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Space, time, and the development of shared leadership networks in multiteam systems

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Abstract

Digital technologies have created the potential for new forms of organizing among geographically dispersed individuals by connecting their ideas across the time and space in complex multiteam systems (MTSs). Realizing this potential requires novel forms of shared leadership structures to shepherd divergent and convergent thinking necessary to nurture innovation. While there is limited research on how space influences leadership and how the time influences leadership, there is virtually no theorizing on how space and time interact together to influence the emergence of shared leadership structures that facilitates innovation. A key contribution of this study is to utilize an agent-based model (ABM) that draws upon the research on leadership, networks, and innovation to specify generative mechanisms (or micro-processes) through which shared leadership structures emerge over space and time. The parameters in this model were estimated from empirical data. Results of virtual experiments (VE) yielded testable hypotheses suggesting that, over time, leadership capacity and between-team ties are negatively influenced by space. Furthermore, the computational model suggests that space increases the concentration of divergent leadership but decreases the concentration of convergent leadership. The study concludes by discussing the implications for the design of effective leadership structures to nurture innovation in MTSs.

Keywords: shared leadership, networks, innovation, multiteam systems, computational modeling, agent based modeling

Digital technologies have created the potential for new forms of organizing among geographically dispersed individuals by connecting their ideas across time and space in complex MTSs. Realizing this potential requires novel forms of shared leadership structures to shepherd divergent and convergent thinking necessary to nurture innovation across time and space. In contrast to traditional views of organizations as being led by a unitary chain of command (Fayol, 1949), there is a going awareness that contemporary organizations are increasingly characterized by shared leadership. *Shared leadership* is defined as a dynamic social influence process whereby the members of a team mutually lead themselves toward the accomplishment of valued goals (Pearce, 2004).

There is also an increasing awareness that leadership in teams is a multidimensional activity facilitating the generation of ideas as well as their implementation. "Creativity is the production of novel and useful ideas in any domain;" however, leadership is also necessary for the "successful implementation" of these ideas (Amabile, 1996, p. 1). Therefore, creative, divergent thinking must be accompanied by focused convergent thinking in order to innovate (Bledow et al., 2009; Somech & Drach-Zahavy, 2013). Research has determined that the right mix of divergent and convergent leadership behaviors are important determinants of the creative or innovative output of a team (Jansen et al., 2009). Further, as knowledge becomes more specialized, these teams work in MTSs (DeChurch & Zaccaro, 2013). MTSs are networks of teams whose component teams work toward local team goals while also working within a larger network of teams toward a global goal shared by all teams.

While there is limited research on how space influences leadership (Druskat & Wheeler, 2003) and how time influences leadership (Lagendijk & Lorentzen, 2007; Meister & Werker, 2004), there is virtually no theorizing on how space and time interact together to influence the emergence of leadership structures in teams in general and those that facilitate divergent and convergent leadership behaviors in MTSs, in particular.

A key contribution of this study is to utilize an agent-based computational model that draws upon research on leadership, networks, and innovation to specify generative mechanisms (or micro-processes) through which leadership structures emerge over space and time in MTSs engaging in innovative activities. The parameters were empirically estimated using data collected from 33 MTSs engaged in innovative tasks over a two month period. We use this ABM to conduct VE to address our primary research question: how does space affect the emergence over time of divergent and convergent shared leadership networks in MTSs engaging in innovative tasks? In order to address this research question, we systematically evaluate the dynamic effects of two dimensions of space—organizational identity and geography—on five topological characterizations of divergent and convergent shared leadership networks that we argue are critical to innovation: (1) leadership capacity (i.e., density), (2) leadership concentration (i.e., in-degree centralization), followership concentration (i.e., out-degree centralization), (3) brokerage concentration (i.e., betweenness centralization), and between-teams leadership (i.e., between-team ties). Results of the VE yielded testable hypotheses about the impact of space and time on the emergence of divergent and convergent shared leadership structures within MTSs. By developing testable hypotheses, we seek to advance our theoretical understanding of how space and time influence leadership structures.

We begin the following section by reviewing research on shared leadership from a network perspective, recent efforts in delineating divergent versus convergent leadership reliance ties, as well as developing topological characterizations of shared leadership structures. In the subsequent section we outline five specific research questions about the impacts of space and time on shared leadership structures. The next section introduces the agent-based computational model that we developed to run VE in order to address these five research questions. This section also reports on the hypotheses deduced from analyzing the results of the VE. We conclude with a discussion of the substantive implications of our findings as well as more generally the use of computational modeling for theory building.

1 Theoretical background: a network perspective on leadership

Networks provide an appropriate framework to characterize the divergent and convergent leadership reliance ties among individuals within teams and between teams in an MTS (Carson et al., 2007). For instance, network representations have been used to characterize concepts such as leadership that is shared among team members (Mayo et al., 2003) as well as leadership concentration and leadership rotation (Carson et al., 2007). There have been recent efforts to review and clarify a variety of approaches that have been used to study leadership from a network perspective (Carter et al., in press; Contractor et al., 2012). They defined a leadership network as a set of individuals and the leadership reliance ties among them. They introduced a series of network-based concepts to characterize various topological dimensions of shared leadership. In the remainder of this section, we offer two extensions to Contractor et al.'s (2012) framework for characterizing shared leadership in teams. First, we distinguish between the content of divergent and convergent leadership reliance ties. Second, we introduce five topological characterizations of the divergent and convergent shared leadership networks that are most likely to impact innovation in MTSs.

1.1 Divergent versus convergent leadership

Leaders shepherd innovation by enacting two forms of leadership behaviors each mirroring distinct processes: exploration and exploitation (March, 1991). A meta-analytic integration of leadership and innovation finds that across leadership taxonomies (e.g., LMX, transformational leadership theory), the opening and closing behaviors of leaders best discriminate among those that give rise to innovation (Rosing et al., 2011). We adapt these behavioral sets to describe two types of leadership reliance network ties that form in MTSs: divergent leadership ties and convergent leadership ties. *Divergent leadership ties* are those whereby one member encourages one or more other members to generate creative ideas, to think outward, to experiment and try out new ideas, and to challenge their assumptions. *Convergent leadership ties* are formed when one member encourages one or more other members to critically evaluate and implement ideas, to narrow their focus, to think inward, and to focus on implementation (Bledow et al., 2009).

