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Research Article

The Dynamics of an Interorganizational Emergency Management Network: Interdependent and Independent Risk Hypotheses

Abstract: *The purpose of this research is to uncover the dynamic structure of an interorganizational emergency management network after a disaster. This research tests two hypothesized network structures: interdependent risk and independent risk. While the former illustrates the importance of trust and information redundancy in coordinating and aligning emergency preparedness and response, the latter captures the tendency for local actors to seek dominant partners to bridge crucial information across the region. A stochastic actor-based model with a forward selection strategy is used to analyze the structural effects of endogenous networks and the effects of exogenous community attributes on interorganizational ties. Based on the data sets collected before and after the 2012 typhoons in South Korea, the results support the interdependent risk hypothesis, suggesting that an interorganizational network structure tends to evolve into the notion of shared collaboration risk.*

Evidence for Practice

- Strengthening interdependent relationships that rely on mutual aid matters in increasing the potential benefits and decreasing the relational risk caused by partners' behavior and deriving from uncertainty among emergency management organizations across sectors.
- Forging direct ties with other emergency management organizations drives the stronger structural benefits of a clustered structure, highlighting associated benefits such as technical resource sharing and the coordination of consensus-based joint activities.
- A close-knit emergency management network based on direct collaborative ties is critical for securing communication channels to build resilient communities at the local level, enhancing effective information and resource mobilization in emergency response and recovery operations.

A growing body of research has highlighted the importance of interorganizational emergency management (EM) networks (Andrew and Carr 2013; Choi and Brower 2006; Guo and Kapucu 2015; Kapucu 2006; Kapucu and Hu 2016; Waugh 2003; Waugh and Streib 2006), but still few researchers have identified how the patterns of social relations among diverse local organizations are changed by a disaster (Hu, Knox, and Kapucu 2014). The changes in the collaborative structure reflect the gap between planned and response EM networks (Song and Jung 2015). The gap exposes the operational problems of disaster response. Given resource limitations and fragmented regional governance, collaborative networks encompassing multilevel governments have been stressed in promoting successful adaptation to adversity (Andrew 2009, 2010; Kapucu, Arslan, and Collins 2010; Kapucu, Hawkins, and Rivera 2013).

Despite the necessity of comprehensive EM networks for effective response, each organization is still exposed to relational risk with its partners (Song, Park, and Jung 2018). To reduce their exposure to risks, organizations may adopt either a risk-sharing strategy based on an interdependent closure network or a risk-relieving strategy based on the creation of relationships with those that are centrally connected to others as coordinators. This research tests the two hypotheses: interdependent risk and independent risk. The former illustrates the importance of trust building and information redundancy in emergency preparedness and response. The latter captures the tendency for local actors to seek dominant partners to bridge crucial information across the region (see Andrew 2009, 2010; Andrew and Carr 2013).

The primary objective of this study is to determine the patterns of interorganizational relations and how planned joint coordination efforts are modified to meet unexpected local demands after a disaster occurs. In the realm of EM, whether planned or not, self-organizing governance emerges during disasters in

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one form or another (Dynes 1994; Dynes, Quarantelli, and Kreps 1972; Kreps 1991). The previous work stream has tended to focus on a normative approach rather than investigate the explanatory factors for generating changes in governance structure. Setting our research at the organizational level, we focus on how a diverse set of organizations are transferring their resources and devising alternative means to overcome unexpected challenges. The autonomous but fragmented authorities that decide whether to participate in a collaborative response are respected; however, this does not always lead to socially desirable collective action. Instead, each authority considers its personal benefits and costs.

The next section provides overview of an institutional collective action framework in emergency management. It is followed by a discussion of how collaborative networks change based on the interdependent and independent risk hypotheses. The research context—the 2012 Korean typhoons—data collection, and methods are then described. After providing the results and discussion, this research concludes with a brief summary of results, policy implications, limitations, and future research recommendations.

Institutional Collective Action Framework

The institutional collective action (ICA) framework posits that the transaction costs of monitoring and enforcing the contracted obligations for collaboration can prevent organizations from working together to achieve better outcomes (Feiock and Scholz 2010). The relative advantage analysis of transaction costs (e.g., information costs, negotiation costs, agency costs, and enforcement costs) provides insights into the obstacles preventing the realization of collective decisions (Feiock 2007; Inman and Rubinfeld 1997). Dilemmas between organizational and societal needs also arise from a system of fragmented authority (i.e., vertical, horizontal, and functional fragmentation), which become barriers to mutually beneficial action because they generate transaction costs at points at which organizations are considering agreements for joint activities. The ICA perspective extends the collective action theory, which is concerned with individuals' behaviors and identifies problems associated with suboptimal outcomes at the organizational level. Despite the existence of an optimal outcome for society, each organizational behavior that seeks to maximize individual benefits may lead to the second-best outcome for society. The framework has also been utilized to study organizational behaviors using contract and transaction cost theories (Feiock 2009; Feiock and Scholz 2010).

In the context of EM, the ICA framework has been applied to study interorganizational collaboration as interactions or interorganizational ties (Andrew and Carr 2013; Andrew et al. 2016; Andrew, Jung, and Li 2015). Such interactions can improve the level of emergency response, as they offer informal mechanisms for actors to reduce the cost of coordination and cooperation (Andrew et al. 2016). A beneficial exchange is realized when actors receive crucial resources from multiple actors.

Disasters can overwhelm the capacity of any single sector or community, necessitating the inclusion of different actors in emergency response activities (Comfort 1994; Kapucu 2006, 2007). Since collaboration between different functional organizations and levels of government often generates coordination problems, creating a "hub" or a bridge that spans multiple actors can facilitate access to new information and novel resources (Burt 2005). The bridging strategy can also broaden the range of participants. The participants then share the risk with adjacent communities, which respond quickly and appropriately. These mechanisms integrate decision making, create mutually binding agreements, delegate authority, and impose authority through networks (Feiock 2013). Each mechanism resolves a collective action dilemma differently. Social network studies suggest that decentralized or centralized coordination strategies are adopted to minimize transaction costs of the collaboration and risks associated with potential default as well as provide information on search costs facing interorganizational governing networks (Berardo and Scholz 2010).

