). Howards Plaza Hotel Taipei, Taiwan, 06-09 May, 2019. 2019 IEEE International Conference on Industrial Cyber Physical Systems (ICPS), Taipei, Taiwan. 5/6/2019 - 5/9/2019. IEEE, Piscataway, NJ, pp. 31–37.

[8] Dejonckheere, J., Disney, S.M., Lambrecht, M.R., Towill, D.R., 2004. The impact of information enrichment on the Bullwhip effect in supply chains: A control engineering perspective. European Journal of Operational Research 153 (3), 727–750.

[9] Panahifar, F., Byrne, P.J., Salam, M.A., Heavey, C., 2018. Supply chain collaboration and firm's performance. Journal of Enterprise Information Management 31 (3), 358–379.

[10] Chiu, C.-M., Hsu, M.-H., Wang, E.T.G., 2006. Understanding knowledge sharing in virtual communities: An integration of social capital and social cognitive theories. Decision Support Systems 42 (3), 1872–1888.

[11] Nahapiet, J., & Ghoshal, S. (1998)., 1998. Social capital, intellectual capital, and the organizational advantage. Academy of management review, 23(2), 242-266.

[12] Lee, C.-H., Ha, B.-C., 2018. The impact of buyer-supplier relationships' social capital on bi-directional information sharing in the supply chain. Journal of Business & Industrial Marketing 33 (3), 325–336.
[13] Patrucco, A., Moretto, A., Trabucchi, D., Golini, R., 2022. How Do Industry 4.0 Technologies Boost Collaborations in Buyer-Supplier Relationships? Research-Technology Management 65 (1), 48–58.
[14] Whipple, J.M., Wiedmer, R., K. Boyer, K., 2015. A Dyadic Investigation of Collaborative Competence, Social Capital, and Performance in Buyer-Supplier Relationships. Journal of Supply Chain Management 51 (2), 3–21.
[15] Al-Tabbaa, O., Ankrah, S., 2016. Social capital to facilitate 'engineered' university–industry collaboration for technology transfer: A dynamic perspective. Technological Forecasting and Social Change 104, 1–15.
[16] Steinmo, M., Rasmussen, E., 2018. The interplay of cognitive and relational social capital dimensions in university-industry collaboration: Overcoming the experience barrier. Research Policy 47 (10), 1964–1974.
[17] Wu, I.-L., Chiu, M.-L., 2018. Examining supply chain collaboration with determinants and performance impact: Social capital, justice, and technology use perspectives. International Journal of Information Management 39, 5–19.
[18] Filieri, R., Alguezaui, S., 2014. Structural social capital and innovation. Is knowledge transfer the missing link? Journal of Knowledge Management 18 (4), 728–757.
[19] Rost, K., 2011. The strength of strong ties in the creation of innovation. Research Policy 40 (4), 588–604.
[20] Robert, L.P., Dennis, A.R., Ahuja, M.K., 2008. Social Capital and Knowledge Integration in Digitally Enabled Teams. Information Systems Research 19 (3), 314–334.
[21] Lawson, B., Tyler, B.B., Cousins, P.D., 2008. Antecedents and consequences of social capital on buyer performance improvement. Journal of Operations Management 26 (3), 446–460.
[22] Adler, P.S., Kwon, S.-W., 2002. Social Capital: Prospects for a New Concept. AMR 27 (1), 17–40.
[23] Bernardes, E.S., 2010. The Effect of Supply Management on Aspects of Social Capital and the Impact on Performance: Social Network Perspective. Journal of Supply Chain Management 46 (1), 45–55.
[24] Steinle, C., Schiele, H., Bohnenkamp, T., 2019. Does supplier opportunism lead to buyer opportunism? A social capital perspective. Journal of Business & Industrial Marketing 35 (2), 362–384.
[25] Hatzakis, T., Lycett, M., Macredie, R.D., Martin, V.A., 2005. Towards the development of a social capital approach to evaluating change management interventions. European Journal of Information Systems 14 (1), 60–74.
[26] Inkpen, A.C., Tsang, E.W.K., 2005. Social Capital, Networks, and Knowledge Transfer. Academy of Management Review 30 (1), 146–165.
[27] Wulf, S., Redlich, T., Krenz, P., 2013. Die Entwicklung der Offenehit im Lebenszyklus von Produktionsnetzwerken. ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb 108 (12), 911–916.
[28] Hilkert, D., Benlian, A., Sarstedt, M., Hess, T., 2011. Perceived Software Platform Openness: The Scale and its Impact on Developer Satisfaction.
[29] van Astyne, M.W., Parker, G.G. and Choudary, S.P., 2016. Pipelines, Platforms, and the New Rules of Strategy. Harvard Business Review 94 (4), 54–60.
[30] Göpfert, I., 2019. Ein Zukunftsmodell für die Handelslogistik im Jahr 2036, in: Göpfert, I. (Ed.), Logistik der Zukunft - Logistics for the Future. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 233–252.
[31] Özer, Ö., Zheng, Y., Ren, Y., 2014. Trust, Trustworthiness, and Information Sharing in Supply Chains Bridging China and the United States. Management Science 60 (10), 2435–2460.
[32] Hallingby, H.K., 2016. Key success factors for a growing technology innovation system based on SMS Application-to-Person in Norway. Technology Analysis & Strategic Management 28 (10), 1123–1137.
[33] Chakravarty, A.K., Zhang, J., 2007. Lateral capacity exchange and its impact on capacity investment decisions. Naval Research Logistics 54 (6), 632–644.
[34] Hodapp, D., Hawlitschek, F., Kramer, D., 2019. Value Co-Creation in Nascent Platform Ecosystems: A Delphi Study in the Context of the Internet of Things, in: Proceedings of the International Conference on Information Systems, Munich.
[35] Lazzarotti, V., Bengtsson, L., Manzini, R., Pellegrini, L., Rippa, P., 2017. Openness and innovation performance. European Journal of Innovation Management 20 (3), 463–492.
[36] Rivera, L., Sheffi, Y., Knoppen, D., 2016. Logistics clusters: The impact of further agglomeration, training and firm size on collaboration and value added services. International Journal of Production Economics 179, 285–294.

