

ORIGINAL ARTICLE

The Coevolution of Multiplex Communication Networks in Organizational Communities

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This research examines the evolutionary patterns and determinants of multiplex organizational communication networks. Based on the data between 1997 and 2005 collected from the records of development projects in the field of Information and Communication Technology for Development, the study demonstrates that dynamics in one network are significant drivers of tie formation in the other network at both dyadic and triadic levels. In particular, results show that the effects of common third-party ties and structural embeddedness exist across multiplex networks. Further, the study suggests that resource similarity of organizational dyads, resource width, and organizational centrality have positive effects on the propensity for multiplex ties. These results have implications for organizations' communication networking strategies in a wide variety of organizational communities.

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The application of evolutionary theories to the study of organizations has significantly contributed to understanding the longitudinal dynamics of organizational change (Aldrich & Reuf, 2006; Baum & McKelvey, 1999). Evolutionary theories, interchangeably referred to as ecological theories, are well suited for explaining the communication processes that are an integral part of the founding, transformation, and failure of organizational communities (Monge, Heiss, & Margolin, 2008). In particular, evolutionary theories emphasize the relational aspects of organizational populations. This has naturally led to increasing scholarly interest in the intersection between ecological theories of organizational communities and theories of organizational networks (DiMaggio, 1994; Monge & Contractor, 2003; Powell, 1990).

Typically, studies of organizational communication networks have explored uniplex networks, those built on a single relation that creates a single network, rather than multiplex networks, those involving multiple relations that create multiple

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networks. Yet, tie multiplexity is a fundamental aspect of social relations because multiple types of network ties are frequently interdependent, and ties in one network have been shown to influence the formation or dissolution of ties in other networks (e.g., Gould, 1991; Robins & Pattison, 2006).

The idea of multiplex networks has been examined in various contexts, often in terms of communication and social ties within organizations. For example, Hartman and Johnson (1989) suggested that employees' involvement in multiplex communication networks was significantly related with organizational commitment. Lazega and Pattison (1999) found evidence for interlocking patterns among collaboration, advice, and friendship ties among members of a corporate law firm. Cross, Borgatti, and Parker (2001) examined five different dimensions in advice relationships—solutions, metaknowledge, problem reformulation, validation, and legitimation—and found that these relations formed an overlapping unidimensional scale.

In the studies of interorganizational networks, scholars have increasingly emphasized the notion of multiplexity (Galaskiewicz & Bielefeld, 1998; Granovetter, 1985; Uzzi, 1997), in which organizations are tied together by various types of resource exchange. Powell, White, Koput, and Owen-Smith's (2005) study of the biotechnology industry examined four types of linkages: basic research, finance, licensing intellectual property, and sales and marketing ties. They demonstrated that multiconnectivity was a fundamental driver of network evolution. Padgett and McLean (2006) found that in the Renaissance Florence, cross-network processes between economic, kinship, and political relations were fundamental to the invention of the partnership system. Yet, there has been relatively little work that has empirically examined the local structural patterns of multiplex relations and the social processes behind them. A few exceptions include a study by Beckman, Haunschild, and Phillips (2004), which distinguished between interlocking directorates and strategic alliances and found that multiplex relations were more likely to happen when there was a higher level of market uncertainty. In addition, Lomi and Pattison (2006) demonstrated the tendency for supply, technology transfer, and equity networks to co-occur in the transportation manufacturing industry.

The current study follows this stream of research and demonstrates that studying multiplex ties is useful for understanding communication patterns and processes across organizations. Specifically, the study focuses on the determinants behind the formation of multiplex ties. Both endogenous (focal network properties) and exogenous (environmental and nodal attributes) determinants are modeled as forces which affect multiplex tie formation. These underlying social processes at the local level are also important in explaining the creation of the global level network structure (Robins, Pattison, & Woolcock, 2005).

The information and communication technology for development community

The research setting of the current study is the international Information and Communication Technology (ICT) for development community, with particular

focus on the initiatives to use ICTs for development goals. The potential of ICTs as a tool for empowering less developed countries has emerged as a vital issue. Since the mid 1990s, major intergovernmental organizations (IGOs) have launched a series of initiatives that aim at enhancing the benefits of ICTs (Wilson, 2004). These issues have also led to the expansion of partnerships across multiple sectors (UNESCO, 2006; UN-ICT Task Force, 2003).

A diverse array of organizational populations has coexisted in the ICT for development community. Interorganizational networks have become imperative because ICT for development initiatives are being built on a collection of financial, administrative, and technical resources (Lusthaus & Milton-Feasby, 2006; Wilson, 2004). Consequently, understanding the structure and evolution of complex, multiplex networks has become crucial. Major types of relationship building in the global society include information exchange, project collaboration, participation in meetings, and membership in advocacy coalitions (Katz & Anheier, 2005). In the ICT for development field, network relations that have emerged from these core activities can be classified into two types: project implementation and knowledge-sharing.