In the underlying ICA framework, collaboration risks reflect incoordination (inaction), division (division of costs), and defection (agreement violation) (Feiock 2013). Defection risks are particularly high in disaster situations because if even one participant does not conform to the agreement, others will likely fail to respond effectively to the disaster. In general, each disaster has a different frequency and intensity. This could change the action of each organization, depending on internal condition or capacity. Collaborative networks are established at the preparedness stage, but rational actors might consider the benefit and cost when they face disasters, regardless of previous agreements. In uncertain situations in which the partners' behavior is not entirely predictable, each organization might not respond to the requests of others or may sequester resources that might be necessary at another point in time during disasters. Conversely, each perceives the possibility that other organizations may not respond to their request. High risk that derives from high uncertainty increases transaction cost.

From the ICA framework, a failed disaster response generally serves as a strong incentive to change the previously arranged collaborative structure or pattern following catastrophic events that involve casualties. The unpredictable and chaotic features of catastrophic events overwhelm the capacity of any single organization; thus, organizations are motivated to include and/or exclude certain actors in emergency response activities (Comfort 1994; Perry and Lindell 2003; Waugh and Streib 2006). From a resource dependency perspective, Salancik and Pfeffer (1978) asserted that if an organization is not self-sufficient, it will adapt to its environment to survive. Disastrous events overwhelm a single organizational capacity, but redundancy or the preparation of resources for disasters cannot always be sufficient. Since the need for acquiring crucial resources suggests that an organization is dependent on other organizations (Scott 2000), the formation of interorganizational ties is determined by both internal and external factors. In situations characterized by resource scarcity, securing the stable mobilization of resources is important in determining the success of a disaster response; this can be accomplished through interdependent relations with others in possession of crucial resources, both in terms of information and physical equipment. For instance, during a period of adversity, resilient organizations are more likely to establish efficient measures for securing tangible resources, which can improve response operations. However, some organizations may have limited sources through which they exchange indispensable resources; thus, they may be unable to manage disaster situations without depending on external assistance (Vogus and Sutcliffe 2007).

Despite the emphasis on the importance of coordination and communication between diverse actors (Kettl 2003; McEntire and Dawson 2007), strategies for mitigating collaboration risk may not work in emergency contexts (Andrew and Carr 2013). That is, collaboration may not materialize in the presence of uncertainty. Unlike efforts to achieve the goal of collaborative relations in the area of mitigation, the cost of establishing and sustaining interorganizational networks can be high and the enforcement mechanism may be absent. The commitments that local governments make in disaster planning documents can be unrealistic if the key elements required to implement the planning activities are not tested. Moreover, changes in collaboration are also affected by changing environmental conditions, such as natural and technical disasters (Dynes and Drabek 1994).

The discussion regarding the changes in an interorganizational EM network could first address predesigned planning networks that cannot fully predict all possible situations of disaster response operations (Abbassi and Kapucu 2016; Hu, Knox, and Kapucu 2014; Song 2018). Nevertheless, it is necessary for a planning network to include guides on how organizations can functionally and hierarchically work together (Kapucu and Hu 2016). Although a planning network is designated based on the plausibility of response operations, it still has limitations in its capacity to fully reflect actual damages and victims (Jung and Song 2014; Jung, Song, and Feiock 2017; Song and Jung 2015). The severity of real-life situations and demands for real-time action and resource mobilization drive the changes following a disaster experience (Comfort and Haase 2006). Organizations attempt to forge stable and trust-warranted relations for better disaster response, but they terminate interrelations when the costs are higher than the perceived benefits of collaboration (Jung, Song, and Feiock 2017). Such changes can be explained by two general hypotheses: interdependent risk and independent risk (Berardo and Scholz 2010). The next section explains the causal mechanisms and strategies to minimize collaborative risk in the presence of disasters.

Interdependent Risk Hypothesis

The interdependent risk hypothesis suggests that organizations have a strong preference to forge ties with those that are closely connected, to enable the sharing of risks and coping with disasters together. Since unexpected incidents require a timely response from EM organizations across levels and sectors of governments, a strong commitment among the organizations involved should be established before a disaster. Otherwise, resource mobilization and/or risk communication that could enable swift response operations may be seriously distorted after the disaster occurs. A lack of strong commitment among organizations augments the risk of defection because the organizations tend to perceive both the uncertainty of joint response operations and the failures of networked operations as costs during a disaster. In other words, an organization that is closely connected to other organizations may be more resilient than another organization that is not as well connected, for several reasons. Andrew (2010) argued that forging a direct tie can broaden the range of collaborators, leading to risk sharing with adjacent communities that enables people to respond quickly. Burt (2005) suggested that when applied to EM, maintaining a close-knit structure provides an informal structural power to directly access and mobilize the indispensable resources that an organization urgently needs during a disaster. Choi and Kim (2007) and Vasavada (2013) noted the importance of associational benefits resulting from close-knit structures, implying that locally clustered organizations mobilize themselves to share resources through formal and informal arrangements following a disaster. Bonding strategy stresses the importance of social cohesion, which enables organizations to pool their resources (Andrew et al. 2016).

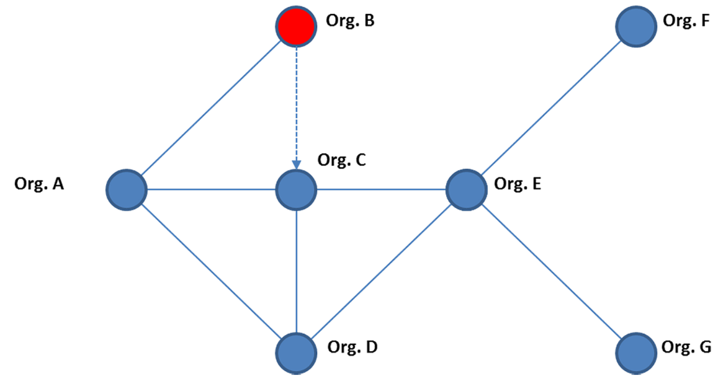


Figure 1 Interdependent Risk Hypothesis

According to the interdependent risk hypothesis (see figure 1), organization B has a motivation to collaborate with organization C to maintain response operations (Comfort et al. 2001; Dooley 1997). Given the hypothesized network, the solid lines indicate existing interorganizational ties, and the dotted line represents the choice made by organization B after a disaster. When deciding whether to collaborate with organizations C, E, F, and G, organization B would rather forge a tie with organization C at time 2. This is because a close-knit triadic structure can not only facilitate mutual reciprocity but also ensure that organizations within the network commit to their agreement to cooperate (Andrew 2010). Since a single organization cannot cope effectively with a disaster (Donaldson 1996; Katz and Kahn 1966), a group of organizations may prefer to share risks by forging ties with those that are socially positioned in a highly clustered network. Therefore, this research hypothesizes the following:

> **Hypothesis 1**: After a disaster, organizations have a strong preference to forge ties with those that are closely connected with each other in order to share risks and cope with the aftermath of the disaster.

Independent Risk Hypothesis

Alternatively, the independent risk hypothesis posits that organizations will mitigate risks by establishing ties with those outside their close-knit circle. The hypothesis highlights the importance of the entrepreneurial behaviors of organizations in their efforts related to risk reduction. Despite the need to request or send aid in response to a disaster, the incoordination risk of not being connected as a broker often hinders the distribution and alleviation of the impact of stress. The independent risk-relieve strategy is important for organizations in minimizing potential losses from a disaster (Kreimer, Arnold, and Carlin 2003). The motivation for organizations to relieve risks and establish ties with a central organization is driven by the notion that by establishing organizational ties with a central actor, the organization can reduce the additional costs of coordination (Andrew 2010). Bridging facilitates the connection to those organizations that would otherwise not be connected to coordinated human and capital resources (Burt 1992).

According to Kapucu (2006), organizations on the periphery of a network prefer to directly link to core actors because they cannot bear the costs of independently crafting and monitoring other collaborators. For instance, organizations with a limited number of skilled personnel and budget constraints may be motivated to seek exclusive exchange partners who can provide an opportunity for additional resources. They also alleviate risks after a disaster if the organization has enhanced organizational capacity. Such a strategy is important if the region has a low probability of disaster occurrence, especially in megacities located in East Asia (Hochrainer and Mechler 2011).

According to the independent risk hypothesis (see figure 2), organization B would rather establish a tie with organization E than organization C, F, or G at time 2. This is because organization E does not have any commitment to organization A. In this situation, organization B can secure exclusive access to organizations F and G. In other words, organization B could more effectively reduce its risks by establishing a tie with organization E (Andrew 2010). This decision is consistent with the entrepreneurial behavior of an organization aiming to secure the most influential actor within its network to cope with internal constraints (Kreimer, Arnold, and Carlin 2003). Thus, this research hypothesizes the following:

> **Hypothesis 2**: After a disaster, an organization prefers to forge ties with those that are centrally connected to policies to relieve risks and cope with the aftermath of the disaster.

Homophily Hypothesis

In the field of EM, the homophily hypothesis allows us to investigate the similarity of organizational attributes. This hypothesis suggests that the similarities of actors will predispose actors toward having comparable policy preferences and strategic behaviors to reduce transaction costs (Goodreau, Kitts, and Morris 2009). Bacharach and Gambetta (2003) argued that the trust-warranting properties of trustee organizations are crucial for selecting potential collaborative partners. Similarity of interests and competence among partners is more likely to secure the willingness and capability of keeping a mutual agreement (Lubell 2007). This is important because it helps reduce transaction costs (Feiock and Scholz 2010) and/or minimize risks derived from collaboration (Gulati and Gargiulo 1999).

According to the homophily hypothesis, an organization has a strong preference to forge ties with another organization if both have similar organizational attributes (i.e., level of government and type of emergency tasks). In the EM literature, collaboration among similar organizations can reduce collaborative risks because previously shared authority can enhance trust and working relationships between organizations after a disaster occurs (Moynihan 2009). In addition, Comfort (2007) indicated that interorganizational cohesion between similar organizations reinforces trust through shared operational cognition. That is, network diversity derived from intersectoral collaboration may hinder effective resource mobilization during a disaster, as the heterogeneity of backgrounds, beliefs, and interests of organizations creates "a greater coordination burden than faced by small homogenous networks" (Moynihan 2009; Provan and Milward 2001, 418). Therefore, this research hypothesizes the following:

> **Hypothesis 3**: After a disaster, organizations with similar organizational attributes have a strong preference to forge ties.

Background of the 2012 Typhoons in South Korea

On August 28, 2012, Typhoon Bolaven devastated the Korean Peninsula, resulting in 25 deaths and causing severe destruction to infrastructure and livelihood. The economic loss was estimated at $374.3 million in South Jeonna and South Kyeongsang provinces. Between August 28 and September 18, 2012, the disaster was caused by three successive typhoons: Bolaven, Tembin, and Sanva (see table 1). The National Emergency Management Agency (NEMA) (2012) reported that the region experienced maximum wind speeds of 130 to 175 miles per hour, which led to overflows of water along the southern coastline and heavy runoff from the Nakdong River basin. More than 1.9 million households in the southwestern provinces experienced a total blackout for more than a week. Approximately 20,000 hectares of agricultural lands were damaged. Samsung, Hyundai, and Kia factories located in the southeastern regions were also affected, especially in the Ulsan Metropolitan area. With an estimated $730 million in economic