1.2 Topological characterizations

1.2.1 MTS leadership capacity

The first topological characterization of shared leadership is the capacity for leadership reliance. The size and scope of MTSs favor systems where members have the ability to rely on leadership ties with multiple individuals. This notion is evidenced in research on shared leadership (e.g. Carson et al., 2007). Innovation in an MTS is more likely when a system has a fully activated leadership reliance network. An idea can enter the MTS at any point, and take hold. The prevalence of many leadership reliance links enables the MTS to shift direction in response to new ideas that arise out of any of its teams. While this ability to uptake new ideas favors creativity, a fully activated leadership network also benefits the second dimension of innovation: implementation. Component teams who have very different expertise are well equipped to vet the ideas of other teams. Having many leadership reliance ties within and across teams, team can often surface problems and offer new solutions that will ultimately enable an innovation that is more implementable. This idea was supported by (Gray, 2008) who found transdisciplinary science teams benefited from multiple leaders required to navigate the complexity of their tasks (Gray, 2008). Accordingly, an important characterization of an MTS leadership network is its overall capacity for offering leadership reliance ties. We operationalize this capacity for leadership as the density of the leadership reliance network. That is the ratio of the observed ties in the shared leadership network to the total possible ties in the leadership reliance network (Wasserman & Faust, 1994).

1.2.2 Leadership concentration

The second topological characterization of shared leadership is the extent to which leadership is concentrated in one or a few individuals within the MTS. As such, it often reflects the degree of hierarchy present in the MTS. This concept is analogous to the notion of vertical leadership that is used in leadership research (Pearce, 2004). The concentration of leadership, the evenness with which influence is distributed has important implications for innovation. While hierarchies benefit the efficiency of a group, heterarchies may be better suited for innovation (Aime et al., 2013). Heterarchies enable groups to shift their reliance on different individuals for leadership according to who has the most relevant expertise, and in response to external pacers such as those imposed by competitor and market forces. We operationalize vertical leadership as the indegree centralization (Freeman, 1979) of leadership reliance ties.

1.2.3 Followership concentration

The third topological characterization of shared leadership is how distributed the followership is within the MTS. DeRue and Ashford (2010) recently articulated a role-based perspective where leadership can be understood as the co-construction of a role by the would-be leader and follower. The script begins when a leader "claims leadership", and ends when the follower "accepts leadership." This conceptualization of leadership and followership is particularly well-suited to testing with a network perspective—essentially explaining the underlying psychological process through which a directed tie is formed. In this case, we study the formation of a leadership reliance tie. Whereas the previous topological characterization of shared leadership, leadership concentration, captures the extent to which one or a few individuals claim leadership that is accepted by many others in the MTS, this third structural characterization of shared leadership, captures the extent to which one or a few individuals accept leadership from many others who claim it. We operationalize followership concentration as the out-degree decentralization (Freeman, 1979) of leadership reliance ties.

1.2.4 Brokerage concentration

The fourth topological characterization of shared leadership is the degree to which brokerage (Burt, 2005) in the leadership reliance network is evenly distributed within the MTS. Brokerage in the leadership reliance network describes the extent to which an individual has a positional advantage by virtue of being relied on as a leader by others who do not rely on each other for leadership. The extent to which this positional advantage is distributed across multiple individuals has important implications for innovation. Structural holes have been found to be important for exploration, and the discovery of new ideas in a variety of contexts (Burt, 2004). The group social capital perspective offered by Oh et al. (2006) also supports the role of brokerage, finding a team's performance to be a function of the external ties connecting that team to new pockets of information. In MTSs, the innovativeness of the overall system would be undermined if these valuable brokerage leadership positions are concentrated in one or a few members of the MTS. We operationalize the brokerage concentration as the betweenness centralization (Freeman, 1979) in the leadership reliance network.

1.2.5 Between-team leadership

The fifth topological characterization of shared leadership is between-team ties, useful during both the exploration and exploitation phases of innovation. During exploration, these conduits allow for the discovery of new ideas through recombination (Fleming, 2001). During exploitation, these conduits between teams allow ideas to be vetted ensuring they are implementable (Burt, 2004). Frequently, however, innovations require the perspectives and expertise possessed by members of multiple functions. An individual working in any of the functions would not be able to find an adequate solution by oneself. For these reasons, organizations frequently assemble diverse teams to address these challenges rather than relying on individuals (Cohen & Bailey, 1997; Mathieu et al., 2008). We operationalize between-team leadership as the count of the number of ties connecting the members of a given team to the members of other teams.

2 The impact of space and time on the emergence of shared leadership networks

In the previous section, we introduced five topological characterizations of shared leadership that we argue are most likely to impact innovation in an MTS. In this section, we focus on understanding how these five characterizations are shaped over time by the space between teams. In a sense, we explore the influence over time of one type of relation, i.e., the distribution of teams in space, on another type of relation, i.e., the leadership reliance ties that form among their members.

There are two important dimensions of space that are likely to influence the emergence of shared leadership networks in MTSs. The first dimension of space is organizational, and emerges as individuals identify themselves as part of an organization. Organizational identity, the extent to which an individual sees oneself as a part of the larger organization, has been linked to a wide range of individual attitudes, job behaviors, and extra role citizenship behaviors (Hatch & Schultz, 2002). The second dimension of space is geographic. Abundant research in the area of virtual and distributed teams convincingly demonstrates that geographic space affects the social relationships that form among individuals (Lagendijk & Lorentzen, 2007; Meister & Werker, 2004). While these studies have demonstrated the impact of organizational and geographic dimensions of space on innovation, it is unclear if and how shared leadership mediates this relationship. Hence, the primary aim of this study is to advance our understanding of the impact of both organizational and geographic space on the five topological characterizations of shared leadership networks thought to impact innovation.