A common problem in the ICT for Development organizational communities has been the discrepancy between project implementation and knowledge-sharing (GKP, 2003). These two types of networks entail different aspects of organizational communication and collaboration. Specifically, implementation networks are created from partnerships in development projects, which are activity-focused and project-based to draw on resources such as funding, technology, and infrastructure (Unwin, 2005). At the same time, the community shares a goal of creating knowledge by learning from ICT experiments (Wilson & Best, 2003). The goal of this network is research, documentation, and dissemination of lessons, often through forums and publication activities (Katz & Anheier, 2005; Madon, 2000). These two networks are likely to be governed by different tie formation patterns, and more interestingly, by conditions that lead to the co-occurrence of these two networks. In the following sections, ecological theory and social networks are used to develop hypotheses about tie formation in multiple networks.

Evolutionary processes and multiplex networks

Early sociocultural evolutionary theories focused on the evolution of organizational populations (Carroll & Hannan, 2000; DiMaggio & Powell, 1983; Hannan & Freeman, 1977, 1984). The community ecology perspective expanded this focus on populations to cover the broader context of organizational communities (Aldrich & Reuf, 2006; Astley & Fombrun, 1987; Baum & McKelvey, 1999; DiMaggio, 1994; Hawley, 1986; Hunt & Aldrich, 1998). Organizational communities can be considered as diverse sets of interacting populations that form functional interdependencies with each other in shared environmental spaces. Wellman (1988) has emphasized that networks of community ties are the founding blocks of the society. For example, communities of people such as relatives, friends, and neighbors are tied by communication, social

support, and resource exchange relationships (Wellman & Wellman, 1992; Wellman & Wortley, 1990). From a structural standpoint (e.g., Newman, 2003), communities are defined based on cohesion, in which there is a high density of ties among members.

Several studies have empirically bridged the fields of community ecology and organizational networks. Owen-Smith and Powell (2004) found that as ties embedded in a dense regional web increased, the accessibility of information transmitted through formal linkages also increased. Audia, Freeman, and Reynolds (2006) found that symbiotic and commensalistic interorganizational networks contribute to information transfer and organizational founding. Further, Shumate, Fulk, and Monge (2005) examined communication network evolution in the international HIV/AIDS community and showed that past ties, geographic proximity, and common ties with IGOs were the predictors of new tie formation. Bryant and Monge (2008) suggested that the changing levels of mutual and competitive networks among organizational populations influenced the evolution of the children's television community.

Community ecology and interorganizational network research share a common emphasis on resources as a central concept. Environmental spaces typically contain limited resources which organizational populations sometimes share and over which they sometimes compete (Aldrich & Reuf, 2006). Therefore, the struggle among populations over survival and growth drives the evolution of the community through processes of variation, selection, and retention (Aldrich & Reuf, 2006; Monge et al., 2008; Monge & Poole, 2008). Further, flows of resources shape both microlevel tie formation and macrolevel emergence of network structure. The dynamics of network structure and evolution are determined by patterns of resource distribution in the larger community. Freeman and Audia (2006) conceptualized communities in two ways: First, spatially, as "places where organizations are located in resource space or in geography" and second, functionally, as "sets of relations between organizational forms" (p. 145; see also Audia et al., 2006). The current study explores how these two aspects of the resource environment affect the likelihood of multiplex tie formation.

Determinants of multiplex tie formation

The multitheoretical, multilevel (MTML) analytic framework (Monge & Contractor, 2003) theorizes that both endogenous and exogenous mechanisms need to be modeled in network structuring processes. Endogenous mechanisms imply that networks are substantially governed by their internal structural logic such as reciprocity and transitivity. Exogenous mechanisms show the influence of external variables on a network, such as other types of networks and nodal attributes. These processes can be viewed from an ecological perspective, in which not only the local structural dynamics of resource relations, but also the surrounding resource environments affect tie formation. In this way, the MTML and ecological frameworks provide a foundation to study the determinants of tie formation.

Endogenous tie structure

Multiplex networks are defined as the set of nodes that link to other nodes on the basis of more than one type of relation (Wasserman & Faust, 1994). The present study examines the dynamics between more than one type of tie, which is one of the endogenous factors behind the tie formation process. The interdependent nature of multiplex networks has been articulated in the theory of embeddedness (Granovetter, 1985), which asserts that economic relations are influenced by social, structural, and personal relations. Particularly, structural embeddedness focuses on the ways in which organizations' structural positions influence opportunities for new social alliances (Gulati, 1999; Gulati & Gargiulo, 1999; Uzzi, 1997). Lomi and Pattison (2006) and Powell et al. (2005) indicated that one reason why the selection procedure could be associated across multiplex networks is the accumulation of organizational learning. Particularly, in fields where sources of expertise are dispersed, organizations are likely to utilize their experiences and learnings from past or current linkages to make decisions about other types of ties.






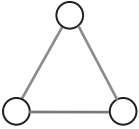
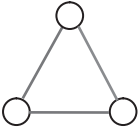
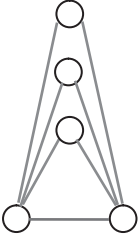


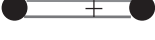
In the context of the current study, multiplex linkages exist when two organizations collaborate for both implementation and knowledge-sharing. If two organizations communicate with each other through knowledge-sharing venues, it is likely that they are aware of each other's capabilities as a potential partner in project implementation. It is expected that the same dynamics will apply in the opposite direction as well. Therefore, the following hypothesis is proposed. The visual pattern of the proposed structure is illustrated in Table 1.