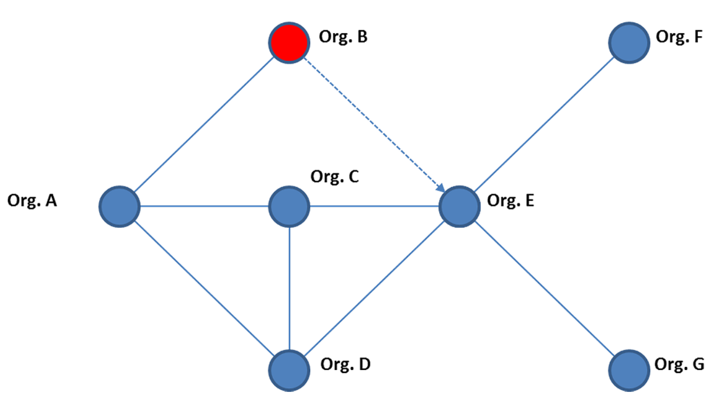


Figure 2 Independent Risk Hypothesis

Table 1 Characteristics and Impacts of Three Typhoons in South Korea, 2012

	Bolaven	Tembin	Sanva
Category (SSHS*)	Category 4 typhoon	Category 4 typhoon	Category 5 super typhoon
Maximum winds	145 mph	130mph	175 mph
Date of impacts	August 28–30, 2012	August 31–September 2, 2012	September 16–18, 2012
Fatality	25	2	2
Total damage	USD 374.3 million	USD 8.25 million	USD 347.5 million

*The Saffir-Simpson Hurricane Scale (SSHS) classifies hurricanes from 1 to 5, distinguished by the intensity of continual winds. A typhoon with maximum sustained winds of at least 74 miles per hour is classified as Category 1. The highest classification in the scale, Category 5, is earmarked for typhoons with winds exceeding 156 miles per hour (National Typhoon Center 2012).
**Source: National Typhoon Center in South Korea (2012).

losses, the Korean national government officially designated 45 cities as "special disaster zones."

Research Design and Methods

Scope of Study, Data Collection, and Survey Instruments

This research focuses on the role of interorganizational coordination in the recovery phase of the southeastern region of South Korea, which consists of Busan Metropolitan City, Ulsan Metropolitan City, and South Kyeongsang Province. The southeastern regions adjacent to the East Sea are located in the path of typhoons almost every summer. This environmental vulnerability requires comprehensive collaboration among EM organizations, and annual drills are conducted. In particular, the region was affected by the three major typhoons in 2012.

The data collection entailed a two-step process. First, before the typhoons, between June 16 and July 8, 2012, emergency management planning related to data collection was conducted. The unit of analysis was at the organizational level (e.g., local and provincial agencies, fire and police stations, and nongovernmental organizations). The survey included three open questions to seek comments from 30 key informants who had direct responsibilities related to processing and/or providing services on behalf of their organizations in the region. The open questions were developed around the following research questions:

1. Which local organizations/agencies coordinate their efforts with yours to provide emergency services in the affected areas?
2. What are the key issues surrounding their coordination planning and the modification they made to meet local demands for services during the response?
3. Given the nature of the disaster, what types of resources have been deployed and utilized to ensure that local communities are able to bounce back from the disasters?

In the second stage, after the typhoons, we administered another survey from January 7 to January 12, 2013. The objective was to determine whether the interorganizational networks changed during the transitional stage of the disaster. A total of 159 organizations were contacted in the region, and 112 organizations agreed to complete the surveys (i.e., 70.4 percent response rate). The personnel responding to the phone survey included senior public officials from municipal governments, assistant chiefs of fire and police, and representatives of nongovernmental organizations.

Table 2 indicates the number of organizations who responded in July 2012 and/or January 2013, indicating that personnel from 43 local government and 25 nongovernmental organizations responded to both surveys, while representatives from only 24 fire and 20 police stations (compared to 34 and 28, respectively, in the first survey) answered the second survey. Basically, the respondents listed as participants for the first survey are the same as those in the second survey. Beyond the survey respondents, other organizations involved in the EM networks are also included based on the participants' responses.

The interorganizational EM networks consisted of 170 respondent organizations and those cited by the organizations. The sociograms are presented in figure 3 and figure 4. The figures illustrate the interorganizational networks of all organizations interacting before and after the natural disasters, and the patterns of both network graphs demonstrate that national agencies (i.e., NEMA and the Ministry of Public Administration and Safety [MPAS]) and metropolitan and provincial governments played a significant role in coordinating EM resources. In addition, it is noteworthy that local governments are placed in a more central position of local EM in the networks compared with other types of organizations. On the contrary, fire and police stations are not well represented in either network. The nongovernmental organizations as shown in the networks suggest different interaction patterns in accordance with their status (e.g., as regionalized or localized branches).

Table 2 Respondents by Type of Organization

	Before Typhoons		After Typhoons	
Type of Organization	Respondents	Others*	Respondents	Others
National agency	—	5	—	5
Regional agency	—	6	—	6
Local government	43	—	43	—
Fire station	34	9	24	19
Police station	28	15	20	23
Nongovernmental organization	25	5	25	5
Total	130	40	112	58

*The other organizations involved in EM network collaboration were added because of information from the survey respondents.