2.1 Organizational space

The first dimension of space likely to affect the emergence of shared leadership networks is organizational. This aspect of space stems from the fact that individuals' identification with a larger organization prompts them to engage in a social categorization process. By this process, other organizational members are viewed as more similar to the self, and the members of other organizations constitute dissimilar out-groups. MTSs can reside in single organizations or cross boundary (Zaccaro et al., 2012). Single organization MTSs are comprised of component teams who are all part of the same organization. Individuals work in different teams, but share an organizational context. Cross-boundary MTSs have component teams which reside in different organizations. The teams of these MTSs are embedded in different contexts and identify with different organizations. Strategic alliances are examples of cross-boundary MTSs. Multidisciplinary research institutes where labs (i.e., teams) of researchers within the same university come together are an example of a single organization MTS.

2.2 Geographic space

The second dimension of space that can influence the emergence of shared leadership networks is geographic. Returning to the example of multidisciplinary research, work by Cummings and Kiesler (2007) supports the importance of geography to the functioning of complex systems. The authors find the productivity of large research centers, is hindered more by the introduction of geographic distance (i.e., multi-university) than by the introduction of disciplinary diversity (i.e., multi-disciplinary).

In this section, we have outlined our current understanding of how two dimensions of space influence innovation over time. The findings indicate that space does have an impact on innovation but there is very limited theoretical or empirical insight about any mediating role of leadership structures. We seek to gain these insights by asking the following research questions:

Characterization of Shared Leadership in MTSs # 1—MTS leadership capacity
RQ1: How does space affect the overall activation of the leadership network?
Characterization of Shared Leadership in MTSs # 2—leadership concentration
RQ2: How does space affect the concentration of leadership?
Characterization of Shared Leadership in MTSs # 3—followership concentration
RQ3: How does space affect the concentration of followership?
Characterization of Shared Leadership in MTSs # 4—brokerage concentration
RQ4: How does space affect the concentration of brokerage?
Characterization of Shared Leadership in MTSs # 5—between-team leadership
RQ5: How does space affect the activation of between-team ties?

In the next section, we describe the use of a computational ABM to conduct VEs in order to address these questions. Our goal is to be able to use the results of these VEs to deduce testable hypotheses of the impact of space on the emergence of shared leadership networks over time.

3 Model

This study is based on the premise that computational models can serve an important role in assisting with theory construction (Hanneman, 1988). Computational models are an appropriate platform to specify theoretically inferred micro-level social processes. This requires converting verbal statements of theories into equations about the processes by which variables in the theories influence one another over time. Since these processes are often non-linear, it is virtually impossible for humans to mentally intuit the emergent macro-level phenomena that are implied by these non-linear micro-level generative mechanisms over time (Monge & Contractor, 2003). After a computation model is specified and the parameters are estimated using empirical data, they can be used to conduct VE to address research questions for which the answers can, in principle, be deduced from the model but which is well-nigh impossible for the human mind to construe. The results of these VE are used to generate testable hypotheses implied by the theory but not easily deduced by simply considering the verbal statements of the theories (Hyatt et al., 1997; Palazzolo et al., 2006). It is important that the results of these experiments be interpreted as hypotheses which if tested and supported would indicate that the underlying generative mechanisms specified in the computational model were not proven incorrect. The results of these experiments should not be interpreted as a valid knowledge claim. Hence, VE are particularly useful for examining phenomena that emerge through complex interactions (Hulin & Ilgen, 2000; Kozlowski et al., 2013). In this study, we use VE to observe the impact of space and time on the five topological characteristics of divergent and convergent shared leadership networks that we argue are most critical in fostering innovation.

3.1 The agent-based model

To address our research questions, we developed an ABM for the emergence of divergent and convergent shared leadership networks (see description provided in Appendix A) based on theory and research in leadership, networks, and innovation. The model captures the process of leadership reliance link formation in networks as a series of four iterative steps. The steps, and the factors that enter the model at each step, are depicted in the Appendix, Figure A2.

Our ABM is built around DeRue and Ashford's model (2010) of leadership as a role making process between dyads where one party *claims* leadership and another party *grants* it. The ABM consists of four steps. The first three steps model the factors that jointly determine the claiming of leadership; these three steps determine whether or not leadership is claimed, what type of leadership, and to whom. The fourth step in the model determines the granting of leadership by the receiver. When leadership is first claimed and then granted, a leadership reliance link is formed. Building on DeRue and Ashford's general framework for leadership reliance link formation, we then dove deep into the leadership literature to inform the selection of the parameters that would shape the claiming of leadership, and the granting of leadership.

Appendix A explains the development of the model and selection of the parameters in more detail. Here, we provide an overview of the steps through which a leadership reliance link is formed. The process begins with an MTS member deciding whether or not to make a leadership claim (Step 1). This decision is influenced by prior leadership claims, the member's personal characteristics (motivation to lead, psychological collectivism, prior leadership experience, extroversion and neuroticism) and the member's network properties (advice indegree centrality and friendship outdegree centrality). If the member decides to make a leadership claim, the member then decides whether to claim convergent or divergent leadership (Step 2). Divergent leadership claims are influenced by certain personal characteristics (i.e., openness to experience, intercultural sensitivity, learning goal orientation), whereas convergence claims are influenced by other personal characteristics (i.e., agreeableness, consciousness, and performance goal orientation). Next, the member decides whether to claim leadership within the component team or across the entire MTS (Step 3). The decision to influence the claim leadership on the entire MTS rather than the team is influenced by the member's traits (i.e., extraversion and consciousness) and the episodic phase of the MTS (i.e., proximity to the MTS deadline; Gersick, 1988).

Once leadership is claimed, members must decide whether or not to grant it (Step 4). The decision to grant leadership is based in part on relational attributes of the leadership claimant and the prospective granter (i.e., behavioral homophily, gender homophily, friendship ties, advice ties, space), and in in part on norms of the fellow team members about granting leadership. If leadership is granted, then a leadership reliance link is formed. Thus, the network of divergent and convergent leadership ties are formed as an accumulation of the giving and granting of leadership among MTS members over the duration of the task. Older attempts decay in their contribution to the strength of subsequent leadership ties.

The model was built using NetLogo (Wilensky, 1999). The parameters for the computational model were estimated using the empirical data collected on all the variables in the model from 33 human MTS sessions which each ran for 47 days (see Appendix A for details on the empirical data used to estimate model parameters). The parameters were estimated using BehaviorSearch (Stonedahl & Wilensky, 2011). We next describe the use of the model in conducting VE to examine the effects of space on leadership network development over time in synthetic MTSs.