H1: The existence of ties in one network type will increase the likelihood of tie formation among the same pair of organizations in another network type.

The logic of local dependencies (Lomi & Pattison, 2006) suggests that the formation of dyadic interorganizational ties is determined by the local neighborhood. One mechanism that falls into this logic is that of the role of common organizational ties to third parties (Granovetter, 1973; Gulati, 1995). Studies have shown that in the absence of prior direct ties between two firms, the larger the number of common third-party ties, the more likely they are to form new alliances with each other. Past theories suggest that a common partner can be a source of legitimacy and reliability (Gulati & Gargiulo, 1999) and collaborative activities provide information about new opportunities (Powell, Koput, & Smith-Doerr, 1996). Burt (1992) referred to the role of such linkages as brokerage, which bridges two nodes that are unconnected to each other. Stephens, Fulk, and Monge (2009) identify a special form of these go-between networks as "cupid alliances," where a third party brokers a relationship between two other organizations for its own benefit.

The current study follows this line of reasoning and extends it to multiplex ties. In other words, accumulated knowledge and trust about partners will facilitate tie formation across more than one type of network. In the context of the ICT for development community, the likelihood of tie formation between two organizations will increase if they have ties in common with a third organization. Therefore, the

Table 1 Visual Representation of XPNet Parameters (adapted from Wang, Robins, & Pattison, 2008)

Legend			
Network A			
Network B			
Nodes with attribute			
Nodes without attribute			
Graph Statistics			
Hypothesis	Theoretical Mechanism	Parameter	Illustration
Hypothesis 1	Multiplex dyadic ties	<i>EdgeAB</i>	
Hypothesis 2a	Multiplex transitivity (single common third-party ties)	<i>TriangleAAB</i>	
		<i>TriangleABB</i>	
Hypothesis 2b	Embedded multiplex transitivity (multiple common third-party ties)	<i>K-TriangleABA</i>	
Hypothesis 3a	Similarity of resource spaces	<i>Same-category-AB</i>	
Hypothesis 3b	Generalist orientation	<i>RAB</i>	
Hypothesis 4	Organizational centrality	<i>SumAB</i>	

following is hypothesized:

H2a: The existence of a common third-party will increase the likelihood of tie formation across different types of networks.

Further, past research has demonstrated that the logic of embeddedness applies to the dynamics of transitivity described above (Gulati, 1995; Gulati & Gargiulo, 1999).

Multiplex ties are driven by embedded relationships to a greater extent than uniplex ties are (Granovetter, 1985; Uzzi, 1996, 1997). In other words, when two organizations share many organizational partners in common, they have a higher likelihood of forming ties with each other. The current study predicts that this mechanism will extend to multiplex networks. For example, having multiple common third-party ties in the implementation network may be associated with tie existence in the knowledge-sharing network. This mechanism may operate in the opposite way as well: When organizational dyads have a knowledge-sharing link, they are likely to share multiple common partners in the implementation network. This is the logic of embedded transitivity:

H2b: Organizational dyads are likely to share multiple common third-parties across different types of networks.

Exogenous environmental attributes

Community ecologists have posited that resource relationships lead to organizations' dependence on each other (Astley, 1985; Baum & Singh, 1994). A proposition that applies this theory to networks is that organizational relationships in resource environments are likely to influence tie formation. Resource spaces or niches are defined as finite sets of resources available to the members of populations (Hannan, Carroll, & Polos, 2003; Hannan & Freeman, 1977). Organizations in different resource spaces possess complementary and nonredundant sets of skills, thereby showing greater interdependence (Gulati, 1995) and forming symbiotic linkages across different organizational populations (Aldrich & Reuf, 2006). In an alternative perspective developed in a related stream of research, scholars have emphasized that knowledge tends to be shared more easily between organizations in similar resource spaces (Audia et al., 2006; McEvily & Zaheer, 1999).

Although these mechanisms have been tested in uniplex tie settings, few studies have explored multiplex ties. As multiplexity requires sustained relationships, it is expected that being located in similar resource spaces would allow organizations to engage in repeated and less costly interactions. As discussed above, the notion of organizational community can be conceptualized from both functional and spatial perspectives. Therefore, both homophily mechanisms, in which organizations with similar functions form ties, as well as spatial proximity mechanisms, in which organizations closely located to each other form ties, are expected to operate. Thus, commensalistic relations should have a positive influence on multiplex ties.

H3a: Organizational dyads in the same resource space are more likely to have multiplex linkages than two organizations in different resource spaces.

The second hypothesis about external environments considers the width of space from which organizations seek resources. Wasserman and Faust (1994) raised the question of which nodes are likely to be involved in many relations and which in few. Based on the formulation of resource relationships as central drivers of tie formation, it is assumed that the moderating condition lies in the widths of resource spaces

that organizations occupy. The widths of the resource spaces, or the degree to which organizations concentrate on specific resource spaces, lead to the distinction between generalist and specialist organizations (Aldrich, 1979). As generalist organizations seek a relatively wider range of resource spaces than specialist organizations, it is expected that they would be able to leverage their resource base across multiple types of networks. Generalist organizations can be defined along both functional (those that address a wide variety of development problems) and spatial (those that cover a wide geographic area) dimensions (Aldrich & Reuf, 2006; Freeman & Audia, 2006). Therefore, it is proposed that:

H3b: Generalist organizations are more likely to have multiplex linkages than specialist organizations.