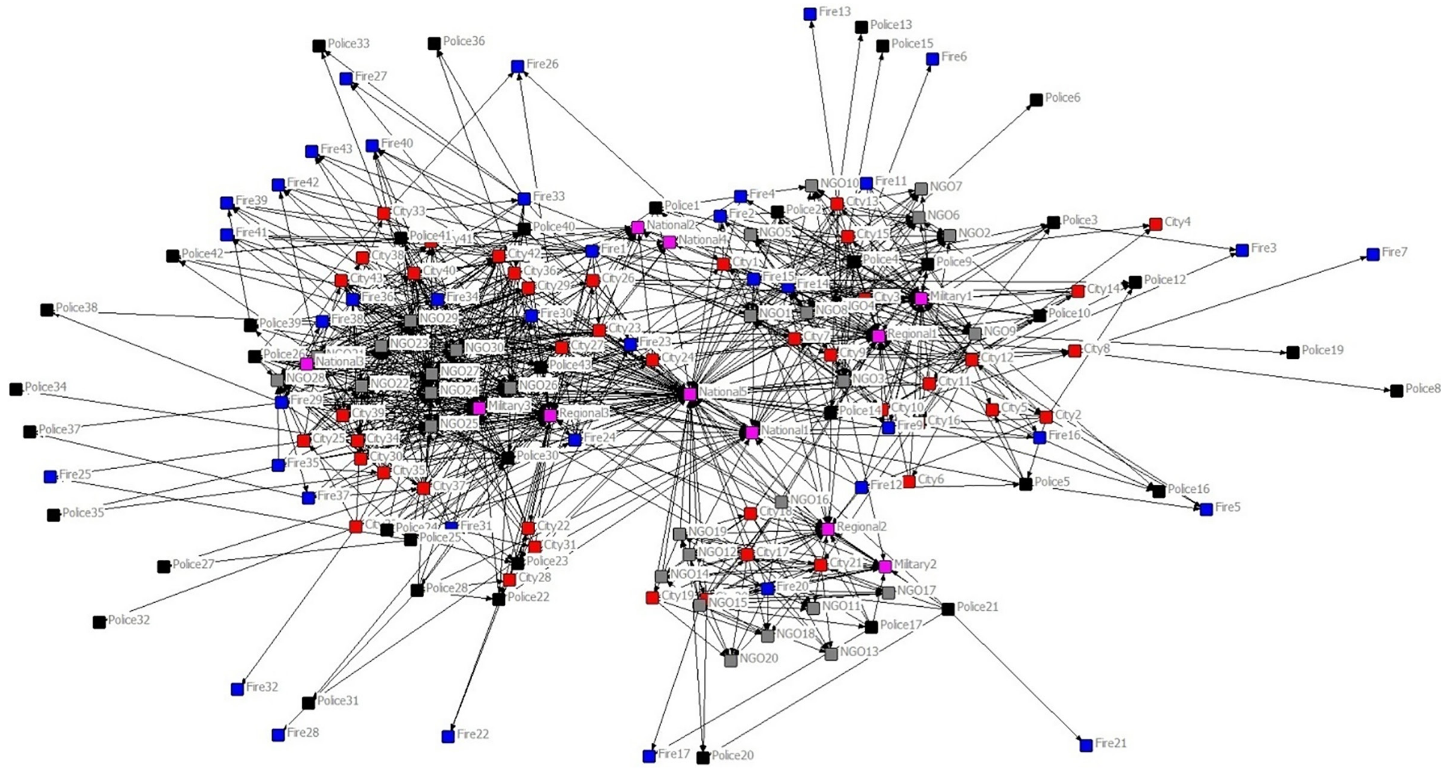
Model Specification

The dynamics of interorganizational ties are estimated by including the endogenous and exogenous effects using the stochastic actor-based models for network evolution (see Snijders 2005; Snijders et al. 2010). The endogenous effects include a set of network effects as specified in SIENA (i.e., reciprocity, distance 2, betweenness, transitive triplets, and three-cycle effects).[1] The exogenous factors include social and environmental vulnerability indicators and a dyadic covariate indicating joint full-sized exercises that encompass professional training and comprehensive education.

In stochastic actor-based models, the model specification simultaneously estimates the rate parameter, network effects, and organizational attributes (Snijders et al. 2010). To capture the probability that organizations will decide to change their ties, the rate parameter estimated the change before and after the 2012 Korean typhoons. The parameter also estimated the average number of changes in bridging and bonding strategies, which are the endogenous factors in this model. The first endogenous effect is the reciprocity effect (see figure 5), which captures the propensity of organizations to establish a mutual tie with those with whom they had a one-way relationship during a catastrophic event. A positive value for the reciprocity parameter indicates that organizations have a strong tendency to forge reciprocal relations, while a negative value suggests these organizations do not have this tendency. This is formally defined as follows:

$$\text{Reciprocity}, s_{i1}^{net}(x) = \sum_j x_{ij} x_{ij}.$$

The interdependent risk hypothesis is tested by identifying the transitive triplets and three-cycle effects (see figure 6 and figure 7). These effects help explore the behaviors of organizations that prefer



Note: Red nodes are local governments; blue nodes are fire stations; black nodes are police stations, gray nodes are nongovernmental organizations; and purple nodes are national and provincial agencies.