3.1.1 Virtual experiment—manipulations

Our virtual experiment was a single factor, fixed effects experiment manipulating space, the degree to which the component teams of an MTS are distributed in different countries and/or embedded within different organizations. Four conditions of increasing space between the four teams were manipulated on an ascending continuum from "no space between teams" (all four teams located in the same country and same organization), to "low space between teams" (all four teams located in the same country, but in different organizations), to "moderate space between teams" (all four teams located in different countries, but within the same organization), to "high space between teams" (all four teams located in different countries and from different organization). The organizational and geographic space within each team was held constant, by placing all team members within the same location and same organization. Hence, whereas we systematically varied the amount and type of "space" between the teams, all members of each of the MTS component teams were located in the same "space".

3.1.2 Synthetic MTSs

We used our computational model to run VE on 2,000 synthetically created (or computer generated) MTSs, comprised of 16 individuals assigned into four teams of four members each. The team members' individual attributes (e.g., enthusiasm and extraversion) were randomly generated based on the aforementioned empirical data. We calculated the mean and standard deviation from the empirical data for each individual attribute included in the model. We then used those means and standard deviations to generate attributes (e.g., enthusiasm and extraversion) for the members of the simulated MTSs. Likewise, the friendship and advice networks for each team were randomly generated to have the same network density as the observed data. The parameters of the model were the same as those fitted to the empirical data (for example, the importance of extroversion in deciding to send an influence attempt).

3.1.3 Simulating MTSs

We used the computational model to simulate the emergence of shared leadership networks for all 2,000 MTSs. We randomly assigned 500 MTSs to each of our four manipulation conditions (i.e., no, low, moderate, and high space between teams). This includes 32,000 simulated individuals working in 8,000 teams assembled into 2,000 MTSs. The magnitude of the dataset underscores the value of using VE as a theory-development and refinement tool, to enable more efficient follow-up experimentation with humans. The simulation was run for a 47 day period, identical to the duration of the MTSs for which empirical data were collected. The divergent and convergent leadership networks for each of the 2,000 MTSs were captured for each of the 47 time points and were used to compute the dependent variables to address our five research questions. These are discussed next.

3.2 Measures

In order to investigate the effects of organizational and geographic space on shared leadership networks, we computed the five topological characteristics of shared leadership network for each of the 2,000 MTSs after the 47 simulated days. This time interval was chosen because it corresponds to the time interval for the sample of project teams that was used to fit the model, and because seven weeks is a reasonable interval within which patterns of influence would develop within groups who are interacting on a regular basis. We used the statnet package in R (Handcock et al., 2008) to compute each of the following network measures separately for divergent and convergent leadership networks.

3.2.1 Leadership capacity

MTS leadership capacity was indexed as the density leadership networks. This represents the proportion of existing ties in each of these networks divided by the number of possible ties among the 16 members of the MTS. Leadership ties were directed, so density scores indicate the number of influence ties present in the MTS out of 240 possible ties (i.e., if every member of the MTS relied on every other member for leadership). These scores are interpretable as the amount of divergent and convergent leadership capacity within the MTS.

3.2.2 Leadership concentration

We indexed leadership concentration, the extent to which influence is concentrated in a few individuals versus evenly distributed across individuals, using *indegree centralization*. The indegree centralization shows how much variance there is in the distribution of centrality among the actors in a network. In our case, high indegree centralization shows that there are few people in the divergent and convergent leadership network that are sought after for their leadership.

3.2.3 Followership concentration

We indexed followership concentration, the extent to which a few members rely on leadership from many more members than others, using *outdegree centralization*. The outdegree centralization shows how much variance there is in the distribution of outdegree centrality among members in a network. High outdegree centralization indicates that the MTS has variation in the degree to which its members rely on the leadership from others. Low outdegree centralization indicates that MTS members show similar levels of followership in the divergent and convergent shared leadership networks.

3.2.4 Brokerage concentration

We indexed the brokerage concentration using betweenness centralization**.** MTSs with high brokerage concentration are those where relatively few individuals maintain influence relationships with individuals who do not directly influence one another. Conversely, MTSs low on brokerage concentration are comprised of members who are relatively even in the extent to which they have influence ties to others who do not directly influence one another. The betweenness centralization metric was computed for both convergent leadership and divergent leadership, indicating how much variance there is in the distribution of betweenness centrality in each of these leadership networks.

3.2.5 Between-team leadership

We indexed between-team leadership as a count of the number of between-team ties connecting the members of a given team to the members of other teams. Each team had 4 members, each of whom could form directed leadership reliance links with 12 other members. And so, a team's between-team leadership score was the number of observed leadership links between the focal team and the other three teams, divided by the total possible number of between-team ties (i.e., 96). The scores for the four teams were then averaged to represent the amount of between-team leadership present in the MTS. In an MTS with high between-team leadership, nearly all possible conduits for leadership across teams will be realized. In an MTS with low between-team leadership, few of the between-team leadership relationships that can be present are actually present.

4 Results

In order to develop testable hypotheses from our five research questions, we used ANOVA to detect statistically significant differences in the resulting leadership network structures based on organizational and geographic space. The divergent and convergent leadership networks for the four conditions were compared using a one-way ANOVA and paired-samples *t*-tests. We used one-way ANOVAs to represent "space" on an ascending continuum from none (same country, same organization), to low (same country, different organization), to moderate (different country, same organization), to high (different country, different organization). Table 1 present the resulting leadership networks at simulated day 47.