Exogenous nodal attributes

The following hypothesis examines whether the structural positions of organizations in a network influence multiplex tie formation. Network positions are associated with perceived influence and prominence (Freeman, 1979) and, therefore, affect alliance formation (Gimeno, 1994; Gulati & Gargiulo, 1999). For example, central organizations are typically more visible to potential partners and also have higher learning capabilities, which enables them to gain organizational prominence (Gulati, 1999). Prior research has examined the association between organizations' structural positions in multiple types of networks as well. For example, Powell et al. (1996) identified a multiplex dynamic in which firms' network centrality increased their number of subsequent exchange relationships by enhancing reputation and visibility. Further, Powell et al. (2005) suggested that as organizations develop various functions, they tend to pursue multiconnectivity, which leads to the attainment of more central positions. In summary, based on the idea that organizations learn to take advantage of different types of alliances, it is expected that nodal-level network positions will influence multiplex tie formation. Thus:

H4: The greater the centrality of two organizations, the greater the likelihood of multiplex ties between those organizations.

Method

Data

The current study is based on the records of interorganizational collaboration activities in the field of ICT for development. The primary data were obtained from the Accessible Information on Development Activities (AiDA) database, an online directory of development aid activities by sectors provided by the Development Gateway Foundation. Two different kinds of projects were selected based on their primary focus.¹ First, implementation projects included those focusing on ICT infrastructure, ICT capacity building, and education. Second, knowledge-sharing projects included conferences, workshops, seminars, and joint publications on the

same topics. A total of 323 projects between 1997 and 2005 were included in the study, 211 of which were implementation projects and 112 knowledge-sharing projects.

Information about the projects and collaborating organizations was coded.² There were a total of 578 unique organizations in the implementation network and 174 in the knowledge-sharing network. Organizations were classified into four types: governmental organizations, IGOs, nongovernmental organizations (NGOs), and for-profit corporations. The geographic location of organizations was coded based on organizational headquarters and categorized into six regions (Africa, Asia, Europe, North America, Latin America and the Caribbean, and Oceania) following data from the UN Statistics Division. Organizations were grouped into one of three categories based on the geographic scope: international, regional, and national. The categorization was determined by whether the organization had international presence including worldwide offices and staffs. Finally, organizations were coded either as ICT-specialized or general depending on whether they were exclusively focused on ICT strategies such as information technologies and telecommunications. Intercoder reliability between the coder and the researcher was assessed based on a subset of 70 randomly selected organizations. The intercoder reliability coefficient was $\kappa = 0.975$ for institution type, 1.000 for geographic location, 0.973 for geographic scope, and 1.000 for specialist/generalist orientation. The coding done by the coder was used in the final analysis.

Links were defined in terms of organizations' affiliations with the above two types of projects; consequently, the original data set consisted of a two-mode affiliation network. These data were reorganized to one-mode organization-to-organization data. Consequently, the data set created was a valued symmetric network, with the value indicating the number of times organizations jointly worked on implementation or knowledge-sharing projects. The networks were then transformed to binary data which indicated the presence or absence of ties. Networks were constructed on the basis of 3-year data windows: 1997–1999, 2000–2002, and 2003–2005. The strategy of taking multiple years has the advantage of capturing networks accurately by considering the duration of ties (e.g., Baum, Rowley, & Shipilov, 2004).

Analysis

Network analysis provides a systematic approach for capturing the relations among a given set of nodes. Data were analyzed with exponential random graph models (ERGM), also called p^* models (Koehly & Pattison, 2005). The ERGM method allows testing of the dependence of a set of tie variables in one network on a set of tie variables in another network at the levels of ties, dyads, triads, and higher-order configurations (Robins & Pattison, 2006). This permits examination of multilevel local network substructures in multiplex configurations. Thus, ERGM provides the opportunity to analyze different forms of substructures articulated in the hypotheses. ERGM also allows the simultaneous estimation of multiple node attribute parameters along with the structural parameters of the model. PNet is a recently developed computer program based on Monte Carlo Markov Chain maximum likelihood estimation to fit a model

to the observed network by obtaining convergent estimates.³ This study used XPNet, which is an extension of PNet that permits the analysis of multivariate networks.

Hypotheses were tested by examining parameter estimates. Parameter estimates that are more than twice their standard error are considered significantly different from 0 ($\alpha = 1.96$, Robins, Snijders, Wang, Handcock, & Pattison, 2007). Positive and significant parameter estimates indicate a structural effect that cannot be explained by a random set of ties or by other effects in the model. Significant negative estimates indicate that fewer configurations are present than what would be expected by chance alone. The convergence *t*-ratio for each parameter estimate in a well-fitting model should be less than or close to 0.1 in absolute value.⁴ After the estimates were obtained, goodness of fit (GOF) statistics was obtained through simulating a large number (more than a million) of graphs. This process compares the networks simulated from the estimated model with the observed network (Goodreau, 2007; Harrigan, 2008).