Figure 3 Interorganizational Emergency Management Networks before the Typhoons

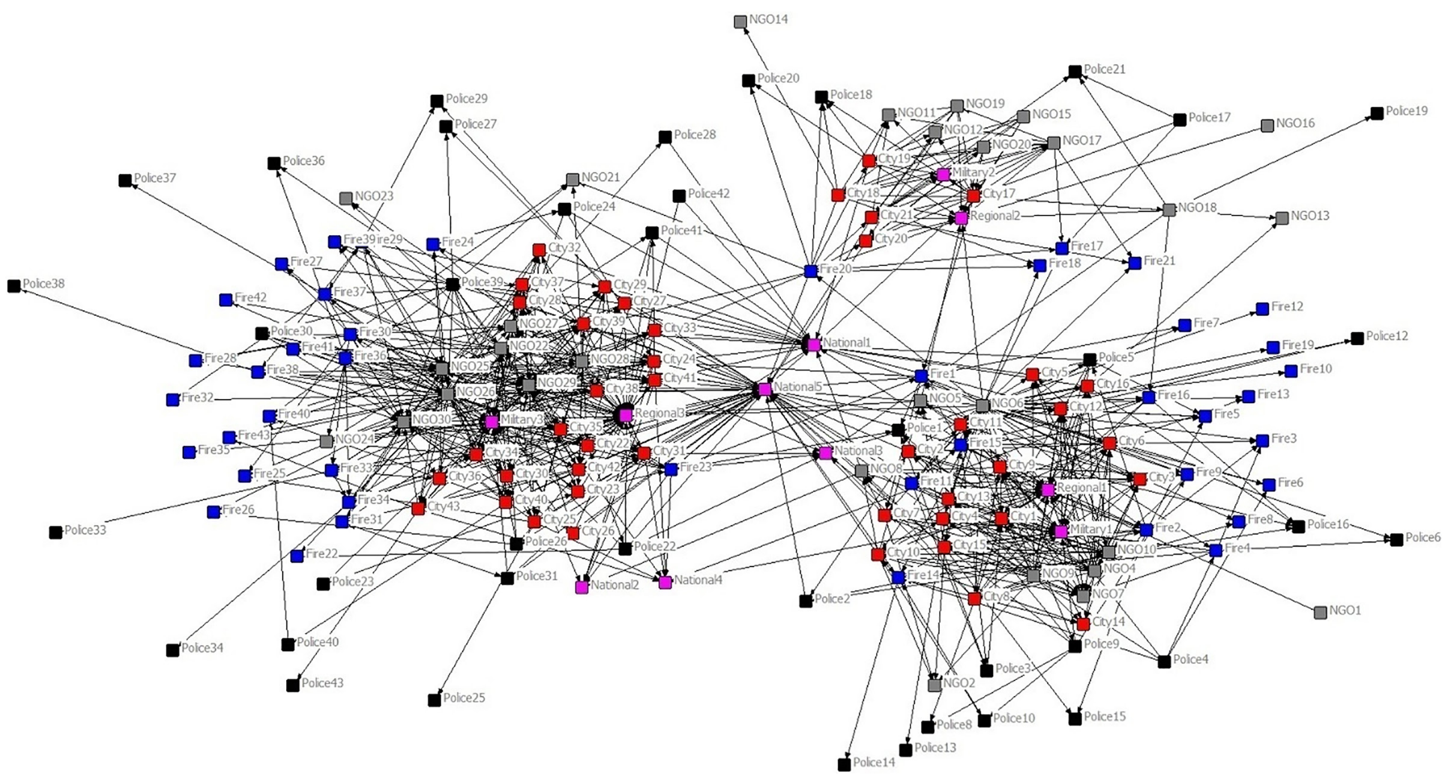


Figure 4 Interorganizational Emergency Management Networks after the Typhoons

to share risks by building a close-knit network structure. Positive parameter values for the transitive triplet and three-cycle effect indicate that to establish a highly clustered network at time t_2, an organization forges direct ties with another organization that was indirectly connected at time t_1. A negative value associated with these effects suggests the interdependent risk effect is not probable. The transitive triplets and three-cycle effect are defined, respectively, as follows:

Figure 5 Reciprocity

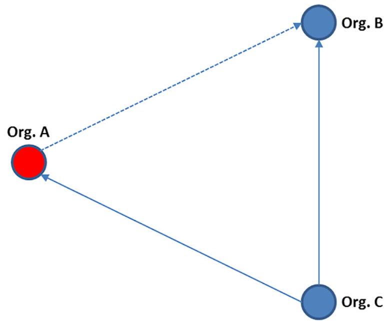


Figure 6 Transitive Triplets

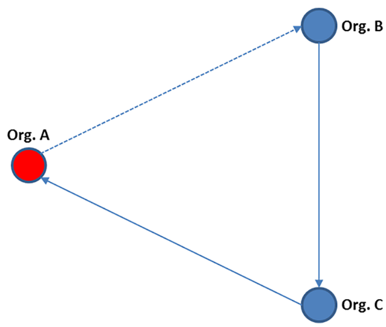


Figure 7 Three Cycles

$$\text{Transitive triplets, } s_{i4}^{net}(x) = \sum x_{ij} x_{ih} x_{jh}.$$

$$\text{three cycles, } s_{i5}^{net}(x) = \sum_{j,k} x_{ij} x_{jh} x_{hi}.$$

The number of actors at distance 2 and the betweenness effects are elements of the independent risk hypothesis that can help explain how an organization mitigates risks after a disaster by seeking a bridging organization or by playing an entrepreneurial role in bridging between two other organizations after a disaster. A positive value suggests that organizations without the bridging organization or role at time t_1 tend to at least forge a tie with one or two other organizations at time t_2. A negative value suggests that organizations have a tendency not to utilize the independent risk strategy because of the higher collaboration risk and uncertainty after a catastrophic event (Jung 2013). The numbers of actors at distance 2 and the betweenness effects (see figure 8 and figure 9) are defined, respectively, as follows:

$$\text{The number of actors at distance 2,}$$

$$s_{i2}^{net}(x) = \#\left\{ j x_{ij} = 0, \max{}_h (x_{ih} x_{hj}) > 0 \right\}.$$

$$\text{Betweenness, } s_{i3}^{net}(x) = \sum_{j,k} x_{hi} x_{ij} (1 - x_{hj}).$$

This research also tests for the homophily effect, which helps in an examination of whether an organization is likely to establish ties with similar organizations. For the homophily effect, a

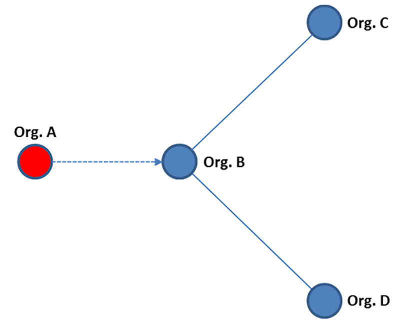


Figure 8 Number of Actors at Distance 2

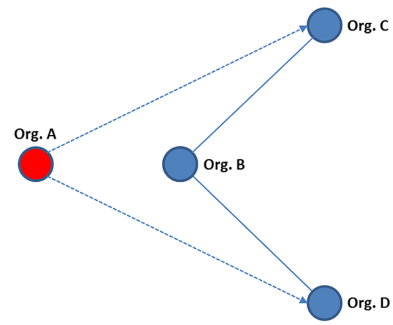


Figure 9 Betweenness Effect

positive parameter implies that actors prefer ties to others with similar preferences, while a negative parameter suggests the actors' preferences for similar actors are less likely to drive actors to establish ties with them. The organizations of interest are the local governments (i.e., whether local governments are likely to establish interorganizational ties before and after a disaster). The indicator function is coded 1 if an organization is a local government and 0 otherwise.

Following Snijders et al. (2010), exogenous effects, such as social and environmental vulnerability, and joint full-sized exercises, which are regular combined drills, are included in the rate function effect. This captures "the average frequency at which an actor gets the opportunity to change their outgoing ties" (Snijders et al. 2010, 53). For instance, organizations with environmental vulnerability may change their network ties more frequently than others that are not located on the coast. Depending on such actors' attributes, a stochastic actor-based model allows us to test whether exogenous factors have an effect on the rate function (see Snijders 1996). A positive parameter value for exogenous effects suggests that organizations with one of the attributes tend to change their network ties.