RQ1: Impact of Space on Leadership Capacity over Time

Results show that overall, MTSs exhibited more divergent leadership capacity than convergent leadership capacity ($t = 509.89$, $p < 0.001$). Table 1 shows the average divergent leadership network density was 90%, whereas the convergent leadership network density was 28%. A one-way ANOVA suggests a significant effect of space on both divergent ($F(3,1996) = 596.60$, $p < 0.001$) and convergent ($F(3,1996) = 661.37$, $p < 0.001$) leadership capacity. Figure 1 shows the leadership capacity of the MTS at all four levels of between-team space. The means presented in Table 1 show that space was inversely related to an MTS leadership capacity. MTSs where teams had no space between them, showed the greatest divergent and convergent leadership capacity, whereas MTSs with teams from different organizations who were also located in different countries had the lowest divergent and convergent leadership capacity. Post-hoc comparisons reveal that all space conditions were significantly different than each other for both divergent and convergent leadership. Based on these results, we posit:

Hypothesis 1: Space between teams suppresses the development of divergent (H1a) and convergent (H1b) leadership capacity in MTSs.

RQ2: Impact of Space on Leadership Concentration over Time

Table 1 also shows that MTSs exhibited less leadership concentration in the divergent leadership network ($M_{\text{indegree centralization}} = 0.11$, $t = -96.91$, $p < 0.001$)

Table 1. *One-way ANOVAs examining the impact of space on topology of shared leadership.*

	Amount of space between teams											
	No space ($n = 500$)		Low space ($n = 500$)		Moderate space ($n = 500$)		High space ($n = 500$)		Overall ($n = 2{,}000$)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F-value	MS
MTS leadership capacity												
Divergent	0.94[a†]	0.03	0.91[b]	0.03	0.90[c]	0.03	0.85[d]	0.03	0.90	0.04	596.60***	0.608
Convergent	0.34[a]	0.05	0.29[b]	0.05	0.27[c]	0.05	0.22[d]	0.04	0.28	0.06	661.37***	1.35
Leadership concentration												
Divergent	0.07[a]	0.03	0.09[b]	0.03	0.11[c]	0.04	0.16[d]	0.04	0.11	0.05	570.55***	0.661
Convergent	0.40[a]	0.10	0.38[b]	0.10	0.36[c]	0.09	0.31[d]	0.08	0.36	0.10	82.63***	0.705
Followership concentration												
Divergent	0.06[a]	0.03	0.09[b]	0.03	0.10[c]	0.03	0.13[d]	0.03	0.10	0.04	480.84***	0.394
Convergent	0.22[a]	0.06	0.21[a]	0.06	0.21[a]	0.06	0.19[b]	0.06	0.21	0.06	13.02***	0.049
Brokerage concentration												
Divergent	0.00[a]	0.01	0.00[a]	0.01	0.01[a]	0.01	0.01[b]	0.01	0.01	0.01	46.15***	0.003
Convergent	0.11[a]	0.05	0.13[b]	0.05	0.14[c]	0.05	0.16[d]	0.06	0.13	0.06	96.31***	0.271
Between-team leadership												
Divergent	43.89[a]	1.64	42.30[b]	1.79	41.61[c]	1.82	38.62[d]	1.95	41.60	2.63	745.04***	2426.7
Convergent	14.48[a]	2.55	11.60[b]	2.18	10.56[c]	2.10	7.48[d]	1.74	11.03	3.31	892.55***	4173.4

Note. Degrees of freedom for all analyses = 3, 1996; $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$.
[†]Superscripts on the mean values indicate which groups of conditions were statistically different from others.

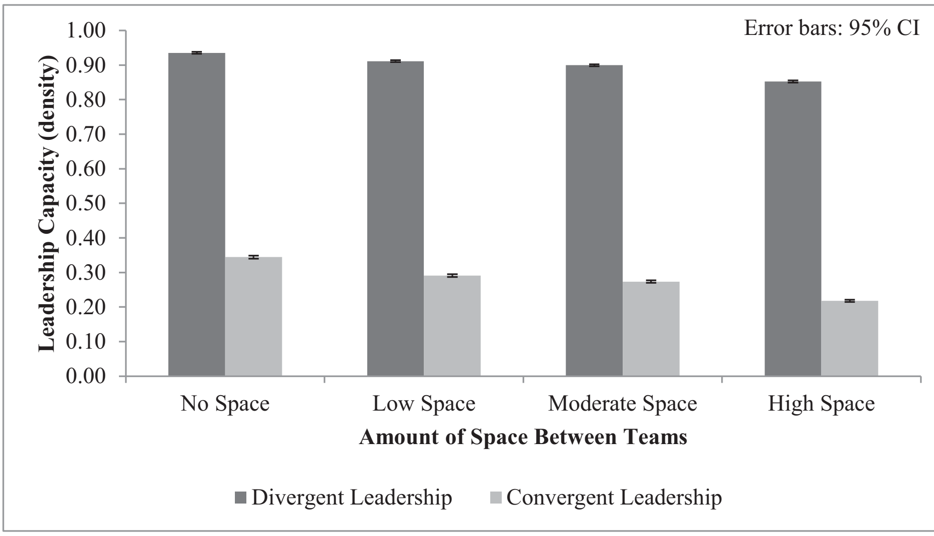

Fig. 1. MTS leadership capacity.

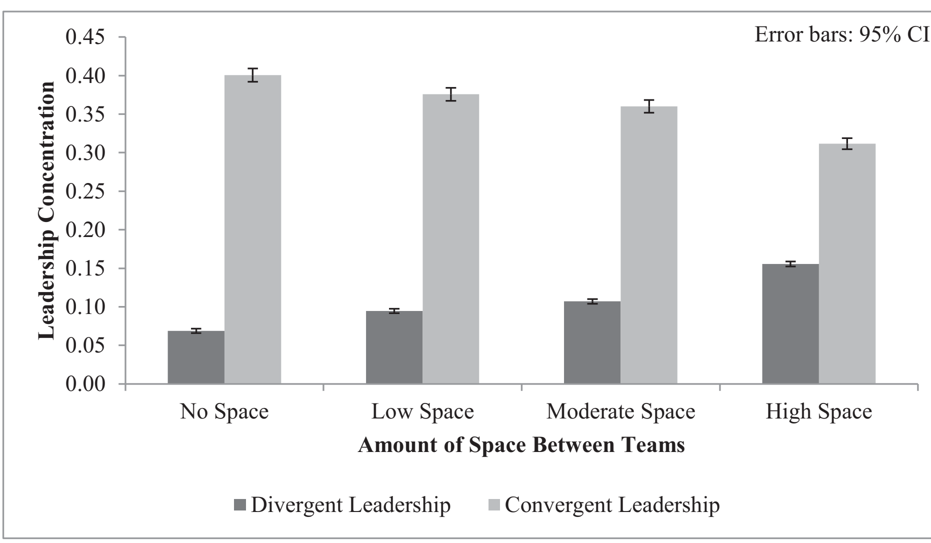

Fig. 2. Leadership concentration.

