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Individual-Level and Unit-Level Knowledge Transfers for Innovation – A Multilevel Network Approach

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Abstract

Knowledge transfer networks are a critical component of the innovation process, enabling the exchange of knowledge, joint problem-solving, and learning, thereby enhancing innovative performance. In new product development (NPD) organizations, such networks are formed at the level of individual employees and the level of NPD units alike. Jointly investigating the formation of networks at these two levels, this study exposes cross-level interdependencies and highlights whether and how transfer ties formed at one level are aligned with or substitute knowledge transfers at the other level. Paying particular attention to boundary spanning and centrality as innovation-critical network characteristics, we apply a multilevel perspective to identify new cross-level mechanisms that determine the complex interplay of knowledge networks across levels of the NPD organization. We utilize exponential random graph modeling for multilevel network data collected on 193 employees belonging to 38 NPD units in a German high-tech firm. With regards to boundary spanning, this approach allows us to identify network patterns of overlap in which ties between two NPD units co-exist with boundary-spanning knowledge transfers between employees nested in these two units. Concerning centrality, we uncover patterns of assortativity reflecting how the network position of units in unit-level networks interacts with the position of their employees in individual-level networks and both function as substitutes. Overall, this research extends existing knowledge on the origins of intra-organizational boundary-spanning and actors' centrality in collaborative networks for NPD and allows for a refined understanding of this critical component of the innovation process.

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Introduction

Collaborative networks have repeatedly been shown to play a critical role in the innovation process (e.g., Aalbers, Dolfsma and Leenders, 2016, Hansen, 1999, Tortoriello, Reagans and McEvily, 2012). In new product development (NPD) organizations, network ties created by individual employees or by their units facilitate the dissemination and recombination of knowledge (Hansen, 1999), the exchange and generation of ideas (Burt, 2004), joint problem-solving (Shah, Cross and Levin, 2015), and coordination (Sosa, Gargiulo and Rowles, 2015), thereby increasing creativity (Perry-Smith, 2006) and innovative performance (e.g., Lechner, Frankenberger and Floyd, 2010). However, not all patterns of ties are equally beneficial for innovation, for instance as they can lead to redundant knowledge (Burt, 1992, Burt, 2004, Soda and Zaheer, 2012), lock-in (Gargiulo and Benassi, 2000, Reagans and McEvily, 2003), or overload (Mariotti and Delbridge, 2012) and impair tied-to individuals or units. Against this background, understanding tie formation and the emergence of network patterns has long been argued essential to improve innovative performance (e.g., Ancona and Caldwell, 1992, Reagans, Zuckerman and McEvily, 2004).

This study sheds new light on the formation of networks for innovation by applying a multilevel perspective to knowledge transfers in NPD organizations. Building on a view of organizations as hierarchical systems consisting of nested and interdependent levels of action (March and Simon, 1958, Simon, 1996), we account for the fact that knowledge transfer networks are created at the level of individual employees and at the level of NPD units, in which employees are nested (e.g., Leenders and Dolfsma, 2016, Phelps, Heidl and Wadhwa, 2012). For instance, employees share knowledge, information, or advice, via informal network ties with colleagues (e.g., Durmuşoğlu, 2013, Tortoriello, 2015), while NPD units exchange work-related information (e.g., Hansen, 1999, Tsai, 2001) or are connected by formal workflows (e.g., Gargiulo and Sosa, 2016, Kratzer, Gemuenden and Lettl, 2008).

Based on this distinction, our study analyzes how knowledge transfer ties established at the level of NPD units as higher level actors are related to ties among individual unit members as lower level actors in the organization. Jointly investigating the formation of networks at these two levels, we highlight whether and how knowledge transfer ties at one level are aligned with or substitute knowledge transfers at the other level.

Analyzing knowledge transfer networks from a multilevel perspective, we pay particular attention to boundary spanning and centrality as network characteristics driving innovative performance (e.g., Brennecke and Stoemmer, 2018, Sivasubramaniam, Liebowitz and Lackman, 2012). Forming boundary-spanning network ties allows access to heterogeneous and novel knowledge (Burt, 1992, 2004) and provides an overview of opportunities available in other parts of the organization (Kleinbaum and Tushman, 2007). Similarly, having a central network position implies timely access to more and alternative resources, particularly knowledge, and fosters learning (Durmuşoğlu, 2013, Kratzer, Leenders and van Engelen, 2010, Lai, Lui and Tsang, 2016). With regards to boundary spanning, we examine patterns of overlap in which network ties between two NPD units co-exist with ties between employees nested in these two units. The uncovered patterns enable us to shed light on a so far overlooked tension charactering collaborative NPD: the same patterns that imply alignment of knowledge transfers across levels constrain individuals' and units' potential to access heterogeneous and novel knowledge. Concerning centrality, we investigate patterns of assortativity reflecting how the network position of units in a unit-level network interacts with the position of their employees in an individual-level network. Based on the latter, we conclude whether knowledge transfers at different levels of the NPD organization function as complements or substitutes and discuss implications for the innovation process.

For our empirical analysis, we rely on survey data collected on 193 individuals nested in 38 units in the R&D department of a German high-tech firm. We build on recent developments in the analysis of so-called "multilevel networks" that link individual-level and unit-level networks based on the nested structuring of organizations (Lazega, Jourda, Mounier and Stofer, 2008, Zappa and Lomi, 2015). Multilevel networks account for individual employees, connected by a set of individual-level network ties – in this study work-related advice transfer –, and the units they belong to, which are themselves linked by a separate set of network ties – here information and workflows. Advice, information, and workflows are seen as distinct forms of knowledge transfers for innovation. To uncover patterns of connectivity resulting from the interplay of these forms of knowledge transfers across levels, we apply exponential random graph modeling (ERGM) for multilevel networks (Wang, Robins, Pattison and Lazega, 2013). This network modeling approach tests hypotheses about mechanisms determining the presence of network ties between actors at different levels of the organization (Zappa and Lomi, 2015) and, hence, allows turning our theoretical propositions into the appropriate statistical representation.

Our study contributes to the literature on collaborative networks as a critical component of the innovation process in multiple ways. The vast majority of previous research has focused on the consequences of networks for NPD and innovation (for recent reviews, see Baer, Evans, Oldham and Boasso, 2015, Brennecke and Stoemmer, 2018, Leenders and Dolfsma, 2016). Taking patterns of network connectivity that either benefit or impair innovative performance as a given, this stream of research raises the question of how these network ties and patterns of ties are formed in the first place. In particular, understanding the mechanisms that determine tie formation can be seen as a precondition to proactively organize and manage collaborative networks for innovation. Applying a multilevel perspective to uncover new cross-level mechanisms that shape patterns of intra-

organizational knowledge transfers in NPD organizations, our research generates insights that go beyond the empirical regularities characterizing innovation networks documented by prior research. First, we highlight whether and how unit-level knowledge transfers overlap with advice transfers among employees belonging to different units in the NPD organization and thereby contribute to knowledge on boundary spanning as a topic of specific interest for scholars of networks and innovation alike (e.g., Aalbers, et al., 2016, Tortoriello, et al., 2012). While boundary-spanning ties are critical for innovative performance (Brennecke and Stoemmer, 2018, Kratzer, et al., 2008), they are at the same time difficult to create and maintain (Burt, 2002, Krackhardt, 1999). Our study enhances understanding of contextual, top-down influences and bottom-up mechanisms that affect boundary-spanning tie formation in NPD organizations. It exposes a tension inherent in collaborative NPD between the alignment of knowledge transfers across levels and the formation of network ties that allow access to novel resources. Second, our research provides a more nuanced understanding of the origins of actors' centrality in innovation networks. Illustrating how and why individuals' network centrality interacts with their units' network centrality, it solves the puzzle raised by Hansen (1999), whether network ties at different levels function as complements or substitutes. It also highlights that a multilevel perspective is necessary to develop a more complete understanding of the NPD process in hierarchical organizational systems.

Theory and Hypotheses

Knowledge Transfer Networks for New Product Development

Work in NPD organizations is typically formally structured around employees nested in separate units, such as divisions, work groups, or project teams, engaged in specialized knowledge-gathering and knowledge-producing activities (Madhavan and Grover, 1998). NPD organizations can, accordingly, be characterized as hierarchical systems with several, partially nested and interdependent levels of action (March and Simon, 1958, Simon, 1996).

In line with this characterization, collaborative networks, such as knowledge transfers, are formed at the level of the individual employee and at the level of the NPD unit alike. For instance, Aalbers, et al. (2016) and Tortoriello and Krackhardt (2010) investigate individual employees exchanging knowledge, advice, or ideas with their colleagues. By contrast, Hansen (1999) and Tsai (2001) examine informal networks of knowledge transfers and resource sharing between units as higher-order entities within the firm and Gargiulo and Sosa (2016) as well as Lomi and Zappa (2015) study formally mandated workflows at the unit level. As these examples highlight, agency for the creation and enactment of knowledge transfer ties aimed at NPD can either be ascribed to the individual unit member or to the unit as a whole. The unit, like an individual, is capable to "process information by encoding, storing, and retrieving it (Brauner and Scholl, 2000)" (Leenders and Dolfsma, 2016: 126) and, similarly, able to form and maintain network ties.