The forward model selection strategy was employed as proposed by Snijders et al. (2010). The approach first considers only endogenous effects followed by the inclusion of exogenous effects. The model convergence was also performed to determine the model fit. This was performed in the following ways: based on a continuous-time Markov chain Monte Carlo simulation—in which the algorithm computes the maximum likelihood estimates—SIENA employed a three-phase stochastic approximation algorithm to estimate the pattern of relationships (Snijders et al. 2010).[2]

Results and Discussion

Descriptive Statistics

The descriptive analysis in table 3 presents the specific network statistics of two interorganizational EM networks. In the overall networks, mutual dyads increased from 54 to 68, while asymmetric dyads decreased from 1,159 to 832. Mutual dyads represent the reciprocal tie relationship between two organizations, but asymmetric dyads describe one-way tie relationships based on either a receiver or a sender of the ties. Network density measures the ratio of the number of actual connections revealed divided by the possible tie connections in a network. Compared to an increase in reciprocal ties, the number of asymmetric dyads dropped sharply after the disaster. As a result, the network density decreased from 0.039 to 0.028. In columns 2–6 of table 4, the samples are organized into five groups by type of organization. In terms of the relationships among those of the same organizational type (i.e., local government, fire and police stations, and organizations in the nongovernmental sector), the network density of the nongovernmental sector (.054) was only greater than the overall density (.039) in the network before the typhoon, while no group density was greater than the overall density (.028) in the network after the typhoon. Despite that, the density of the fire station group increased from .012 to .014 throughout the disaster. The density of relationships across sectors decreased from .038 to .029 but was greater than any other type of organization after the typhoon, indicating that approximate 89.7 percent of mutual and 91.9 percent of asymmetric dyads were established by relationships across sectors.

Table 4 shows the tie changes between subsequent observations. The changes in ties indicate that organizations participating in the EM network maintained 1,183 ties through the catastrophic event while also establishing 487 new ties and terminating 696 previous ties. Meanwhile, Andrew (2009) and Steglich, Snijders, and West (2006) argued that the changes of ties may not be appropriate for examining the dynamics of the network evolution because of limited methods of data collection based on documents and contents. However, this research proposes that at least the changes in ties show dynamic impacts of the catastrophic event when the data collection procedures based on the peer-to-peer survey covered a full range of organizations in both networks. In other words, tie changes after disasters imply that the networked organizations would rearrange the collaborative relationships with their partners to maintain their current ties, terminate their previous inefficient ties, and forge new ties based on what they learned and experienced from the previous natural disaster response.

Stochastic Actor-Based Models

This study tests the estimation of changes in interorganizational ties by investigating the endogenous and exogenous effects based on the stochastic actor-based models and the convergence criteria met by the model selection. The model specification simultaneously estimated the rate parameter, network effects, and organizational attributes (Snijders et al. 2010). The statistical results of the interdependent and independent risk hypothesis showed that the interdependent risk hypothesis variables were significantly positive, but the independent risk hypothesis variables were significantly negative. Also, the homophily effect was statistically significant and positive. In terms of exogenous effects, environmental vulnerability and joint full-scale exercise were statistically significant, while social vulnerability was insignificant.

The parameters for the interdependent risk hypothesis (i.e., the effect of transitive triplets and three-cycle effects) were positive and statistically significant, indicating that the organizations tended to not only have reciprocity in an exchange, but they also interpreted the hierarchy of the network differently (Snijders et al. 2010). For example, through the 2012 Korean typhoons, the local interorganizational networks that organized themselves within the administrative boundary of each city may have switched from hierarchical to nonhierarchical EM structures. Because disasters require a comprehensive response from different organizations, previous research has focused on networks that functionally collaborate and interact at the same organizational level, even though national organizations, such as the NEMA and MPAS, help coordinate local efforts. During a disaster, the government may not be able to manage all aspects of the situation, but diverse organizations can collaborate to help local governments respond effectively.

The parameters for the independent risk hypothesis (i.e., the number of actors at distance 2 and the betweenness) were negative and statistically significant. They indicate that the organizations were not inclined to alleviate risk during a disaster. From the perspective of the ICA framework (Feiock 2013), the results show that the

Table 4 Changes in Ties between Subsequent EM Networks

	No Tie	New Tie	Broken Tie	Maintained Tie
	0 → 0	0 → 1	1 → 0	1 → 1
$t_1 - t_2$	27,228	487	696	1,183

Table 3 Network Statistics

	Overall Network	Among Governments Gov ↔ Gov	Among Fire Stations FS ↔ FS	Among Police Stations PS ↔ PS	Among Nongovernmental Organizations NGO ↔ NGO	Across Sectors
Before typhoons						
Mutual	54	4	2	2	1	45
Asymmetric	1159	22	19	15	45	1058
Null	16352	879	882	886	389	13316
Density	.039	.014	.012	.009	.054	.038
Average degree	6.351	.605	.488	.395	1.567	6.937
After typhoons						
Mutual	68	1	2	1	3	61
Asymmetric	832	24	21	8	14	765
Null	19753	878	880	894	418	16683
Density	.028	.014	.014	.005	.023	.029
Average degree	4.741	.605	.581	.209	.667	5.194

Table 5 Parameter Estimates and Standard Errors

		Model 1		Model 2	
		Estimates	SE	Estimates	SE
Rate parameter (rho) $t_{1\text{-}2}$		13.907***	.358	13.059***	.317
Endogenous effects	Reciprocity	2.048***	.231	2.051***	.274
	Transitive triplets	.239***	.05	.285***	.058
	Three cycles	.945***	.256	1.354***	.302
	Number of actors at distance 2	−1.112***	.287	−1.354***	.302
	Betweenness	−.164***	.042	−.148***	.023
Homophily effects	Local government	.544***	.075	.548***	.082
Exogenous effects on rate function	Social vulnerability	—	—	−.048	.070
	Environmental vulnerability	—	—	.461***	.078
	Joint full-scale exercise	—	—	.293***	.082

Note: All coefficients were a result of SIENA (3.12) estimations with directed network matrices; all statistics converged with a *t*-statistic <0.1 with a minimum of 1,000 iterations.
***$p<.01$; **$p<.05$; *$p<.1$.

collaboration risks generated by the 2012 Korean typhoons may have encouraged organizations to collaborate directly with other organizations with critical resources and information rather than rely on national and regional agencies. The findings imply that sharing risk with other organizations may not happen effectively during a disaster response (Comfort and Haase 2006). In addition, the homophily effect of local government was positive and significant ($E=0.548$; $p<.01$), indicating that interorganizational ties were more likely to be established among local governments. The finding is consistent with Andrew's (2009) argument, indicating that local governments tend to establish ties with other local governments under regional EM coordination enforced by metropolitan and provincial governments to reduce administrative costs.