than in the convergent leadership network ($M_{\text{indegree centralization}} = 0.36$). ANOVA results indicate that divergent leadership was more concentrated among MTSs that had more space between teams ($F(3,1996) = 570.55$, $p < 0.001$). Figure 2 depicts the leadership concentration at the four levels of between-team space. Post-hoc comparisons show that the concentration of both divergent and convergent leadership was significantly different at each level of space ($F(3,1996) = 82.65$, $p < 0.001$). Based on these observations, we posit two hypotheses about the impact of space on leadership network emergence:

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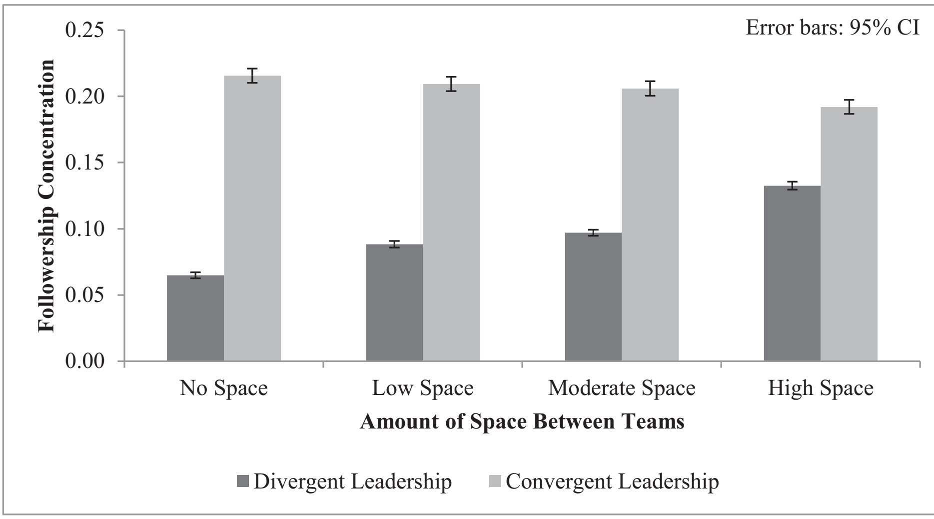

Fig. 3. Followership concentration.

Hypothesis 2: MTSs where component teams have larger space between teams have more concentrated divergent leadership networks than do MTSs where component teams have smaller space between teams.

Hypothesis 3: MTSs where component teams have larger space between teams have less concentrated convergent leadership networks than do MTSs where component teams have smaller space between teams.

RQ3: Impact of Space on Followership Concentration over Time

Table 1 shows the follower concentration was lower for the divergent leadership network ($M_{\text{outdegree centralization}} = 0.10$) than for the convergent network ($M_{\text{outdegree centralization}} = 0.21$, $t = 64.99$, $p < 0.001$). ANOVA results indicate that MTSs with more space between teams have more concentrated divergent followership networks than do MTSs with less space between teams ($F(3{,}1996) = 480.84$, $p < 0.001$). In contrast, ANOVA results also show that MTSs with more space between teams have less concentrated convergent followership networks than do MTSs with less space between teams ($F(3{,}1996) = 13.02$, $p < 0.001$). Figure 3 presents the followership concentration of the divergent and convergent leadership networks at each level of space. Post-hoc tests show follower concentration in the divergent leadership network was significantly different at each level of space, whereas follower concentration in the convergent leadership network was only different when comparing MTSs where teams had no space between them, to those with any space between them. Based on these observations, we posit two hypotheses about the impact of space on followership concentration:

Hypothesis 4: MTSs where component teams have larger space between teams have more concentrated divergent followership networks than do MTSs where component teams have smaller space between teams.

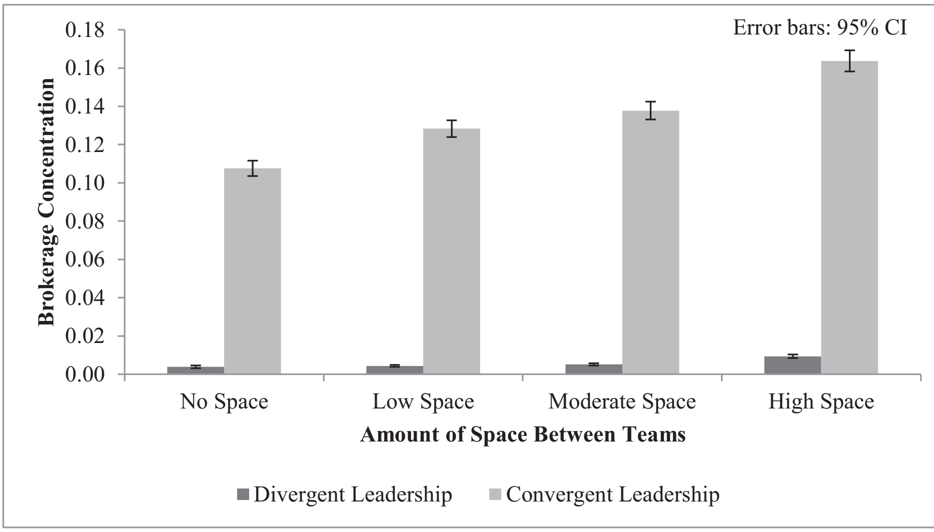

Fig. 4. Brokerage concentration.

Hypothesis 5: MTSs where component teams have any (i.e., low, moderate, or high) space between teams have less concentrated convergent followership networks than do MTSs where component teams have no space between teams.