In this study, we investigate work-related advice transfers as network ties formed at the level of individual employees. Advice transfers are not part of formal role requirements (McEvily, Soda and Tortoriello, 2014). They are informal, interpersonal network ties, considered as main conduit through which knowledge flows within an organization (e.g., Durmuşoğlu, 2013, Lomi, Lusher, Pattison and Robins, 2014, Nebus, 2006). Advice ties benefit performance, particularly in innovation-intensive settings (Ibarra, 1993). In line with a unit's purpose to lessen coordination efforts, serve as repository of specialized knowledge, and facilitate localized learning (e.g., Allen, 1977, March and Simon, 1958), they are commonly formed among members belonging to the same NPD unit (Allen, James and Gamlen, 2007, Brennecke and Rank, 2016). At the same time, the complexity and ambiguity of the innovation process increasingly lead NPD employees to transfer advice across unit boundaries (e.g., Aalbers, et al., 2016, Tortoriello and Krackhardt, 2010). Mechanisms such as similarity in individual characteristics or individual agency function as facilitators for such

boundary-spanning tie formation (e.g., Ahuja, Soda and Zaheer, 2012, Kleinbaum, Stuart and Tushman, 2013). Regarding centrality, variation in individuals' number of informal collaborative ties is typically ascribed to differences in resource endowments, such as expertise and status (e.g., Brennecke and Rank, 2017).

At the unit level, we distinguish informal information transfers and formal workflows as two distinct types of knowledge transfer networks characterizing NPD organizations. While both types of unit-level knowledge transfers depend on individual unit members for execution, they are typically ascribed to the unit level. Explaining how agency can lie at the level of the unit, Hansen (1999) provides a detailed account of informal knowledge transfers among units in a corporate R&D setting. He describes that while an individual often initiates unit-level network ties, they are maintained and enacted by the unit as a whole. They are "institutionalized in that they were regularly occurring patterns of activities between groups of people from different [units] that were enforced by a common belief system […] (cf. Zucker, 1977; DiMaggio and Powell, 1983)." (Hansen, 1999: 91-92). Hence, these ties are ascribed to the unit rather than to its individual members, who know about their existence and use them, if the need arises, to foster unit-level goals. Similar to individual-level advice ties, such unit-level transfer of knowledge and information is informal; it is not mandated, but ties are formed voluntarily, driven mainly by resource considerations (Hansen, 1999) and investigated previously by Hansen (1999, 2002), Tsai (2000, 2001), and Tsai and Ghoshal (1998).[1] With regards to formal unit-level network ties, we examine the transfer of modules characteristic for NPD organizations that seek to break down the development of complex products into subsystems (Baldwin and Clark, 2000). Module transfers reflect mandated task

[1] Our conceptualization of unit-level networks needs to be distinguished from network conceptualizations in studies that assign ties created at the level of the individual unit member (for instance, interpersonal ties created by the unit leader) to the level of their unit (e.g., Bercovitz & Feldman, 2011; Chung & Jackson, 2013; Kratzer et al., 2008b). We argue that there is a fundamental difference between network ties created and enacted by individuals as opposed to units, as in each case agency lies at a distinct level of the organization.

interdependencies, or workflow ties, at the unit level, which are determined by managements' work design considerations (Gargiulo and Sosa, 2016, Kratzer, et al., 2008).

All three networks in this study, individual-level advice transfer and unit-level information transfer and workflows, concern the transfer of knowledge for NPD, and are, hence, characterized by functional overlap. Therefore, and because the different types of knowledge ties are created at nested levels of action, we expect tie formation at the individual level and at the unit level to be mutually dependent. Individual-level advice transfers and unit-level knowledge flows may be aligned complementarily or function as substitutes in the innovation process. In the following, we explore different cross-level mechanisms that may determine the interplay of individual-level and unit-level networks for NPD.

Cross-Level Mechanisms Determining Knowledge Transfers

While mechanisms driving the formation of knowledge transfer ties at a single organizational level, for instance resource endowments or similarity, are well-understood (cf. Ahuja, et al., 2012), we know little about cross-level interdependencies that shape networks for innovation. In collaborative NPD, such interdependencies between individual and unit-level networks exist if knowledge transfer ties at one level influence the presence of ties at the other level. The cross-level mechanisms underlying these interdependencies may operate top-down or bottom-up (Kozlowski and Klein, 2000). Top-down, formal or informal knowledge transfers enacted by a unit shape the formation of advice ties by its members, reflecting contextual influences on individual behavior. Regarding bottom-up influences, we have to distinguish: individual-level advice transfers may well influence the formation of informal unit-level ties, that is, transfer of information among NPD units. By contrast, the formal transfer of modules is exogenously mandated. Workflow ties are, therefore, unlikely to be affected bottom-up by advice transfers. Thus, the top-down mechanisms we propose

refer to formal and informal knowledge transfers alike, while the bottom-up mechanisms solely concern the interplay of informal information and advice ties across levels.

The mechanisms we discuss determine the formation of knowledge transfer ties at different levels of the NPD organization and, thereby, lead to distinct multilevel patterns of network ties that affect the intra-organizational dissemination and use of knowledge for innovation. In the following, we derive hypotheses on the occurrence of these multilevel patterns in knowledge networks for NPD. In the discussion section, we will then shed light on the implications of each uncovered pattern for collaborative NPD. To facilitate the identification of patterns, we follow the method described by Zappa and Lomi (2015) and conceptualize individual-level and unit-level networks jointly as one multilevel network, as schematically depicted in Figure 1. In this multilevel network, the different network levels correspond to distinct levels of action – individual and unit – in the NPD organization; levels are linked, as individuals are hierarchically nested in units by means of unit membership.

--- Insert Figure 1 about here ---

In line with our focus on boundary spanning and centrality as innovation-critical network characteristics, we differentiate between two categories of multilevel network patterns: we first link our analysis of boundary spanning to multilevel patterns of tie overlap and then discuss multilevel patterns of assortativity capturing individuals' and units' centrality in collaborative networks for innovation. In each case, we consider the direction of knowledge transfers, distinguishing between individuals and units as providers of knowledge to others on the one hand and acquiring knowledge from others on the other.

A Multilevel Perspective on Boundary Spanning: Cross-Level Overlap

In general, intra-organizational boundary spanning concerns the formation of network ties across divides, such as here unit boundaries. Adding a multilevel perspective, this study investigates whether and how boundary-spanning knowledge transfer ties between two NPD

units overlap with boundary-spanning advice ties between employees nested in these two distinct units. Taking into account the direction of knowledge transfers and reciprocation of ties within levels, we distinguish three multilevel patterns of boundary-spanning tie overlap illustrated in Figure 2: a) cross-level entrainment, b) cross-level exchange, and c) cross-level entrainment reciprocity (cf. Zappa and Lomi, 2015).

--- Insert Figure 2 about here ---

Cross-level entrainment. Cross-level entrainment describes boundary-spanning tie overlap in terms of unit-level modules and information being transferred in the same direction as individual-level advice. From a top-down perspective capturing the contextual influence of unit-level ties on advice transfers between unit members, cross-level entrainment results from members of different NPD units getting in touch interpersonally, enabled by their units' connectedness. They receive the opportunity to extend their personal networks, for instance acquiring boundary-spanning advice from members in those units, from which their own unit acquires modules or information. In this arrangement, the informal advice acquired at the individual level may directly complement the knowledge acquired at the unit level, for example in form of additional input on a module. In many NPD organizations, such informal interpersonal communication to back-up and reinforce formal workflows is downright expected, indicating alignment of formal and informal structures (Gargiulo and Sosa, 2016, Sosa, et al., 2015). The content of work-related advice may, however, also be detached from the content of the unit-level knowledge transfer. Building on Kleinbaum, et al. (2013), unit-level ties may foster interpersonal tie formation across unit boundaries as they increase individuals' convenience sample of potential exchange partners. In this case, the contextual influence of higher-level network ties enhances awareness of and familiarity with the knowledge available elsewhere in the organization (e.g., Ren and Argote, 2011) and facilitates individuals' attempts to create boundary-spanning network ties for innovation.

Empirical support for such top-down influences comes from Berends, van Burg and van Raaij (2011) who demonstrate that contractual, organizational-level ties lead to informal, interpersonal network contacts, arguing that "contacts follow contracts".

From a bottom-up perspective, individual-level advice transfers may foster the creation of more institutionalized, unit-level transfers of information aimed at NPD. That is, interpersonal relationships provide the foundation for members of different NPD units to identify collaborative opportunities at the unit level and, consequently, establish a – informal rather than formal – unit-level tie. Individual-level ties might even be a precondition for ties to get institutionalized at the unit level as, in line with Hansen's (1999) account, the latter often are initiated by individual employees. In this process, units would benefit from the social capital of their members (Oh, Chung and Labianca, 2004). Top-down and bottom-up mechanisms both indicate alignment of work-related knowledge transfers across levels and lead us to expect:

> *Hypothesis 1a: Multilevel networks aimed at NPD will be characterized by boundary-spanning patterns of cross-level entrainment.*

Cross-level exchange. Cross-level exchange captures unit-level information and modules flowing in the opposite direction as individual-level advice. That is, nested actors' knowledge provision at one level overlaps with boundary-spanning knowledge acquisition at the other level.

From a top-down perspective, we expect to observe patterns of cross-level exchange characterizing multilevel networks for NPD for two main reasons. First, while the exchange pattern implies that the knowledge transferred at different levels of the NPD organization cannot be directly complementary, acquiring work-related advice from colleagues whose units regularly acquire and, thus, process information or modules from one's own unit can function as a feedback mechanism. That is, following a unit-level knowledge transfer, individuals informally source knowledge aimed at improving future transfers, module

specificities, or more broadly cross-boundary coordination and innovative performance. Second, the presence of formal or informal unit-level ties is expected to exert contextual influence that facilitates the formation of individual-level advice ties. Even if knowledge transfers are not directly complementary and there is no inherent need to address members from tied-to units for advice, the presence of a unit-level knowledge provision tie is still assumed to reduce the typically high costs of boundary spanning (Burt, 2002, Krackhardt, 1999) and offer common ground for interpersonal advice ties to develop. As discussed above, the existence of unit-level ties widens unit members' convenience sample of potential advisors (Kleinbaum, et al., 2013) and fosters familiarity and trust.