Four sets of models were specified to test the theory and hypotheses articulated above: the baseline linkage propensity, endogenous structure, exogenous environmental attributes, and endogenous nodal attributes. In Model 1, *EdgeA*, *EdgeB*, and *EdgeAB* parameters were estimated. In Model 2, endogenous tie structure was estimated based on *EdgeAB* and *K-TriangleABA* parameters. In Model 3, a combination of environmental attribute parameters were estimated while controlling for *EdgeAB* to test the environmental effects on the propensity of multiplex tie formation in addition to the baseline propensity of multiplex ties to occur. In Model 4, nodal attribute parameters were estimated with *EdgeAB* being controlled. The results were obtained from models at the three time periods. At each time period the networks were constructed into 292×292 , 513×513 , and 549×549 nondirectional matrices. As illustrated in Table 1, XPNet parameters capture multiplex dynamics as seen in the coexistence of implementation (orange) and knowledge-sharing (green) edges.

For Hypothesis 1, the estimation was conducted with the *EdgeAB* parameter. A significant and positive *EdgeAB* would suggest that organizational dyads with tie *A* are likely to have tie *B* as well. Hypothesis 2a tested the effects of a common third party with the *TriangleAAB* and *TriangleABB* parameters. Significant and positive parameters would suggest that if organization *A* had ties with organization *C* and organization *B* had ties to organization *C*, it is likely that organizations *A* and *B* would have ties with each other. Hypothesis 2b was tested with a higher-order transitivity structure, captured by the *K-TriangleABA* parameter.

Hypothesis 3a examined the effects of resource spaces (geographic location and organizational population). The estimation was done with the *Same-category-AB* parameter. Hypothesis 3b examined generalist versus specialist organizations based on two organizational attributes (international vs. noninternational scope and ICT-specialized vs. general). The *RAB* parameter was estimated, in which a positive and significant value would suggest that there is a higher likelihood of tie formation for organizations with the hypothesized binary attribute. Hypothesis 4 suggested the

effects of the structural position of organizations. Normalized degree centrality was obtained from UCINET 6 (Borgatti, Everett, & Freeman, 2002). A significant and positive *SumAB* parameter was used to determine whether a tie was more likely to exist between two organizations that had higher centrality collectively.

Results

Table 2 provides estimates, standard errors, and statistical tests of the structural parameters for the baseline model as well as advanced models with both structural and nodal attribute parameters that correspond with each hypothesis. Parameter estimates were obtained from converged models in three time periods, respectively. The model building process started with a simple model based on a Bernoulli distribution that assumes independence of ties, with only the *Edge* parameters. The results showed that the *EdgeA* and *EdgeB* parameters were negative and significant across all converged models (Model 1), which implies that there is a low baseline propensity to form ties net of other effects (Robins, Snijders et al., 2007).

Hypothesis 1 tested the likelihood of tie formation across multiple networks (Model 1). The models converged and the *EdgeAB* parameters showed a significant and positive value ($EdgeAB_{1997-1999} = 1.83$, $EdgeAB_{2000-2002} = 2.90$, and $EdgeAB_{2003-2005} = 2.36$, all statistically significant at $p < .05$). Thus, Hypothesis 1 was supported: Ties between the implementation and knowledge-sharing networks co-occurred beyond what would be expected by chance alone.

Hypotheses 2a and 2b predicted that organizational dyads that have one or more common third parties would have a higher likelihood of forming multiplex ties. First, Hypothesis 2a modeled a single common third-party tie mechanism in multiplex networks. This model did not converge; therefore, Hypothesis 2a was not supported.

To test Hypothesis 2b, which assumed complexity in the multiplex networks, the higher-order parameter, *K-TriangleABA*, was estimated. As shown in Model 2, the models which incorporated the parameter converged, and the *K-TriangleABA* parameters were positive and significant in 2000–2002 ($K-TriangleABA_{2000-2002} = 1.47$, $p < .05$) and 2003–2005 ($K-TriangleABA_{2003-2005} = 1.18$, $p < .05$). However, the 1997–1999 network yielded a converged model, but with nonsignificant parameters ($K-TriangleABA_{1997-1999} = 0.29$, n.s.). Therefore, Hypothesis 2b was partially supported, indicating that this mechanism is observed more strongly in later time periods. However, it is also important to note the combination of the rejection of Hypothesis 2a and support for Hypothesis 2b. The co-occurrence of nonsignificant *Triangle* and significant *K-Triangle* parameters implies that the triangle effects are not necessary to explain the data once the higher-order transitivity is accounted for (Robins, Snijders et al., 2007).⁵

Hypothesis 3a, which predicted that the likelihood of multiplex tie formation would be higher when organizations shared the same resources, was partially supported (see Model 3). All of the three models showed full convergence. For geographic