RQ4: Impact of Space on the Brokerage Concentration over Time

Table 1 shows that brokerage was less concentrated for the divergent leadership network ($M_{\text{betweenness centralization}} = 0.01$) than for the convergent leadership network ($M_{\text{betweenness centralization}} = 0.13$, $t = 101.46$, $p < 0.001$). ANOVA results indicate that space exhibits a significant effect on the concentration of brokerage in both the divergent and convergent leadership networks. MTSs with more space between teams had more concentrated brokerage in their divergent leadership networks than did MTSs with less space between teams ($F(3{,}1996) = 46.15$, $p < 0.001$). Conversely, MTSs with more space between teams had more concentrated brokerage in their convergent leadership networks than did MTSs with less space between teams ($F(3{,}1996) = 96.31$, $p < 0.001$). Figure 4 presents the brokerage concentration for the divergent and convergent leadership networks. Post-hoc tests showed that for the divergent leadership network, brokerage was more concentrated in the "high space" condition than in no, low, and moderate space conditions. There were no significant differences in the brokerage concentration of the divergent leadership network for the no, low, and moderate space conditions. For the convergent leadership networks, the brokerage concentration was significantly different at each level of space.

Hypothesis 6: MTSs where component teams have large space between teams have more concentrated divergent brokerage networks than do MTSs where component teams have no, low, or moderate space between teams.

Hypothesis 7: MTSs where component teams have larger space between teams have less concentrated convergent brokerage networks than do MTSs where component teams have smaller space between teams.

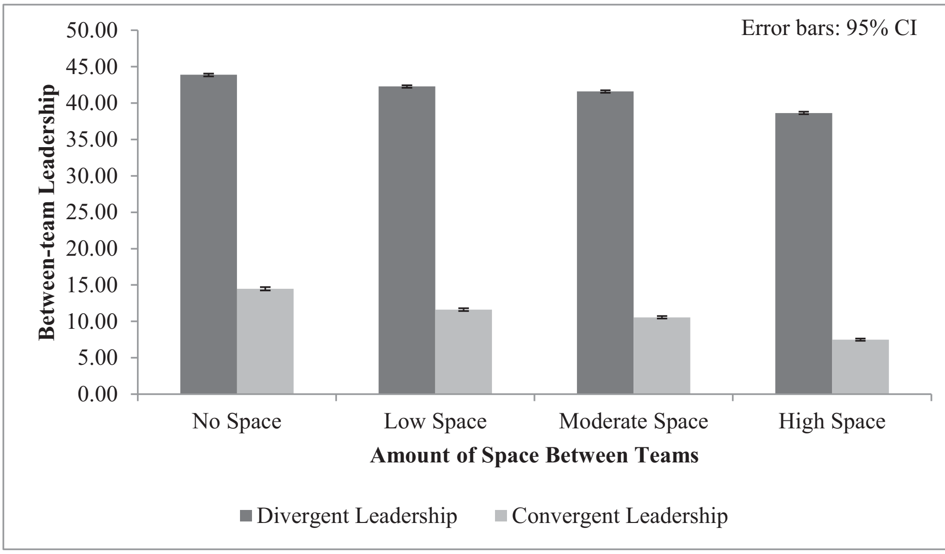

Fig. 5. Between-team leadership.

RQ5: Impact of Space on Between-team Leadership over Time

Table 1 shows that MTSs had more between-team leadership ties in their divergent leadership networks (M = 41.60) than in their convergent leadership networks (M = 11.03, $t = -500.58$, $p < 0.001$). ANOVA results show that there are fewer between-team divergent leadership ties when space is higher than when it is lower ($F(3{,}1996) = 745.04$, $p < 0.001$). Similarly, there are fewer between-team convergent leadership ties when space is higher than when it is lower ($F(3{,}1996) = 892.55$, $p < 0.001$). Figure 5 presents the number of between-team ties based on the degree of space between teams. Post-hoc comparisons reveal that, for both the divergent and convergent leadership networks, the number of between-team ties is significantly lower at each increasing level of space.

Hypothesis 8: MTSs where component teams have larger space between teams have fewer between-team divergent (H8a) and convergent (H8b) leadership network ties than do MTSs where component teams have smaller space between teams.

5 Discussion

New forms of organizing have prompted new interest on the impact of space and time on the emergence of leadership structures. While there is some research indicating that space influences leadership and others that document the influence of the time over leadership, there is little theoretical or empirical understanding of the influence of space and time on divergent and convergent shared leadership in teams in general and, more particularly, in MTSs engaging in innovative tasks.

This study reported results of VE conducted using empirically-estimated the agent-based computational models to explore the effects of space and time on leadership structures in MTSs. More specifically, we systematically evaluate the effects of two dimensions of space—organizational and geographic—and time on the five topological characterizations of shared leadership in MTSs. This research makes two key contributions: a substantive contribution on the effects of space and time on shared leadership; and a methodological contribution on the use of empirically estimated ABM s to conduct VE to deduce new testable hypotheses about network structures. We discuss these two contributions in further detail below.

5.1 Effects of space and time on shared leadership

Findings suggest that, over time, the introduction of space between teams in an MTS affects the topological aspects of leadership network formation. Often the effects of space on the emergence of divergent shared leadership networks differ from those of convergent shared leadership networks. We now consider the results of our VE in closer detail.

5.1.1 Leadership capacity

Our first research question was, how does space affect the overall activation of the leadership network? Our findings suggest that space suppresses the leadership capacity of MTSs. When teams are more distant—as is created by both geographic and organizational spatial separation, there is an overall reduction in the number of leadership reliance links that develop within the MTS. This same pattern was observed for both the divergent and convergent leadership networks. This may be particularly problematic given that MTSs with component teams far apart are precisely those most in need of greater leadership capacity than their “close” counterparts. When component teams work at a distance, the suppression of leadership capacity relative to co-located, single-organization MTSs will serve to reinforce the team boundaries. This may ultimately prevent the MTS from benefiting from the diverse perspectives brought to bear by multiple teams. These ideas are in need of the future testing. If supported, this finding suggests network interventions that promote the development of leadership reliance links, for example through team staffing practices, are particularly important.

5.1.2 Leadership concentration

Abundant research has shown that teams benefit from collective leadership (Pearce, 2004). Contractor et al. (2012) placed a network lens over the collective leadership phenomenon, elaborating how shared leadership can be characterized by using network concepts such as concentration. Leadership capacity in teams and MTSs increases as concentration is reduced and leadership is more diffuse, where multiple individuals evenly share in the leadership of the collective.