Bottom-up mechanisms might also lead to patterns of cross-level exchange. Similar to the argument presented for cross-level entrainment, individual-level advice ties can provide a basis for the recognition of unit-level collaborative opportunities and initiate the creation of information transfer ties between two NPD units. Hence, we suggest:

> *Hypothesis 1b: Multilevel networks aimed at NPD will be characterized by boundary-spanning patterns of cross-level exchange.*

Cross-level entrainment reciprocity. To take the above one step further, we bring reciprocity of tie formation into the equation and discuss boundary-spanning patterns of tie overlap, in which uni-directional knowledge transfer at one level of the NPD organization coincides with reciprocal exchange of knowledge at the other level (see Figure 2c). Reciprocity is an inherent characteristic of knowledge transfers (Lai, et al., 2016) and networks for innovation (Leenders and Dolfsma, 2016), reflecting a quid-pro-quo norm: the willingness of one actor to provide resources to another depends on the resources that the other party is willing or able to return (Gouldner, 1960). While constraining the free flow of knowledge, reciprocated exchange is perceived as fair (Cabrera and Cabrera, 2005), reduces the risk of opportunistic behavior (Coleman, 1988), and promotes trust (Uzzi, 1997) as precondition for high performance in collaborative NPD (Bstieler, 2006).

With respect to patterns of boundary-spanning tie overlap across multiple levels of the NPD organization, we suggest that the presence of knowledge transfer ties at one level may take over these functions – reduction of opportunistic behavior and promotion of fairness and trust – and replace the need for reciprocity at the other level. Top-down, we follow arguments by Brennecke and Rank (2016) investigating individual-level advice transfers within and across unit boundaries. The authors provide evidence that the norm of reciprocity plays a smaller role among employees belonging to the same rather than to different organizational units. They argue that employees in the same unit overcome quid-pro-quo thinking, because joint unit membership fosters familiarity and trust, promotes a collective identity, and implies working towards a common goal. Comparable effects can result from the existence of higher-level network ties: Since their units share information or work towards a common goal as indicated by formal workflows, employees might be more willing to informally transfer advice to colleagues in another unit without an immediate expectation of reciprocity.

While less obvious, a similar mechanism might characterize the bottom-up influence of boundary-spanning advice ties at least on the informal transfer of information among units. Strong individual-level connections among the members of two NPD units may replace the necessity of reciprocation, which according to Hansen (1999) also characterizes unit-level networks. We propose:

> *Hypothesis 1c: Multilevel networks aimed at NPD will not be characterized by boundary-spanning patterns of cross-level entrainment reciprocity.*

A Multilevel Perspective on Centrality: Cross-Level Assortativity

The term assortativity is used in network research to describe tendencies of actors with similar network centrality – more precisely, similar numbers of ties – to connect with each other (Ahuja, et al., 2012). It can, hence, be seen as positive interaction between actors' positions in a network. For instance, two individuals who both create a large number of knowledge-provision (or -acquisition) ties with others in their organization are connected to

each other. By contrast, if an individual who creates few ties connects with a colleague heavily involved in knowledge-tie creation we speak of dissassortativity. Extended to the interplay between networks at different levels of the NPD organization, cross-level assortativity describes the interaction between the propensity of a unit and the propensity of this unit's members to form knowledge transfer ties at their respective levels (Zappa and Lomi, 2015, Zappa and Robins, 2016). In other words, it captures whether and how the centrality of unit members in the individual-level advice network is linked to the centrality of their units in unit-level networks of formal or informal knowledge transfers. Again, we take into account the direction of knowledge transfers and distinguish between two different patterns of multilevel assortativity illustrated in Figure 3: a) cross-level provision assortativity and b) cross-level acquisition assortativity.

--- Insert Figure 3 about here ---

Cross-level provision assortativity. Cross-level provision assortativity in multilevel networks for NPD is observed if individual employees and the units in which they are nested create comparable amounts of knowledge provision ties at their respective levels. Conversely, cross-level provision disassortativity implies that individuals heavily involved in advice provision are nested in NPD units creating few knowledge provision ties with other units, or, vice versa, units providing a lot of knowledge having members who provide little advice.

For collaborative NPD, cross-level provision *dis*assortativity indicates substitution of knowledge transfers across levels. For instance, if a unit maintains many knowledge provision ties with other units, its members may be less sought-after to informally provide advice because the specialized knowledge contained within the unit is already sufficiently disseminated. Alternatively, unit members may also be so busy executing their unit's ties that they are unable to informally provide advice to their colleagues. Conversely, individual members of a specific NPD unit might become especially sought-after and, hence, create

many advice-provision ties if their unit is not willing or able to disseminate its knowledge by means of providing modules or information to other units.

While such substitution mechanisms would explain dissassortativity across levels, we expect the formation of network ties for NPD to be characterized by a positive cross-level interaction effect. From a top-down perspective, cross-level provision assortativity is assumed to result from a signaling effect (Spence, 1974). The central position of a unit in the informal information or formal workflow network creates awareness within the NPD organization of the knowledge and innovation potential it contains (Podolny, 2001) and signals its willingness to share this potential with other units. In an attempt to benefit from this on an interpersonal level, individuals might turn to the unit's members for task-related advice. A general status spillover effect might further add to this: A central network position is typically associated with high levels of reputation and status (cf. Ahuja, et al., 2012) and previous research has demonstrated that actors connected with high-status others are themselves viewed more favorably (Podolny, 2001). Translating the latter into a cross-level mechanism, employees nested in NPD units centrally embedded in the unit-level networks should be attributed higher status and gain more attention, therefore becoming particularly sough-after as providers of work-related advice in the individual-level network.

Comparable effects might also trigger bottom-up influences of unit members' position in the advice network on their units' propensity to create information-provision ties with other units. As individuals informally provide advice to colleagues, they signal competence, innovative potential, and a general openness towards knowledge sharing, which could foster the institutionalization of unit-level information ties. Tentative evidence for such a bottom-up influence comes from Eisenhardt and Schoonhoven (1996) who show that a prominent network position of individual managers increases alliance formation rates in an inter-organizational network. Based on the above, we expect:

Hypothesis 2a: Multilevel networks aimed at NPD will be characterized by centrality-related patterns of cross-level provision assortativity.

Cross-level acquisition assortativity. Analogue to the above, cross-level acquisition *dis*assortativity indicates substitution of knowledge inflows across levels. It would be observed if knowledge acquisition at one level of the NPD organization renders knowledge acquisition at the other level unnecessary or difficult to maintain. It can equally be the result of a lack of knowledge acquisition at one level compensated for at the other level.

By contrast, cross-level acquisition assortativity implies that, top down, individuals nested in NPD units that acquire a lot of external input from other units try to match their units' knowledge intake. This matching behavior could result from necessity, as individuals perceive the need to gather work-related advice in order to deal with the external knowledge inflow at the unit level. It could also indicate an attempt to benefit from the opportunity structures provided by their unit and use the unit's visibility to improve their own network of advisors. Finally, it could indicate a certain networking culture or ability that spreads from the unit to the individual level, and possibly the other way around. Zappa and Robins (2016) show that individuals nested in units highly dependent on other units with regard to formal workflows get used to relying on others in their daily work and seek more advice. Focusing on networking ability, Tortoriello (2015) suggests that individuals develop a capacity for boundary-spanning knowledge acquisition by maintaining a differentiated and wide network. Potentially, the development of this capacity also benefits from being embedded in a context – the NPD unit – that emphasizes networking for innovation. We propose:

Hypothesis 2b: Multilevel networks aimed at NPD will be characterized by centrality-related patterns of cross-level acquisition assortativity.

Data and Methods

Empirical Setting

For our empirical analysis, we rely on data collected from employees working in NPD at the largest site of a German high-tech firm within the electrics and electronics industry. The firm employs a modular approach to NPD. Accordingly, its R&D department is formally structured into small, interdependent NPD units ranging in size between two and 11 members, each with its own leader. Each employee belongs to one unit. The units belong to five different product divisions with a distinct topical focus. By focusing on one site only, we are able to remove the complicating presence of geographical proximity influencing networks for innovation (Boschma, 2005).

We conducted an online survey among NPD unit leaders and members. Before constructing our questionnaire, we engaged in multiple in-depth discussions with senior managers of the firm, including the head of the R&D department, to develop an understanding of the types of formal and informal knowledge transfers taking place at different organizational levels. Based on this information, we selected the network questions described below, to capture individual-level and unit-level knowledge transfers for NPD. The questions were pre-tested on a small sample of employees to ensure that meanings were clear. In line with the modular organization of work in the R&D department, we capture formal workflows at the unit level rather than the individual level. At the individual level, we account for formal structure by controlling for NPD unit membership as well as hierarchical reporting lines further explained below.

NPD unit leaders provided information on their unit's formal and informal network ties with other units in the R&D department. Leaders and members indicated their individual-level advice ties. Information on the firm's hierarchical structure, unit memberships, and employee tenure was provided by management based on company records. There were 43

NPD units in the site under investigation; of those we had to exclude five units due to leader non-participation and, consequently, missing data on unit-level network ties. The unit-level response rate is 88 percent. There were 247 predominantly male employees working in the 38 units retained; 193 employees completed our survey, resulting in an individual-level response rate of 78 percent.