The exogenous effects on rate function were included in model 2. Model 2 tested the probability that organizations under certain social and environmental conditions (e.g., social and environmental) that participated in joint full-sized exercises were more likely to collaborate with other organizations after a disaster. The results reported that the organizations on the coastline ($E=.461$; $p<.01$) with joint full-sized exercises ($E=.293$; $p<.01$) were more likely to create interorganizational ties after the typhoons. Both results may support the notion that organizations collaborating with other organizations are influenced by environmental vulnerability (Villa and McLeod 2002). This also implies that by enhancing joint exercise activities for hazard mitigation before a disaster, organizations actively secure critical resources and information under an unexpected condition (Randolph 2012). The final results are presented in table 5.

Conclusion

Interorganizational collaboration for building a resilient community comes in many forms; thus, it is critical to understand the changes in its formation before and after a catastrophic event. Given the uncertainty and complexity of building resilient communities (National Research Council 2010), the dilemmas of local organizations include (1) whether to forge a tie as an interorganizational collaboration and (2) with whom one should create collaborative ties. Through much trial and error in dealing with these dilemmas, interorganizational EM networks have evolved over the years (Feiock and Scholz 2010; Kapucu, Hawkins, and Rivera 2013). The network evolution in terms of natural disasters is predicated on the success of previous collaborations, the significance of current partners, and the expectations of subsequent collaborations that ultimately build resilient communities. Consequently, by perceiving, experiencing, and learning the significance of collaborative ties through a disaster, organizations optimize the costs to establish new ties, terminate previous ties, and maintain existing ties as procedures of the network evolution.

The findings provide two contributions to the current understanding of the dynamics affecting interorganizational EM networks. First, strengthening interdependent relationships that are reliant on mutual aid rather than unilateral aid is effective in dealing with disasters. Since reciprocal connections secure the potential benefits but decrease relational risk from partners' behavior, which is derived from uncertainty among local organizations and across sectors (Feiock and Scholz 2010), individual organizations in self-organizing EM networks are more likely to forge mutual bonds instead of simply creating multiple ties with others. The analysis results of stochastic actor-based models suggested that collaborative operations based on unilateral aid to address the disaster caused by the three typhoons revealed a serious problem of commitment and enforcement. Also, the findings from three open questions as part of the survey revealed that collaboration based on bilateral connections was more supportive of resource mobilization among the organizations during the disasters. However, emergency support by unilateral agreement was less effective in managing the disastrous incidents.

Second, forging direct ties with other organizations drives the strengthening of structural benefits of close-knit EM networks. Formulating a clustered structure in efforts to build resilient communities provides associational benefits, such as reputation, knowledge, and institutional norms. Further, closer network structure often offers practical advantages, such as technical resource sharing and the coordination of consensus-based joint activities that reflect organizational preferences (Randolph 2012). Clustered collaboration can be enhanced through formal and informal communication and the availability of resource sharing (Andrew 2009; Kapucu, Hawkins, and Rivera 2013). According to the comments of three open questions with a contact at the main fire station in the City of Changwon, a close-knit EM network is important because direct collaborative ties can secure communication channels to build resilient communities at the local level. Those findings imply that separate communication channels of organizations, such as local governments, police, and fire stations, have impeded effective information and resource mobilization in emergency responsiveness and recovery procedures.

While scholars in the field of EM have speculated for years on the importance of networks, they have fallen short in predicting the structural changes that are likely to emerge after a natural disaster (Andrew and Kendra 2012; Kapucu 2006; Kapucu, Arslan, and Collins 2010; Kapucu, Hawkins, and Rivera 2013; Waugh and Streib 2006). This research tested two hypotheses—interdependent risk and independent risk—and to draw implications about the formation of interorganizational EM collaborations that can enhance a particular configuration of ties. The findings in this research are considerably consistent with the argument provided by the director of the National Urban Disaster Management Research Center, Dr. Byoungjae Lee (2017). He strongly underscored the point that because current interorganizational collaboration tends to rely heavily on emergency planning and a paper-based system, a sparse network based on one-way relationships is more likely to fail in securing the resources and critical information needed by local organizations during a catastrophe. This emphasizes the necessity of transforming interorganizational collaboration into bilateral relationships, as confirmed by this research.

Despite these significant findings, this research has two limitations. First, an entire network relies on egocentric measures. As Scott (2000) noted, unreported ties may influence different network measures. Second, this study only examined a case in the Seoul metropolitan area in South Korea, so it may not be generalized to other regions and states. Future research could examine other metropolitan areas and identify key actors at local, regional, and national levels. Also, in-depth interviews with local officials could validate future research. Third, it is possible that the organizational behaviors noted by the representatives who responded to the survey no longer exist. Although it may be assumed that organizational representatives can act with agency on behalf of the organization itself, their perspective might not fully reflect the organization's behavior. Fourth, forging ties might be affected by other embedded relationships unrelated to disaster-oriented incidents. Despite a focus on the changes in ties before and after a disaster, they may also be influenced by other factors.

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Notes

1. All model specifications, estimates, and simulations were conducted using an RSiena package on the R platform (Ripley, Snijders, and Preciado 2012) and SIENA version 3.2 (Snijders et al. 2009). Also, SIENA stands for Simulation Investigation for Empirical Network Analysis.
2. Through these methods, a test of convergence (using SIENA) was conducted for each variable. If the convergence diagnostic statistics for the algorithm were less than 0.2 in absolute value, the parameter estimates were considered to have good convergence, and they were considered excellent when they were less than 0.1 (Snijders et al. 2010). The convergence diagnostic, covariance, and derivative matrices were based on one thousand iterations, and the *t*-value provided a significance test of the estimated parameters.

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