Table 2 Parameter Values for Converged Models

Model	1 (H1)	2 (H2b)	3 (H3a,b)	4 (H4)
Endogenous tie structure				
<i>EdgeA</i>				
1997–1999	−3.55 ^{*,a} (0.03)	−3.56 ^{*,a} (0.03)	−3.54 ^{*,a} (0.03)	−3.54 ^{*,a} (0.03)
2000–2002	−3.92 ^{*,a} (0.02)	−3.99 ^{*,a} (0.02)	−3.92 ^{*,a} (0.02)	−3.93 ^{*,a} (0.02)
2003–2005	−4.03 ^{*,a} (0.02)	−4.14 ^{*,a} (0.02)	−4.02 ^{*,a} (0.02)	−4.03 ^{*,a} (0.02)
<i>EdgeB</i>				
1997–1999	−5.82 ^{*,a} (0.09)	−5.88 ^{*,a} (0.10)	−5.81 ^{*,a} (0.08)	−5.81 ^{*,a} (0.09)
2000–2002	−6.70 ^{*,a} (0.07)	−7.22 ^{*,a} (0.11)	−6.71 ^{*,a} (0.08)	−6.71 ^{*,a} (0.07)
2003–2005	−5.80 ^{*,a} (0.05)	−6.15 ^{*,a} (0.06)	−5.80 ^{*,a} (0.05)	−5.81 ^{*,a} (0.05)
<i>EdgeAB</i>				
1997–1999	1.83 ^{*,a} (0.24)	1.83 ^{*,a} (0.23)	−0.79 ^a (0.80)	−0.75 ^a (0.64)
2000–2002	2.90 ^{*,a} (0.15)	2.85 ^{*,a} (0.15)	1.10 ^{*,a} (0.45)	1.72 ^{*,a} (0.27)
2003–2005	2.36 ^{*,a} (0.12)	2.33 ^{*,a} (0.12)	0.33 ^a (0.39)	1.16 ^{*,a} (0.20)
<i>K-TriangleABA</i>				
1997–1999		0.29 ^a (0.17)		
2000–2002		1.47 ^{*,a} (0.11)		
2003–2005		1.18 ^{*,a} (0.08)		
Exogenous environmental attributes				
<i>Same-category-AB (Region)</i>				
1997–1999			0.55 ^a (0.43)	
2000–2002			0.62 ^{*,a} (0.28)	
2003–2005			0.83 ^{*,a} (0.23)	
<i>Same-category-AB (Org. population)</i>				
1997–1999			0.91 ^{*,a} (0.43)	
2000–2002			0.50 ^{*,a} (0.25)	
2003–2005			0.48 ^{*,a} (0.21)	
<i>RAB (geographic scope: international)</i>				
1997–1999			1.71 ^{*,a} (0.34)	
2000–2002			1.19 ^{*,a} (0.19)	
2003–2005			1.19 ^{*,a} (0.15)	
<i>RAB (functional scope: general)</i>				
1997–1999			0.22 ^a (0.36)	
2000–2002			0.29 ^a (0.22)	
2003–2005			0.35 ^a (0.19)	
Exogenous nodal attributes				
<i>SumAB (centrality in I-network)</i>				
1997–1999				0.07 ^{*,a} (0.03)
2000–2002				0.01 ^a (0.03)
2003–2005				−0.03 ^a (0.03)
<i>SumAB (centrality in K-network)</i>				
1997–1999				0.30 ^{*,a} (0.07)
2000–2002				0.47 ^{*,a} (0.09)
2003–2005				0.41 ^{*,a} (0.05)

Note: Standard errors in parentheses.

^aIndicates parameter converged at convergence *t*-ratios <0.10.

*Indicates significant parameter at *p* < .05.

region, the parameter estimate was positive and significant in the later two periods at $p < .05$ ($\text{Same-category}AB_{2000-2002} = 0.62$; $\text{Same-category}AB_{2003-2005} = 0.83$), but was nonsignificant in 1997–1999 ($\text{Same-category}AB_{1997-1999} = 0.55$, n.s.). In terms of organizational populations, the parameter was positive and significant at $p < .05$ in all three time periods ($\text{Same-category}AB_{1997-1999} = 0.91$; $\text{Same-category}AB_{2000-2002} = 0.50$; $\text{Same-category}AB_{2003-2005} = 0.48$). These results provide support for Hypothesis 3a, except for the case of geographic location in 1997–1999, by showing that organizational dyads in the same resource spaces, in terms of both geographic location and organizational population, have a statistically significant general tendency to form multiplex ties.

Hypothesis 3b suggested that generalist organizations would be more likely to have multiplex ties than specialist organizations. Model 3 shows the estimation results. For geographic scope, organizations with international scope were likely to have multiplex ties in all three time periods evidenced by positive and significant parameters at $p < .05$ ($RAB_{1997-1999} = 1.71$; $RAB_{2000-2002} = 1.19$; $RAB_{2003-2005} = 1.19$). For functional scope, the RAB parameter was not significant in any time periods ($RAB_{1997-1999} = 0.22$; $RAB_{2000-2002} = 0.29$; $RAB_{2003-2005} = 0.35$). Thus, organizational specialization did not influence the likelihood of multiplex tie formation. These findings provide partial support for Hypothesis 3b.