Network and Actor Attribute Data

To capture the unit-level information network, we asked unit leaders to indicate from which other unit their unit acquired "important work-related information (e.g., market- or technology-trends, technical details, ideas on new solutions)." To capture formal workflows, we asked "To which other units did your unit provide modules and the associated knowhow in the past?" We provided unit leaders with a roster of all units in the R&D department and they could choose the units with which their unit had either type of network tie. Ties were recorded dichotomously and arranged in two 38 × 38 binary adjacency matrices. To align the direction of knowledge flows reflected by the two networks, we transposed the information network to capture the provision of information.

To collect data on individual-level advice transfer, we used the roster method to capture individuals' ties to colleagues belonging to the same division and a name generator for colleagues belonging to different divisions (for a similar approach see Oh, et al., 2004). In line with established practice (e.g., Lomi, et al., 2014, Reagans and McEvily, 2003), we asked all NPD employees to name colleagues to whom they turned to regularly to acquire work-related advice. Ties were coded dichotomously and arranged in a 193 × 193 binary adjacency matrix. Similar to the unit-level information network, we transposed this matrix to reflect the provision of work-related advice. To consider the nested structure of our research design, we created a 193 x 38 affiliation matrix reflecting individuals' unit membership and

used this matrix to link the individual-level network to the unit-level networks as depicted in Figure 1.

As control variables, we include different actor attributes in our analyses that are assumed to influence the likelihood of observing knowledge network ties. We account for *division membership* as a categorical variable capturing individuals' and units' higher-order affiliation with one of the five divisions. Moreover, we consider *leader status*, which is a binary variable distinguishing unit leaders (1) from unit members (0). We additionally account for supervisor-subordinate relations at the dyadic level by creating two dyadic network attributes capturing whether, first, an employee is *subordinate of* or, second, is *supervisor of* another employee. Finally, we consider *tenure* in the organization measured in years; employees average tenure is 10 years (SD = 8.1). The next section explains how these attributes are included into our statistical models estimated to explain the interplay of individual-level and unit-level networks for NPD.

Exponential Random Graph Modeling

We use the multilevel extension of ERGM (Wang, et al., 2013, Wang, Robins, Pattison and Lazega, 2016) to investigate which patterns of connectivity characterize the observed multilevel network consisting of individual-level and unit-level ties and, based thereon, draw conclusions on the mechanisms that determined knowledge tie formation for NPD. Unlike other multilevel modeling techniques such as hierarchical linear modeling (HLM), multilevel ERGM not only assumes that interdependence between network actors results from nested hierarchical structures; it additionally accounts for interdependencies resulting from network ties connecting individuals and units (Zappa and Lomi, 2015). The aim is to estimate parameters describing the likelihood of observing specific patterns of ties (such as the multilevel patterns illustrated in Figures 2 and 3) that characterize observed multilevel networks. To this end, ERGM assumes a stochastic process in which the presence

of a specific network tie at either level is influenced by different sets of variables. In this study, this entails a) multilevel patterns reflecting variables of theoretical interest, as well as b) single-level attribute-based patterns and b) single-level network endogenous patterns as control variables. We explain them in turn.

Multilevel patterns. To capture tie overlap across levels of the NPD organization, we model *cross-level entrainment* and *cross-level exchange*, capturing overlap of individual-level and unit-level knowledge transfers in the same (entrainment) or in opposite (exchange) directions. Moreover, we include *cross-level entrainment unit-reciprocity* and *cross-level entrainment individual-reciprocity*, capturing overlap of uni-directional knowledge transfer at one level with reciprocated exchange at the other level. We include *cross-level provision assortativity* to capture the interaction between units' and their members' propensity to create knowledge-provision ties and, vice versa, *cross-level acquisition assortativity* to account for the interaction between units' and their members' propensity to acquire knowledge via the creation of network ties at their respective levels. We include two other multilevel patterns as control variables. W*ithin-unit knowledge transfer* and *within-unit reciprocity* account for known tendencies of members nested in the same unit to transfer but not necessarily reciprocally exchange advice (Brennecke and Rank, 2016). All multilevel network patterns are explained in Table 1.

--- Table 1 about here ---

Attribute-based patterns. Attribute-based patterns capture the influence of actor characteristics on the likelihood of observing network ties at a single organizational level. We account for different characteristics of the individual employees and distinguished attribute provision, attribute acquisition, attribute similarity/ dissimilarity, and dyadic attribute entrainment patterns as summarized in Table 2.

--- Table 2 about here ---

We employ *attribute provision* and *attribute acquisition* patterns for leader status and tenure as defined above to capture the influence of the two attributes on individuals' propensity to provide advice and to acquire advice via individual-level network ties. In addition, we include *attribute similarity/dissimilarity* for leader status, tenure, and division membership to account for advice ties being created between individuals who are similar or dissimilar with respect to these attributes. For binary and categorical attributes (i.e., leader status and division), attribute similarity/dissimilarity patterns capture mere similarity, with a positive parameter value indicating that connected actors tend to possess the same characteristic. For continuous attributes (i.e., tenure), they capture dissimilarity: more precisely, the difference in size between values of the attribute. A negative parameter value indicates a small absolute difference, suggesting that individuals are similar. Finally, we include the two dyadic network attributes subordinate of and supervisor of another employee as *dyadic attribute entrainment* patterns. These patterns allow controlling for formal reporting lines at the individual level and capture whether subordinates create informal advice ties with their supervisors and vice versa.

Network endogenous patterns. Network endogenous patterns refer to a single organizational level. They capture tendencies of network ties to self-organize, as tie formation is influenced by actors' own existing network ties as well as by their network partners' ties with others. Ignoring endogenous dependencies can cause spurious results regarding the drivers of network ties (Krackhardt, 1987). We control for the same patterns driving the creation of individual- and unit-level ties and, first, account for tendencies towards *reciprocity*. Moreover, we consider differences in individuals' and units' propensity to provide knowledge to others (*provision spread*), and vice versa, to acquire knowledge (*acquisition spread*). The *brokerage* pattern controls for the correlation between actors' propensity to provide and acquire knowledge. Finally, we include patterns to capture

clustering – specifically, tendencies towards *transitive closure* and *cyclic closure* – and account for *multiple connectivity*, that is, multiple open paths between two actors (Robins, Pattison and Wang, 2009). Table 3 illustrates the endogenous patterns included in our models.

--- Table 3 about here ---

Model estimation. We estimated separate models for the interplay of the individual-level advice network with the unit-level information network (*Information Model*) and with the formal unit-level module transfer network (*Workflow Model*). Employing MPNet software (Wang, Robins, Pattison and Koskinen, 2016), we used Markov-Chain Monte-Carlo maximum-likelihood to estimate parameter values for each pattern included in the models. In line with existing ERGM applications (e.g., Zappa and Robins, 2016), we fixed network density to aid model convergence and fixed the affiliation network to treat the nested structure of individuals belonging to units as exogenously given. Finally, following the assumption that advice transfers are unlikely to exert bottom-up influence on the formally mandated – and hence exogenously determined – transfer of modules between units, we fixed the unit-level network when estimating the Workflow Model.

Results

Table 4 summarizes the descriptive statistics for the individual-level advice network and the two unit-level networks. Table 5 presents the results of the model estimations with the Information Model on the left and the Workflow Model on the right. The estimated parameter values are log odd ratios, providing information on the likelihood of observing a given network pattern versus not observing it. Overall, we find that with two exceptions pertaining to control variables, the results of both models are identical with regards to the direction and significance of parameters. In the following, we first present the results for the multilevel patterns relating to our hypotheses and then summarize the remaining findings.

--- Table 4 about here ---

--- Table 5 about here ---

The parameter estimates for the *cross-level entrainment* and *cross-level exchange* patterns are positive and significant in the Information Model and in the Workflow Model. In support of Hypotheses 1a and 1b, knowledge transfer ties at both levels of the NPD organization tend to be aligned, with knowledge flowing in the same and in opposite directions across levels. As predicted by Hypothesis 1c, this multilevel alignment outweighs the need for reciprocity typically characterizing single-level knowledge transfers. Both, *cross-level entrainment unit-reciprocity* and *cross-level entrainment individual-reciprocity* parameters are negative and significant in the Information and Workflow Models indicating tendencies against reciprocity at the individual and unit level if a knowledge transfer tie is present at the respective other level. Turning to cross-level assortativity, we find negative *cross-level provision* and *cross-level acquisition assortativity* parameters in both models, implying that disassortativity mechanisms shape nested actors' knowledge network centrality. Contrary to our expectations, individuals' propensity to provide work-related advice interacts negatively with their units' propensity to create knowledge-provision ties; similarly, there is a negative interaction between individuals' number of advice-acquisition ties and their unit's propensity to acquire information or modules from other units. Consequently, we reject Hypotheses 2a and 2b.

Regarding the control variables, the positive within-unit knowledge transfer and negative within-unit reciprocity parameters confirm earlier research showing that work-related advice ties are more likely to be created among members of the same unit, but that the norm of reciprocation is more predominant in boundary-spanning exchanges (Brennecke and Rank, 2016, Caimo and Lomi, 2015). Similarly, the attribute-based and network endogenous patterns controlling for mechanisms underlying tie formation at the individual and unit level

per se confirm findings of existing research. With respect to the influence of actor attributes, we find that unit leaders receive less advice than employees without leader status (negative *leader receiver* parameter) and that tenure is positively related to providing advice (positive *tenure provider* parameter). Moreover, as indicated by the positive *leader similarity* and negative *tenure dissimilarity* parameters, employees with similar leader status and tenure are more likely to establish advice ties. Likewise, employees belonging to the same division are more likely to transfer work-related advice (positive *division similarity* parameter). Finally, subordinates tend to create informal advice ties with their supervisors and vice versa (positive *supervisor entrainment* and *supervisee entrainment* parameters).