[37] Drechsler, W., Natter, M., 2012. Understanding a firm's openness decisions in innovation. Journal of Business Research 65 (3), 438–445.
[38] Geuna, A., Fontana, R., Matt, M., 2006. Firm size and openness: the driving forces of university– industry collaboration, in: Caloghirou, Y., Constantelou, A., Vonortas, N. (Eds.), Knowledge Flows in European Industry. Routledge.
[39] Spithoven, A., Vanhaverbeke, W., Roijakkers, N., 2013. Open innovation practices in SMEs and large enterprises. Small Business Economics 41 (3), 537–562.
[40] van de Vrande, V., Jong, J.P.J. de, Vanhaverbeke, W., Rochemont, M. de, 2009. Open innovation in SMEs: Trends, motives and management challenges. Technovation 29 (6-7), 423–437.
[41] Bogers, M., 2011. Knowledge sharing and protection in R&D collaborations. European Journal of Innovation Management 14 (1), 93–117.
[42] Soosay, C.A., Hyland, P.W., Ferrer, M., 2008. Supply chain collaboration: capabilities for continuous innovation. Supply Chain Management: An International Journal 13 (2), 160–169.
[43] Broekel, T., Boschma, R., 2012. Knowledge networks in the Dutch aviation industry: the proximity paradox. Journal of Economic Geography 12 (2), 409–433.
[44] Ponds, R., van Oort, F., Frenken, K., 2007. The geographical and institutional proximity of research collaboration. Papers Regional Science 86 (3), 423–443.
[45] Ganguly, A., Talukdar, A., Chatterjee, D., 2019. Evaluating the role of social capital, tacit knowledge sharing, knowledge quality and reciprocity in determining innovation capability of an organization. Journal of Knowledge Management 23 (6), 1105–1135.
[46] Rass, M., Dumbach, M., Danzinger, F., Bullinger, A.C., Moeslein, K.M., 2013. Open Innovation and Firm Performance: The Mediating Role of Social Capital. Creativity and Innovation Management 22 (2), 177–194.
[47] Zhao, L., Huo, B., Sun, L., Zhao, X., 2013. The impact of supply chain risk on supply chain integration and company performance: a global investigation. Supply Chain Management: An International Journal 18 (2), 115–131.
[48] Dobson, G., Pinker, E.J., 2006. The value of sharing lead time information. IIE Transactions 38 (3), 171–183.
[49] Luthans, F., Avey, J.B., Avolio, B.J., Peterson, S.J., 2010. The development and resulting performance impact of positive psychological capital. Human Resource Development Quarterly 21 (1), 41–67.
[50] Ghazawneh, A., Henfridsson, O., 2013. Balancing platform control and external contribution in third-party development: the boundary resources model. Information Systems Journal 23 (2), 173–192.
[51] te Molder, J., van Lier, B., Jansen, S., 2011. Clopenness of Systems: The Interwoven Nature of Ecosystems, in: Proceedings of the Third International Workshop on Software Ecosystems, Brussels, pp. 52–64.
[52] Chang, H.H., Chuang, S.-S., 2011. Social capital and individual motivations on knowledge sharing: Participant involvement as a moderator. Information & Management 48 (1), 9–18.
[53] Wang, Q., Li, J.J., Ross, W.T., Craighead, C.W., 2013. The interplay of drivers and deterrents of opportunism in buyer–supplier relationships. Journal of the Academy of Marketing Science 41 (1), 111–131.
[54] Yli-Renko, H., Autio, E., Sapienza, H.J., 2001. Social capital, knowledge acquisition, and knowledge exploitation in young technology-based firms. Strategic Management Journal 22 (6-7), 587–613.

Biography

Dr. Anja Leckel obtained her Ph.D. at the Institute for Technology and Innovation Management (TIM) at RWTH Aachen University. Specializing in innovation, entrepreneurship and marketing, she studied and conducted research at RWTH Aachen University, University of Quebec in Montreal, Laval University in Quebec City and University of Technology Sydney. Her research focuses on the role of innovation intermediaries that facilitate collaboration and knowledge exchange in innovation ecosystems.

Maria Linnartz, M. Sc. is a research associate at the Institute for Industrial Management (FIR) at the RWTH Aachen in the research group Supply Chain Management. She studied Business Administration and Engineering specializing in Mechanical Engineering at the RWTH Aachen University. Currently, she is working on the research project “Internet of Production”, which aims to develop data-driven decision support systems.