Hypothesis 4 predicted that central organizations would have a larger number of ties that span both types of networks (see Model 4). First, the effect of centrality in the implementation-network was examined. The parameter estimate varied slightly across time periods. In 1997–1999, the parameter was positive and significant at $p < .05$ ($\text{Sum}AB_{1997-1999} = 0.07$). In the later two time periods, the parameters were not significant ($\text{Sum}AB_{2000-2002} = 0.01$; $\text{Sum}AB_{2003-2005} = -0.03$). These results show partial support for the claim that there is a higher likelihood of multiplex ties for organizational dyads that are central in the implementation network. In the knowledge-sharing network, the result showed stronger and consistent support for the hypothesis. The parameter values were $\text{Sum}AB_{1997-1999} = 0.30$, $\text{Sum}AB_{2000-2002} = 0.47$, and $\text{Sum}AB_{2003-2005} = 0.41$, all positive and significant at $p < .05$. The results indicate that the centrality of organizational dyads in the knowledge-sharing network is a significant predictor of multiplex ties. Taken together, the findings provide substantial support for Hypothesis 4.

The GOF diagnostics for the models from each year showed that the statistics for the estimated parameters closely matched the distribution of parameters in the observed graphs. The convergence t -ratios were less than or close to 0.1 in absolute value, suggesting that the models show a good fit to the data (Goodreau, 2007; Robins, Snijders et al., 2007).⁶

Discussion

This article fills the gap in past research on interorganizational communication ties by identifying the patterns and determinants of multiplex ties. Overall, the

results suggested that the interlocking relationship between the implementation and knowledge-sharing networks showed significant multiplex patterns. The study further examined the specific patterns of multiplex ties and the environmental and nodal attributes that contribute to these interlocking patterns.

First, the research examined endogenous mechanisms behind multiplex tie formation. Empirical support was provided for complex patterns of embedded transitivity (Hypothesis 2b). The significance of the *K-TriangleABA* parameter has two implications. First, the network is best represented by a complex pattern in which multiple triangles are embedded. Second, the network has dense regions built upon cliques, in which triangles are grouped together by sharing one edge. Further, this mechanism was found in the later two time periods, implying an increase in the magnitude of embedded structure over time. This suggests that organizations' accumulation of collaborative experiences as well as the maturity of the community has facilitated the interlocking patterns behind multiplex ties.

Second, the study found that exogenous environments have significant influence on multiplex ties. The results showed that colocated organizations were more likely to have multiplex ties at later points in time, confirming the effect of spatial proximity (Hypothesis 3a). These findings are consistent with studies on the structure of international telecommunications that have found increases in regional integration (e.g., Barnett, 2001; Lee, Monge, Bar, & Matei, 2007). In addition, organizations in the same population had higher probability of multiplexity. Overall, these results show the effects of homophily in the context of resource similarity. These findings support the emphasis on organizational dynamics at the smaller geographic and functional levels, which shows that organizations engage in relationships with those that pursue the same resources in their local environments (Aldrich & Reuf, 2006; Baum & Haveman, 1997). Further, in contrast to the effect of resource complementarity on uniplex tie formation (Astley, 1985; Baum & Singh, 1994; Fombrun, 1986; Gulati, 1995), the study suggested that commensalistic relations are stronger drivers of multiplex tie formation than symbiotic relations.

From a practical viewpoint, these results suggest that the transfer of knowledge from projects is often kept within regional boundaries and among similar organizational types. These practices are more evident in the Northern developed regions and in more traditional organizational types such as IGOs. Although there has been an increasing voice for the role of multisector partnerships and civil society actors, the current study reveals that these patterns are yet to be evidenced in the field. These lead to the suggestion that more cross-region and cross-organizational multiplex ties are likely to be beneficial for the community.

The study found partial support for the claim forwarded in Hypothesis 3b that generalist organizations have higher likelihood of forming multiplex ties than specialist organizations. Specifically, organizations operating at the international scope formed a larger number of multiplex ties than those at the regional or national scope. The results show that both the development efforts and policy formation process in the international telecommunications arena are relatively dominated

by international organizations. These situations pose a challenge for making the development practices relevant to the local stakeholders.

The study found that network positions in a single network affect the likelihood of tie formation, thus providing mixed support for Hypothesis 4. In the knowledge-sharing networks, the effect of centrality on multiplex ties corresponded to previous explanations about the advantages of prominent positions for tie formation (Barabasi, 2002; Gulati, 1999; Powell et al., 1996). In particular, the results demonstrate that the effect of network centrality on facilitating multiplex tie formation was more evident in the knowledge-sharing networks, which may suggest that prominent organizations are more visible in knowledge-sharing projects in which the activities are centered on communication, learning, and social bonds among organizations.

The findings lead to several theoretical contributions. First, the study highlighted the importance of attention to resources that has been proposed by theories of ecology (Aldrich & Reuf, 2006) and social networks (Borgatti & Foster, 2003; Monge et al., 2008). The findings suggest that ecology theories provide a useful framework for explaining network changes at multiple levels including the community, populations, and local neighborhoods of organizations. Further, the study suggested a theoretical extension of the concept of organizational community from both the functional and spatial aspects to the domain of multiplex networks.

Further, this study was added to the current development of knowledge on multiplex networks. In particular, this study found that various determinants that have been found to influence alliance formation, such as common third-party ties (Burt, 1976), resource width (Carroll & Hannan, 2000), and network centrality (Gimeno, 1994), were also applicable to multiplex contexts. These findings can be applied to a broader set of collaborative contexts such as individual interactions within organizations. Lewis (2006) identifies collaboration as a “communicative interaction and/or process among participants” (p. 201). Lewis also suggests that processes and emergent properties which are self-organized by the participants are the central aspects of collaborative activities. Further, studies about communities of practice have dealt with the interactive processes between working together and the creating and sharing of knowledge (Brown & Duguid, 2000). Given the multidimensionality of communication (Hartman & Johnson, 1989) and the mutual influence among these multiple relationships, understanding multiplex dynamics can advance our knowledge about the emergent nature of collaborative processes.