The network endogenous patterns illustrate that the individual-level advice network is characterized by an overall propensity for *reciprocity*. While the *provision spread* parameter is insignificant, the positive *acquisition spread* parameter indicates that the advice network is centralized around some individuals who form many knowledge acquisition ties, while others form few. The negative *brokerage* parameter further indicates a division of roles: Some individuals provide a lot of advice and a different set of employees acquires a lot of advice. The advice network is also characterized by joint tendencies towards *transitive closure* and against *cyclic closure*, pointing towards hierarchical differences between individuals, in the sense that only one individual in a triad is approached for advice by the other two (Rank, Robins and Pattison, 2010). Finally, there are tendencies against *multiple connectivity* in the advice network, indicating that multiple open paths connecting individuals are uncommon.

Regarding unit-level knowledge transfers, we only control for mechanisms driving the formation of information ties. As explained above, the workflow network is exogenously mandated and module tie formation is, therefore, not modeled. Very similar to the exogenous patterns characterizing the individual-level advice network, the unit-level information

network is characterized by propensities towards *reciprocity* and *transitive closure* but against *cyclic closure* and *multiple connectivity*. The remaining patterns are insignificant.

As advised by Hunter, Goodreau and Handcock (2008), we tested model goodness of fit (GOF) and found that all patterns included in the model are below the threshold criteria recommended by Robins, et al. (2009).

Discussion and Conclusion

Accounting for the inherent multilevel nature of networks for innovation (Leenders and Dolfsma, 2016), this study sheds new light on the origins of intra-organizational boundary spanning and centrality as innovation-critical network characteristics. We identified distinct patterns of multilevel connectivity resulting from the interplay of individual employees' and their units' knowledge transfer networks. First, findings show that employees' boundary-spanning advice transfers overlap with their units' knowledge transfer ties, giving rise to patterns of cross-level entrainment and exchange. This alignment of network ties across levels further leads to a decreasing importance of reciprocity typically found to characterize knowledge transfers at single levels of the organization. Second, the cross-level disassortativity results imply that either individuals create many advice ties, leading to a central network position, or their units maintain many knowledge transfer ties, but not both. These findings do not differ for formal workflows or informal information transfers at the unit level and, hence, seem to be robust and generalizable across different types of knowledge transfers. Interpreting the results on multilevel overlap and assortativity patterns together, we can conclude that nested organizational actors – that is, NPD units and their members – only transfer knowledge simultaneously at both levels if these transfers are directed at other nested actors. In other words, network ties are only aligned across levels if they involve two units and these two units' employees. Outside of such "closed" arrangements, individual- and unit-level knowledge transfers for NPD function as substitutes.

Our research contributes to the NPD and innovation literature by adding a multilevel perspective to knowledge transfers as critical activity in the innovation process. We theoretically and empirically acknowledge the separate – but highly interdependent – agency of employees and units in NPD organizations, which previous research on innovation networks has often neglected or even conflated, for instance by aggregating ties created by individuals to the unit level (e.g., Bercovitz and Feldman, 2011) or drawing on individual-level findings to back-up unit-level arguments (e.g., Lechner, et al., 2010). Explicitly accounting for the multilevel nature of collaborative networks, we were able to uncover cross-level mechanisms of knowledge tie formation that extend the existing understanding of boundary spanning, the functioning of reciprocity, and actors' centrality in innovation networks. Our findings have multiple implications for research on and management of collaborative NPD.

Theoretical Implications

Our results on the distinct multilevel patterns of boundary-spanning tie overlap that characterize knowledge transfers for NPD shed light on a tension organizational actors face in the innovation process. Following research on the alignment of formal task interdependencies with informal communication on the one hand, and research on network multiplexity[2] on the other, the cross-level entrainment pattern we uncover indicates consistency, complementarity, and relationship strength (e.g., Soda and Zaheer, 2012, Sosa, et al., 2015), typically assumed beneficial for performance (Shah, Parker and Waldstrøm, 2017, Sosa, et al., 2015). However, building on boundary-spanning research, overlap of knowledge ties across levels also implies redundancy, argued to be detrimental for innovation (e.g., Burt, 2004, Soda and Zaheer, 2012); employees do not have access to truly novel

[2] Network multiplexity describes the co-existence of multiple types of network ties between two actors at the same level (Kilduff and Brass, 2010).

insights if they replicate a unit-level tie at the individual level and vice versa. In addition, cross-level entrainment indicates a form of hierarchy in knowledge networks that, as we show, permeates the levels of the NPD organization: if a unit functions as resource provider for another unit, its employees are likely to mirror this function at the individual level.

Going beyond entrainment, we demonstrate that more complex cross-level mechanisms shape boundary-spanning knowledge transfers in collaborative NPD. Cross-level exchange of individual-level advice for unit-level information and modules indicates that actors at nested levels of action are able to overcome hierarchy in knowledge transfer for the sake of innovating. In particular, cross-level exchange can be interpreted as an elaborate feedback loop that spans different levels of the NPD organization: to improve module specificities or cross-boundary coordination and collaboration, individuals seek advice from colleagues who receive and process their unit's knowledge.

Finally, we find that overlap of individual advice transfers with formal and informal unit-level knowledge transfers serves to overcome the quid-pro-quo mentality that is known to characterize particularly boundary-spanning advice tie formation (Brennecke and Rank, 2016, Caimo and Lomi, 2015). If a higher level tie is present, individuals are willing to provide advice to members of the tied-to unit without an immediate expectation of reciprocity, suggesting that knowledge is shared and disseminated more freely. A similar principle applies to reciprocated exchange of information at the unit level, which is compensated for by the existence of work-related advice ties between individual unit members. Implying a form of multilevel reciprocity the cross-level exchange pattern adds an interesting dimension to this: instead of occurring within levels, reciprocation for knowledge provided at one level seems to occur at the other level of the NPD organization.

Overall, our findings on multilevel overlap of knowledge transfers for NPD first highlight that boundary-spanning tie formation might be less driven by individual agency

than previously assumed (e.g., Allen, et al., 2007, Cross and Parker, 2004). In line with studies showing that boundary-spanning network ties are difficult to create and maintain (Burt, 2002, Krackhardt, 1999), we provide evidence that employees hardly form advice ties with members of other NPD units independent of higher-level structures. Instead, cross-boundary interactions are sustained – or constrained – by formal and informal knowledge flows at the unit level. Similarly, individual-level advice ties seem to function as enablers for informal information transfers at the unit level. Second, our findings demonstrate that multilevel overlap gives rise to a so far overlooked cross-level form of reciprocity, which replaces the norm for reciprocation that characterizes single-level knowledge networks for NPD. By applying a multilevel perspective to knowledge transfers, we are, hence, able to extend understanding of the functioning of boundary spanning and reciprocity as fundamental characteristics of collaborative networks for innovation (e.g., Burt, 2004, Lai, et al., 2016, Leenders and Dolfsma, 2016).

Just like the findings on multilevel overlap refine knowledge on boundary spanning and reciprocity, our results on multilevel disassortativity provide more nuanced insights on the origins of actors' centrality in innovation networks. Employees' position in the work-related advice network – both, their centrality as providers of advice for others and acquiring advice from others – interacts with their units' position in higher-level networks. Against our initial expectations, this cross-level interaction is negative, indicating substitution of knowledge provision and acquisition ties across organizational levels. If a unit creates many knowledge-provision ties with other units, its members are less sought-after for informal advice provision, and, vice versa, if a unit provides little knowledge, its members compensate by providing more advice. Similarly, if their unit benefits from high levels of knowledge acquired from other units, individual unit members seem to need fewer advice-acquisition ties. The other way around, they compensate for lacking network ties at the unit level by

acquiring a lot of work-related advice informally. This way, they might also try to pave the way for the future institutionalization of knowledge-acquisition ties at the unit level (Hansen, 1999) and thereby foster patterns of multilevel overlap. The uncovered patterns of substitution could also indicate that it is difficult for nested actors to maintain knowledge transfer ties at both organizational levels of action simultaneously. That is, unit members are either able to establish interpersonal advice ties to their colleagues or execute their unit's formal workflows or informal information transfers, but not both.

Given that past research has repeatedly associated individuals' and units' network centrality with innovative performance (e.g., Hansen, 1999, Tsai, 2001) showing that it not only depends on actor attributes, such as status, specialist knowledge, or other resource endowments, but critically hinges on higher- and lower-level networks seems particularly insightful for understanding how knowledge is disseminated and used for NPD. Neglecting to account for higher and lower level influences can lead to cross-level fallacies, that is, spurious conclusions on the drivers of knowledge transfers caused by ignoring the context in which individual behavior is embedded or not considering the role of individual behavior for higher-level outcomes (Rousseau, 1985).

Managerial Implications

From a practical point of view, our findings on the cross-level mechanisms that determine the formation of individual- and unit-level knowledge transfer ties offer insights for managers trying to nurture specific network patterns for innovation. The findings on tie overlap across levels raise the question in how far boundary-spanning advice ties can enable access to heterogeneous and novel input if they are aligned with and, therefore, potentially constrained by higher-level structures. Indeed, prior research on the interplay of formal and informal structures at the individual level has shown that some inconsistency instead of alignment is beneficial for accessing heterogeneous resources and fostering innovative

performance (Soda and Zaheer, 2012). Similarly, the impact of individual-level advice ties connecting members of two units on the creation of informal information ties between their units suggests that informal unit-level knowledge transfers are at least partly based on social rather than functional, work-related considerations. In order to foster desired patterns of connectivity, managers first need to be aware of these influences on knowledge tie formation and then find means to mitigate them.

While the above addresses potential downsides of tie overlap, our findings on cross-level entrainment reciprocity and cross-level exchange suggest there are upsides as well: cross-level instead of single-level reciprocity shapes knowledge transfers in aligned arrangements. Thus, knowledge seems to be shared more freely without immediate quid-pro-quo expectations. Moreover, feedback loops exist that span levels of the organization. This complex system of knowledge transfers seems highly functional for collaborative NPD and managers might want to maintain and strengthen it. Finally, understanding that outside of closed arrangements units' and their members' knowledge ties function as substitutes provides a novel take on the problem of network overload (cf. Mariotti and Delbridge, 2012) that organizational actors increasingly face and managers are supposed to address. For instance, creating awareness that knowledge transfers at different organizational levels can and do substitute for each other may alleviate pressure from employees in innovation-intensive settings, who are spurred by lay theories of networking (Kuwabara, Hildebrand and Zou, 2016) and the popular management literature to network extensively. At the same time, managers need to understand that employees may not have the capacity to execute a high number of knowledge transfers at multiple organizational levels simultaneously.

Limitations and Future Research

There are several limitations to our study pointing towards opportunities for future research. The first limitation stems from our cross-sectional research design. The multilevel

patterns uncovered based on our ERGM analyses can best be interpreted as traces left by causal mechanisms generating the observed multilevel network (Zappa and Lomi, 2015). Yet, we do not observe the temporal sequencing of tie formation. Regarding the interplay of informal network ties across levels, we follow Berends, et al. (2011) and assume that top-down and bottom-up mechanisms both determined the observed multilevel structure. However, this does not yet imply that they function similarly or synchronously. Top-down influences exerted by institutionalized information ties might be stronger or follow a different sequencing than bottom-up influences of informal advice networks. Accordingly, future studies might attempt to uncover how networks at multiple levels evolve over time and mutually shape each other. Second, our conceptualization of knowledge transfer ties at different organizational levels does not account for different types or characteristics of knowledge, such as richness or quality (Durmuşoğlu, 2013); neither do we take into account the strength of network ties, which has been shown to influence the process and the outcomes of knowledge transfers for innovation alike (e.g., Hansen, 1999, Reagans and McEvily, 2003). Instead, following a long tradition in organizational network research, this study sheds light on novel network structures first, thereby providing the basis for future investigations adding a content dimension. Finally, extrapolating from previous research on the network-performance relationship (e.g., Brennecke and Stoemmer, 2018, Burt, 2004, Soda and Zaheer, 2012), we briefly discussed the potential functionality of the uncovered patterns of connectivity for collaborative NPD. Future research is needed to explicitly link the distinct multilevel patterns to innovative performance at the level of the individual, the NPD unit, and the organization as a whole. For instance, studies should test whether tie overlap across levels leads to redundant knowledge or, instead, benefits performance and at which levels.

References

Aalbers, R., Dolfsma, W. and Leenders, R. (2016). Vertical and Horizontal Cross-Ties: Benefits of Cross-Hierarchy and Cross-Unit Ties for Innovative Projects. *Journal of Product Innovation Management* 33(2), 141-153.

Ahuja, G., Soda, G. and Zaheer, A. (2012). The Genesis and Dynamics of Organizational Networks. *Organization Science* 23(2), 434–448.

Allen, J., James, A.D. and Gamlen, P. (2007). Formal versus informal knowledge networks in R&D: a case study using social network analysis. *R&D Management* 37(3), 179–196.

Allen, T.J. (1977). *Managing the Flow of Technology*. Cambridge: MIT Press.

Ancona, D.G. and Caldwell, D.F. (1992). Bridging the Boundary: External Activity and Performance in Organizational Teams. *Administrative Science Quarterly* 37(4), 634–665.

Baer, M., Evans, K., Oldham, G.R. and Boasso, A. (2015). The social network side of individual innovation: A meta-analysis and path-analytic integration. *Organizational Psychology Review* 5(3), 191-223.

Baldwin, C.Y. and Clark, K.B. (2000). *Design rules: The power of modularity*: MIT press.

Bercovitz, J. and Feldman, M. (2011). The mechanisms of collaboration in inventive teams: Composition, social networks, and geography. *Research Policy* 40(1), 81–93.

Berends, H., van Burg, E. and van Raaij, E.M. (2011). Contacts and Contracts: Cross-Level Network Dynamics in the Development of an Aircraft Material. *Organization Science* 22(4), 940–960.

Boschma, R. (2005). Proximity and Innovation: A Critical Assessment. *Regional Studies* 39(1), 61-74.

Brennecke, J. and Rank, O.N. (2016). The interplay between formal project memberships and informal advice seeking in knowledge-intensive firms: A multilevel network approach. *Social Networks* 44, 307-318.

Brennecke, J. and Rank, O.N. (2017). The firm's knowledge network and the transfer of advice among corporate inventors—A multilevel network study. *Research Policy* 46(4), 768–783.

Brennecke, J. and Stoemmer, N. (2018). The Network-Performance Relationship in Knowledge-Intensive Contexts—A Meta-Analysis and Cross-Level Comparison. *Human Resource Management* 57(1), 11-36.

Bstieler, L. (2006). Trust Formation in Collaborative New Product Development. *Journal of Product Innovation Management* 23(1), 56-72.

Burt, R.S. (1992). *Structural holes: The social structure of competition*. Cambridge: Harvard University Press.

Burt, R.S. (2002). Bridge decay. *Social Networks* 24(4), 333-363.

Burt, R.S. (2004). Structural Holes and Good Ideas. *American Journal of Sociology* 110(2), 349–399.

Cabrera, E.F. and Cabrera, A. (2005). Fostering knowledge sharing through people management practices. *The International Journal of Human Resource Management* 16(5), 720-735.

Caimo, A. and Lomi, A. (2015). Knowledge Sharing in Organizations: A Bayesian Analysis of the Role of Reciprocity and Formal Structure. *Journal of Management* 41(2), 665-691.

Coleman, J.S. (1988). Social capital in the creation of human capital. *American Journal of Sociology* 94, 95–120.

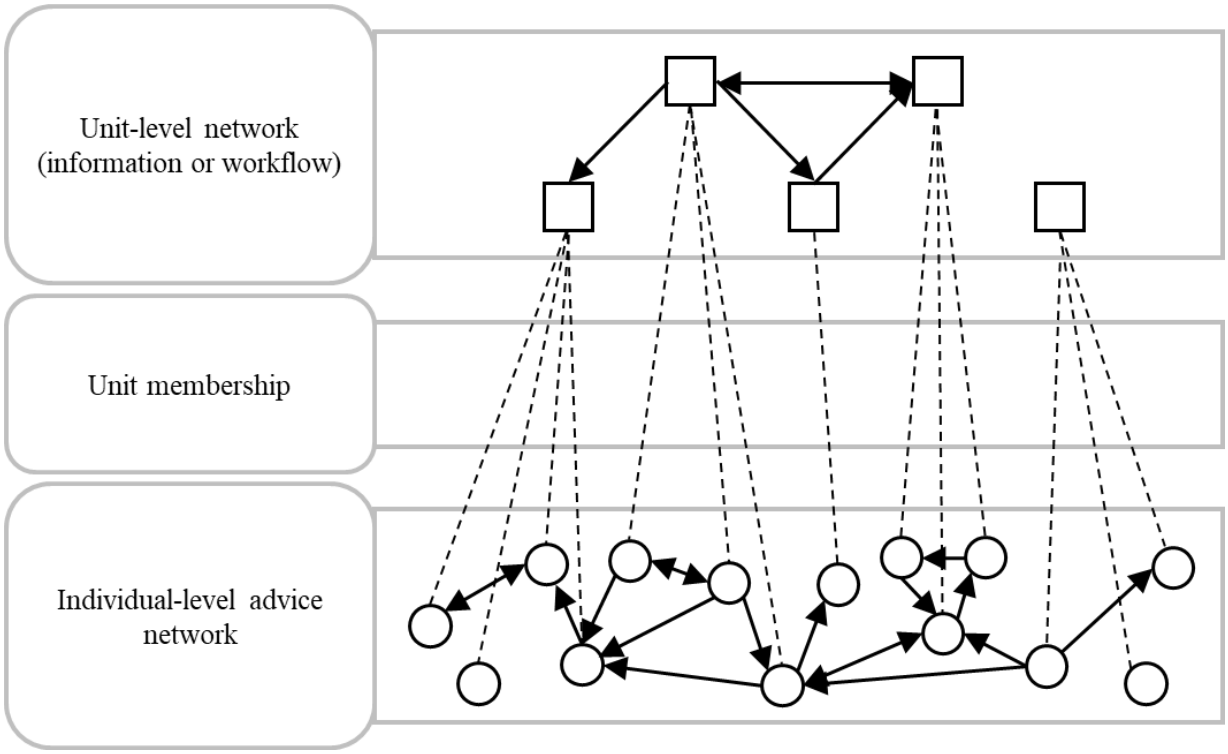
Cross, R.L. and Parker, A. (2004). *The hidden power of social networks: Understanding how work really gets done in organizations*: Harvard Business Press.