The study also provides practical implications for the ICT for development communities. Development communication scholars have emphasized communication and collaboration between marginalized people and experts (Melkote, 2002). This approach also puts emphasis on knowledge generation as well as the empowerment of local knowledge. Several studies have shown that communication networks among various organizations influence social development outcomes in various contexts such as civil society building (Doerfel & Taylor, 2004; Taylor & Doerfel, 2003), international aid (Lim, Barnett, & Kim, 2008), and global health (Shumate

et al., 2005). Building on this research, the current study empirically investigated interorganizational network structures and collaborative processes.

Ultimately, the dynamics of multiplex networks suggest that organizations can take advantage of their position in one network for building their positions in other networks. Second, efforts for selecting potential partners can be facilitated across multiple networks, as the presence of ties in one network is expected to increase potential tie formation in other networks. Third, for the purpose of mitigating the uneven structure of global networks, it is expected that intervention in one network will influence other networks. For example, it is likely that the effort to increase the participation of Southern organizations in implementation networks will enhance their structural position in the knowledge-sharing networks as well.

Directions for future research

This study has several empirical limitations. First, the data are not representative of all organizational populations in the ICT for development community. The major sources of the data set are IGOs and other traditional donor organizations, which led to the underrepresentation of private corporations and nontraditional donors. Second, the data source lacks detailed information on collaborating organizations due to confidentiality reasons. Third, the data set did not provide details on the nature of ties such as the direction and substance of relations. Once a more complete data set becomes available, analyses will be able to generate useful insights about the direction of resource flows, collaborative versus competitive ties, and power relations.

There are methodological limitations as well. First, the study examined network configurations in three time periods and did not consider multiplex dynamics in a strict longitudinal sense. A longitudinal analysis of year-to-year changes will allow investigation of the formation, retention, and dissolution of ties. An important research agenda would be to investigate how these evolutionary dynamics are affected by multiplexity. Second, analyses in the current study were based on binary network data to enable multiplexity analysis based on ERGM. A more complete understanding will be obtained by incorporating valued ties. Third, as the network data were extracted from organization–affiliation data, some of the results need to be interpreted with special consideration. For example, the common third-party partners may originate from collaborating on different projects, as well as from collaborating on the same implementation project or participating in the same knowledge-sharing venues. Although the ERGM result itself does not distinguish between the two cases, further interpretations of the transitivity mechanism will require a supplementary exploration of each case.

This study provides the basis for a wide range of interesting future theorizing and research. First, there is a high level of competition in development communities for scarce resources such as funding, political opportunity, and media attention (McAdam, McCarthy, & Zald, 1996). Future research should examine the ways in which the competitive dynamics among organizations influence the evolution of the community. Second, networks can be detrimental as well as beneficial, and this aspect

has important implications in the context of development communities. For example, there have been debates about the negative aspects of NGOs' dependence on donor funding and the dependence of recipient organizations on governments (Lister, 2004; Smith, 2004). Future studies are encouraged to examine the conditions under which networks fail to achieve organizational goals or create unanticipated negative outcomes. Third, the analyses undertaken in the current study can be applied to the examination of broader development practice in which organizational partnership practices play important roles. In these various fields of organizational communities, examining multiplex communication relations will broaden our understanding of the complexity of network evolution and the surrounding environments.

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Notes

- 1 The classification of project types was based on a keyword search of project titles and abstracts. Projects with keywords including conferences, workshops, meetings, seminars, forums, and publications were coded as knowledge-sharing projects. Implementation projects included projects that focused on ICT infrastructure, ICT capacity building, and ICT education.
- 2 From each project listing in AiDA, the following attributes were extracted: project title, year started, year ended, location, project description, and collaborating organizations. Data fields regarding recipient institutions, implementing agencies, contractor organizations, and sponsors were coded as collaborating organizations. Information about organizational attributes (institution type, geographic location, and geographic scope) was extracted from precoded categories listed in the donor Web sites and when unavailable, from individual organizations' Web sites. The details of coding process can be obtained from S.L.
- 3 The advantage of PNet over earlier Markov random graph models is that it includes a wider range of higher-order parameters, especially those representing transitivity processes, which result in improved model performance (Robins, Pattison, Kalish, & Lusher, 2007).
- 4 This convergence t -ratio is distinct from the conventional t -statistic, which is defined as a parameter estimate divided by its standard error (Robins, Snijders et al., 2007).
- 5 Previous literature suggests that the Markov parameters are not appropriate for large and complex networks and the higher-order model specifications offer substantial improvement (Goodreau, 2007; Robins, Pattison et al., 2007).
- 6 The parameters were close to the 0.1 threshold which is considered to be an excellent fit; the 0.2 threshold is considered to be a good fit (Snijders, 2002). The details of GOF test results can be obtained from S.L.

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