DiMaggio, P.J. and Powell, W.W. (1983). The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. *American Sociological Review* 48(2), 147–160.
Durmuşoğlu, S.S. (2013). Merits of Task Advice during New Product Development: Network Centrality Antecedents and New Product Outcomes of Knowledge Richness and Knowledge Quality. *Journal of Product Innovation Management* 30(3), 487-499.
Eisenhardt, K.M. and Schoonhoven, C.B. (1996). Resource-Based View of Strategic Alliance Formation: Strategic and Social Effects in Entrepreneurial Firms. *Organization Science* 7(2), 136–150.
Gargiulo, M. and Benassi, M. (2000). Trapped in Your Own Net? Network Cohesion, Structural Holes, and the Adaptation of Social Capital. *Organization Science* 11(2), 183–196.
Gargiulo, M. and Sosa, M.E. (2016). Common Third Parties and Coordination Disruptions in New Product Development Organizations. *Journal of Product Innovation Management* 33(2), 132-140.
Gouldner, A.W. (1960). The Norm of Reciprocity: A Preliminary Statement. *American Sociological Review* 25(2), 161–178.
Hansen, M.T. (1999). The Search-Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organization Subunits. *Administrative Science Quarterly* 44(1), 82–111.
Hansen, M.T. (2002). Knowledge Networks: Explaining Effective Knowledge Sharing in Multiunit Companies. *Organization Science* 13(3), 232–248.
Hunter, D.R., Goodreau, S.M. and Handcock, M.S. (2008). Goodness of Fit of Social Network Models. *Journal of the American Statistical Association* 103(481), 248-258.
Ibarra, H. (1993). Network Centrality, Power, and Innovation Involvement: Determinants of Technical and Administrative Roles. *Academy of Management Journal* 36(3), 471–501.
Kleinbaum, A.M., Stuart, T.E. and Tushman, M.L. (2013). Discretion Within Constraint: Homophily and Structure in a Formal Organization. *Organization Science* 24(5), 1316–1336.
Kleinbaum, A.M. and Tushman, M.L. (2007). Building bridges: the social structure of interdependent innovation. *Strategic Entrepreneurship Journal* 1(1-2), 103–122.
Kozlowski, S.W.J. and Klein, K.J. (2000). A multilevel approach to theory and research in organizations: Contextual, temporal, and emergent processes. In: *Multilevel theory, research, and methods in organizations*. Katherine J. Klein and Steve W. J. Kozlowski (eds.). San Francisco: Jossey-Bass, pp. 3–90.
Krackhardt, D. (1987). QAP partialling as a test of spuriousness. *Social Networks* 9(2), 171-186.
Krackhardt, D. (1999). The ties that torture: Simmelian tie analysis in organizations. *Research in the Sociology of Organizations* 16(1), 183-210.
Kratzer, J., Gemuenden, H.G. and Lettl, C. (2008). Balancing creativity and time efficiency in multi-team R&D projects: the alignment of formal and informal networks. *R&D Management* 38(5), 538–549.
Kratzer, J., Leenders, R.T.A.J. and van Engelen, J.M.L. (2010). The social network among engineering design teams and their creativity: A case study among teams in two product development programs. *International Journal of Project Management* 28(5), 428–436.
Kuwabara, K., Hildebrand, C. and Zou, X. (2016). Implicit Theories of Networking: Effects of Lay Beliefs on Attitudes and Engagement toward Instrumental Networking. *Academy of Management Review*.
Lai, J., Lui, S.S. and Tsang, E.W.K. (2016). Intrafirm Knowledge Transfer and Employee Innovative Behavior: The Role of Total and Balanced Knowledge Flows. *Journal of Product Innovation Management* 33(1), 90-103.

Lazega, E., Jourda, M.-T., Mounier, L. and Stofer, R. (2008). Catching up with big fish in the big pond? Multi-level network analysis through linked design. *Social Networks* 30(2), 159–176.
Lechner, C., Frankenberger, K. and Floyd, S.W. (2010). Task contingencies in the curvilinear relationships between intergroup networks and initiative performance. *Academy of Management Journal* 53(4), 865-889.
Leenders, R.T.A.J. and Dolfsma, W.A. (2016). Social Networks for Innovation and New Product Development. *Journal of Product Innovation Management* 33(2), 123-131.
Lomi, A., Lusher, D., Pattison, P.E. and Robins, G.L. (2014). The Focused Organization of Advice Relations: A Study in Boundary Crossing. *Organization Science* 25(2), 438–457.
Lomi, A. and Zappa, P. (2015). Knowledge Transfer in Multilevel Networks: Contingent Effect of Organizational and Social Structure. *Academy of Management Proceedings* 2015(1).
Madhavan, R. and Grover, R. (1998). From embedded knowledge to embodied knowledge: new product development as knowledge management. *Journal of Marketing* 62(4), 1-12.
March, J.G. and Simon, H.A. (1958). *Organizations*. New York: John Wiley & Sons.
Mariotti, F. and Delbridge, R. (2012). Overcoming Network Overload and Redundancy in Interorganizational Networks: The Roles of Potential and Latent Ties. *Organization Science* 23(2), 511-528.
McEvily, B., Soda, G. and Tortoriello, M. (2014). More Formally: Rediscovering the Missing Link between Formal Organization and Informal Social Structure. *Academy of Management Annals* 8(1), 299–345.
Nebus, J. (2006). Building Collegial Information Networks: A Theory of Advice Network Generation. *Academy of Management Review* 31(3), 615–637.
Oh, H., Chung, M.-H. and Labianca, G. (2004). Group Social Capital and Group Effectiveness: The Role of Informal Socializing Ties. *Academy of Management Journal* 47(6), 860–875.
Perry-Smith, J.E. (2006). Social yet creative: The role of social relationships in facilitating individual creativity. *Academy of Management Journal* 49(1), 85–101.
Phelps, C., Heidl, R. and Wadhwa, A. (2012). Knowledge, Networks, and Knowledge Networks: A Review and Research Agenda. *Journal of Management* 38(4), 1115–1166.
Podolny, J.M. (2001). Networks as the Pipes and Prisms of the Market. *American Journal of Sociology* 107(1), 33–60.
Rank, O.N., Robins, G.L. and Pattison, P.E. (2010). Structural logic of intraorganizational networks. *Organization Science* 21(3), 745–764.
Reagans, R. and McEvily, B. (2003). Network Structure and Knowledge Transfer: The Effects of Cohesion and Range. *Administrative Science Quarterly* 48(2), 240–267.
Reagans, R., Zuckerman, E. and McEvily, B. (2004). How to Make the Team: Social Networks vs. Demography as Criteria for Designing Effective Teams. *Administrative Science Quarterly* 49(1), 101–133.
Ren, Y. and Argote, L. (2011). Transactive memory systems 1985–2010: An integrative framework of key dimensions, antecedents, and consequences. *Academy of Management Annals* 5(1), 189-229.
Robins, G.L., Pattison, P.E. and Wang, P. (2009). Closure, connectivity and degree distributions: Exponential random graph (p*) models for directed social networks. *Social Networks* 31(2), 105–117.
Rousseau, D.M. (1985). Issues of level in organizational research: Multi-level and cross-level perspectives. *Research in Organizational Behavior* 7, 1–37.
Shah, N.P., Cross, R. and Levin, D.Z. (2015). Performance Benefits From Providing Assistance in Networks: Relationships That Generate Learning. *Journal of Management*.

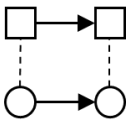
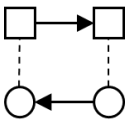
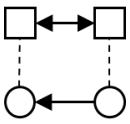
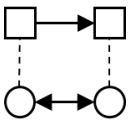
Shah, N.P., Parker, A. and Waldstrøm, C. (2017). Examining the Overlap: Individual Performance Benefits of Multiplex Relationships. *Management Communication Quarterly* 31(1), 5-38.
Simon, H.A. (1996). *The sciences of the artificial*. Cambridge, MA: MIT Press.
Sivasubramaniam, N., Liebowitz, S.J. and Lackman, C.L. (2012). Determinants of New Product Development Team Performance: A Meta-analytic Review. *Journal of Product Innovation Management* 29(5), 803-820.
Soda, G. and Zaheer, A. (2012). A network perspective on organizational architecture: performance effects of the interplay of formal and informal organization. *Strategic Management Journal* 33(6), 751–771.
Sosa, M., Gargiulo, M. and Rowles, C. (2015). Can Informal Communication Networks Disrupt Coordination in New Product Development Projects? *Organization Science* 26(4), 1059–1078.
Spence, A.M. (1974). *Market signaling*. Cambridge; Mass: Harvard University Press.
Tortoriello, M. (2015). The social underpinnings of absorptive capacity: The moderating effects of structural holes on innovation generation based on external knowledge. *Strategic Management Journal* 36(4), 586–597.
Tortoriello, M. and Krackhardt, D. (2010). Activating cross-boundary knowledge: The role of Simmelian ties in the generation of innovations. *Academy of Management Journal* 53(1), 167–181.
Tortoriello, M., Reagans, R. and McEvily, B. (2012). Bridging the Knowledge Gap: The Influence of Strong Ties, Network Cohesion, and Network Range on the Transfer of Knowledge Between Organizational Units. *Organization Science* 23(4), 1024–1039.
Tsai, W. (2000). Social Capital, Strategic Relatedness and the Formation of Intraorganizational Linkages. *Strategic Management Journal* 21(9), 925–939.
Tsai, W. (2001). Knowledge transfer in intraorganizational networks: Effects of network position and absorptive capacity on business unit innovation and performance. *Academy of Management Journal* 44(5), 996–1004.
Tsai, W. and Ghoshal, S. (1998). Social capital and value creation: The role of intrafirm networks. *Academy of Management Journal* 41(4), 464–476.
Uzzi, B. (1997). Social Structure and Competition in Interfirm Networks: The Paradox of Embeddedness. *Administrative Science Quarterly* 42(1), 35–67.
Wang, P., Robins, G., Pattison, P. and Koskinen, J. (2016). MPNet: A program for the simulation and estimation of exponential random graph models: Swinburne University of Technology.
Wang, P., Robins, G.L., Pattison, P. and Lazega, E. (2013). Exponential random graph models for multilevel networks. *Social Networks* 35(1), 96–115.
Wang, P., Robins, G.L., Pattison, P.E. and Lazega, E. (2016). Social selection models for multilevel networks. *Social Networks* 44, 346-362.
Zappa, P. and Lomi, A. (2015). The Analysis of Multilevel Networks in Organizations: Models and Empirical Tests. *Organizational Research Methods* 18(3), 542-569.
Zappa, P. and Robins, G. (2016). Organizational learning across multi-level networks. *Social Networks* 44, 295-306.
Zucker, L.G. (1977). The role of institutionalization in cultural persistence. *American Sociological Review* 42(5), 726-743.

Figure 1. Stylized illustration of a multilevel network



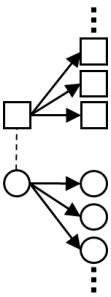
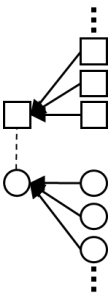
Notes. □ = unit; ○ = individual; → = knowledge provision; ----- = unit membership

Figure 2. Multilevel overlap patterns capturing boundary spanning

a) Cross-level entrainment (H1a)	b) Cross-level exchange (H1b)	c) Cross-level entrainment reciprocity (H1c)	
			

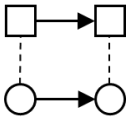
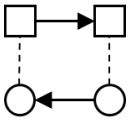
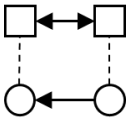
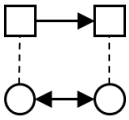
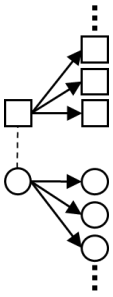
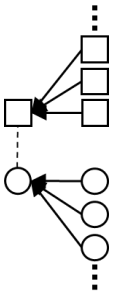
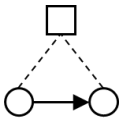
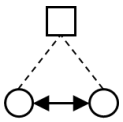
Notes. □ = unit; ○ = individual; → = knowledge provision; ----- = unit membership

Figure 3. Multilevel assortativity patterns capturing centrality

a) Cross-level provision assortativity (H2a)	b) Cross-level acquisition assortativity (H2b)
	

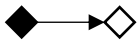
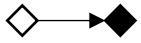
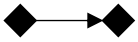
Notes. □ = unit; ○ = individual; → = knowledge provision; ----- = unit membership

Table 1. Multilevel patterns included in the models

Mechanism	Pattern	Interpretation
Cross-level entrainment (H1a)		Propensity for individual-level advice to be transferred in the same direction as unit-level modules or information
Cross-level exchange (H1b)		Propensity for individual-level advice to be transferred in the opposite direction as unit-level modules or information
Cross-level entrainment unit-reciprocity (H1c)		Propensity for uni-directional advice transfer to overlap with reciprocated transfer of unit-level modules or information
Cross-level entrainment individual-reciprocity (H1c)		Propensity for reciprocated transfer of individual-level advice to overlap with uni-directional transfer of modules or information at the unit level
Cross-level provision assortativity (H2a)		Interaction between individuals creating advice-provision ties and their units providing modules/information (positive parameter = assortativity; negative parameter = disassortativity)
Cross-level acquisition assortativity (H2b)		Interaction between individuals acquiring advice via interpersonal network ties and their units acquiring modules/information (positive parameter = assortativity; negative parameter = disassortativity)
Within-unit knowledge transfer		Propensity for members of the same unit to transfer advice
Within-unit reciprocity		Propensity for members of the same unit to reciprocally exchange advice

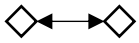
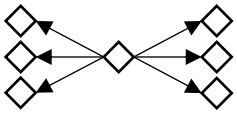
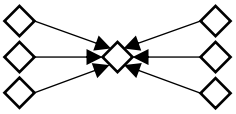
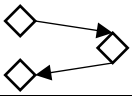
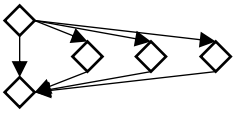
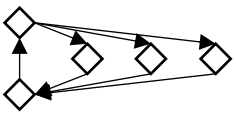
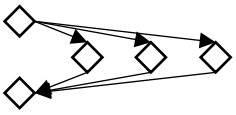
Notes. □ = unit; ◯ = individual; → = knowledge provision; ----- = unit membership

Table 2. Single-level attribute-based patterns included in the models

Mechanism	Pattern	Interpretation
Attribute provision		Propensity for actors with a specific continuous or binary to provide knowledge
Attribute acquisition		Propensity for actors with a specific continuous or binary to acquire knowledge
Attribute similarity/ dissimilarity*		Propensity for network ties to occur between dyads of actors (dis-)similar with respect to a categorical, continuous, or binary attribute
Dyadic attribute entrainment		Propensity for network ties to occur between dyads of actors if a dyadic attribute is present

Notes. ◇ = actor (i.e., individual or unit); ◆ = individual or unit with a binary or categorical attribute or high values on a continuous attribute; ⌒→ = dyadic covariate. * For binary and categorical attributes the variable captures similarity. For continuous attributes, it captures dissimilarity, particularly the difference in size between values of the attribute. A negative parameter value indicates a small difference, suggesting that individuals are similar.

Table 3. Single-level network endogenous patterns included in the models

Mechanism	Pattern	Interpretation
Reciprocity		Propensity towards reciprocation
Provision spread		Propensity for variation in the number of knowledge-provision ties among actors
Acquisition spread		Propensity for variation in the number of knowledge-acquisition ties among actors
Brokerage		Correlation between actors' propensity to provide and to acquire knowledge
Transitive closure		Propensity for triadic closure, indicative of transitivity
Cyclic closure		Propensity for cyclic closure, indicative of a prevailing generalized exchange
Multiple connectivity		Propensity for ties to form as part of formations involving multiple short paths

Notes. ◇ = actor (i.e., individual or unit).

Table 4. Descriptive network statistics

Statistic	Individual-level advice	Unit-level information	Unit-level modules
# of actors	193	38	38
# of ties	1915	295	283
Network density	0.052	0.210	0.201
Reciprocity rate	0.382	0.288	0.225
Mean in-/outdegree	9.922	7.763	7.447
Standard deviation outdegree	5.045	3.545	5.820
Minimum outdegree	1	1	0
Maximum outdegree	29	17	25
Standard deviation indegree	5.978	5.920	2.777
Minimum indegree	0	0	3
Maximum indegree	29	24	15

Notes. Actors' indegree captures their number of knowledge acquisition ties, outdegree reflects the number of knowledge provision ties.

Table 5. Multilevel ERG models for the interplay of individual- and unit-level networks

	Information Model	Workflow Model
	Parameter Estimate (SE)	Parameter Estimate (SE)
Multilevel patterns		
Cross-level entrainment (H1a)	0.357** (0.032)	0.401** (0.039)
Cross-level exchange (H1b)	0.239**(0.035)	0.374** (0.041)
Cross-level entrainment unit-reciprocity (H1c)	-0.175** (0.031)	-0.285** (0.044)
Cross-level entrainment individual-reciprocity (H1c)	-0.242** (0.049)	-0.247** (0.060)
Cross-level provision assortativity (H2a)	-0.026* (0.012)	-0.480** (0.095)
Cross-level acquisition assortativity (H2b)	-0.056** (0.013)	-0.502** (0.127)
Within-unit knowledge transfer	2.683** (0.189)	2.754** (0.201)
Within-unit reciprocity	-2.618** (0.286)	-2.400** (0.307)
Single-level attribute-based patterns		
Leader status provision	-0.072 (0.071)	-0.077 (0.074)
Leader status acquisition	-0.220** (0.077)	-0.209** (0.073)
Leader status similarity	1.085** (0.109)	1.308** (0.117)
Tenure provision	0.010** (0.003)	0.008** (0.003)
Tenure acquisition	0.002 (0.002)	0.001 (0.003)
Tenure dissimilarity	-0.015** (0.003)	-0.012** (0.004)
Division membership similarity	0.085** (0.020)	0.190** (0.035)
Dyadic subordinate of entrainment	3.193** (0.518)	3.131** (0.508)
Dyadic supervisor of entrainment	0.946** (0.278)	0.980** (0.285)
Single-level network endogenous patterns		
Individual-level reciprocity	3.089** (0.198)	2.915** (0.218)
Individual-level provision spread	-0.058 (0.292)	0.252 (0.327)
Individual-level acquisition spread	0.233 (0.145)	0.753** (0.190)
Individual-level brokerage	-0.022** (0.004)	-0.004 (0.005)
Individual-level transitive closure	1.406** (0.057)	1.341** (0.056)
Individual-level cyclic closure	-0.295** (0.030)	-0.323** (0.031)
Individual-level multiple connectivity	-0.068** (0.006)	-0.074** (0.007)
Unit-level reciprocity	1.334** (0.324)	fixed
Unit-level provision spread	-0.743 (0.664)	fixed
Unit-level acquisition spread	0.174 (0.300)	fixed
Unit-level brokerage	0.026 (0.018)	fixed
Unit-level transitive closure	0.962** (0.150)	fixed
Unit-level cyclic closure	-0.272** (0.076)	fixed
Unit-level multiple connectivity	-0.070* (0.03)	fixed

Notes. N = 193 individuals; M = 38 units; density fixed; unstandardized estimates; two-tailed significance tests are reported; *p < .05; **p < .01