Our second research question was, how does space affect the concentration of leadership? The experimental results show interesting differences result from the introduction of space. Whereas space prompts divergent leadership to become more concentrated, it helps to distribute the convergent leadership more evenly. Simply put, when MTS component teams work at a distance, they tend to rely on fewer individuals to push for divergent thinking that enables the creative dimension of innovation. However, they rely evenly on individuals to push for convergent thinking that enables the implementation dimension of innovation. In terms of innovation, this tendency could be partially counterproductive, as MTSs need both divergent and convergent leadership. The uneven distribution of divergent leadership may impede the discovery of novel ideas residing within MTS members. If these hypotheses were empirically supported, it would invite interesting theoretical considerations.

5.1.3 Followership concentration

Building on DeRue and Ashforth's (2010) notion of claiming and granting leadership, we advance the topological notion of followership concentration in shared leadership networks. While the research has emphasized the importance of distributing leadership across members of the group, the flip side is that followership also needs to be evenly distributed. Individuals need to be relatively uniform in the number of members to whom they grant leadership. When followership is highly concentrated, the MTS has a few "faithfuls" who grant leadership to many more members than the rest of their peers. Hence, the MTS misses out on the ideas and inputs of those individuals with few followers.

We posed the question, how does space between teams affect the concentration of followership? Our findings suggest that space has differential effects on the concentration of followership in the divergent as compared to the convergent shared leadership networks. Findings suggest that space prompts followership of the divergent shared leadership to become more concentrated. A relative few are following attempts of many more leaders than their peers to probe the MTS to discover new ideas. On the other hand, findings suggest that space prompts the distribution of followership more evenly for convergent shared leadership. That is, more individuals are evenly granting leadership to gain convergence around ideas. Interestingly, results show that MTSs benefit in terms of followership distribution, by any amount of space between teams. The change was not significant between the low, medium, and high space conditions, indicating that even a little distance between component teams is enough to trigger even distribution of followership. In the case of followership, even distributions of both the divergent and convergent leadership are needed to nurture innovation via exploration and exploitation efforts, respectively. If this hypothesis is supported, future research is needed that evaluates the theoretical mechanisms, and explores interventions that may alter the development of followership when it comes to divergent leadership.

5.1.4 Brokerage concentration

A fourth characterization of shared leadership networks is the extent to which the positional advantages of brokerage are concentrated in the hands of an influential few versus distributed evenly within the MTS. The concentration of brokerage may harm the implementation dimension of innovation as it creates a discrepancy in the relative power of members in influencing others who are not able to influence one another directly. The implementation dimension is more closely associated with the convergent leadership. On the other hand, it may also be the case that concentrated brokerage benefits the creative dimension of innovation by allowing for a relatively few individuals to efficiently transmit the ideas of MTS members who do not follow one another. The creative dimension of innovation is more closely associated with divergent leadership.

The fourth research question posed in this study is how does space affect the concentration of brokerage in the leadership networks? Our findings showed interesting differences in how space affects the emergence of divergent and convergent leadership networks. For divergent leadership, brokerage was more concentrated if MTSs exhibited high space. That is if component teams were both geographically dispersed as well as drawn from multiple organizations. This suggests that geographically distributed MTSs from multiple organizations may be more effective in the creative dimension of innovation. Findings did not suggest significant differences in the brokerage concentration for the remaining three—no, low, and moderate—space conditions. Findings also show that component teams with more space have less concentrated brokerage networks than do MTSs whose teams are less separated. Here, again geographically distributed MTSs appear to be more effective in the implementation dimension of innovation. If this hypothesis were supported, it would generate considerable new theorizing on the heretofore unanticipated virtues of the divergent and convergent shared leadership in geographically and organizationally distributed MTSs for fostering innovation.

5.1.5 Between-team leadership

A robust idea both in the MTS and network's literature is that innovation wins when diverse ideas are brought together. In MTSs, superordinate goals require that component teams have leadership links to other teams. Benefiting from novel combinations of ideas has been show in the networks literature to spur innovation (Fleming et al., 2007). Thus, our final research question was: how does space affect the activation of between-team ties? Findings show that space is harmful to the formation of between-team leadership ties. Given the importance of between-team ties to the coherent functioning of an MTS (Zaccaro & DeChurch, 2012), this finding raises a clear concern. MTSs with spatial dispersion between teams are the most likely to suffer from between-team process losses such as a lack of shared context (Hinds & Mortensen, 2005). This hypothesis, if supported, poses an important challenge for the future research, to identify leverage points that change the course of leadership network emergence and allow for the formation of more between-team leadership links.

5.2 Computational approach

In addition to advancing theory of leadership networks and the effects of space on the emergence of leadership networks, this research makes a second valuable contribution. This research uses methodologies to build theory and hasten the design of efficient studies that hone in on critical issues in the emergence of leadership networks. Agent based modeling and virtual experimentation are underutilized in the social sciences in general, and in leadership research in particular. This study illustrates how these tools can be fruitfully applied to understand complex social phenomenon. It demonstrates the ability of VEs to help us theoretically principled manner the differences (such as larger or smaller spaces between teams) that ought to make a difference (in the emergence of shared leadership structures). This is a parsimonious approach to theory development since it helps refine the design and execution of experiments or field studies to test only those factors that we anticipate will have an impact.

5.3 Limitations

While this study makes a number of important contributions to the leadership, innovation, and networks literatures, we consider a number of important limitations. First, we used well-supported leadership and network theories to build the ABM; however, there are influences that we did not include in the model to avoid it becoming too complex. Second, the parameters of the model were fit using a sample of 33 MTSs with between 10 and 12 members each. Ideally, we would have had more and larger MTSs. Finally, since we are using a computational model, our results can only guide us in generating hypotheses about how shared leadership is affected by space. These hypotheses must still be tested before we can make any valid knowledge claim about the effects of space on the emergence of shared leadership networks.

5.4 Future directions

A major contribution of this research is the generation of hypotheses about the effects of space on the emergence of five topological aspects of leadership networks. These findings suggest two interesting avenues for the future research. First, these findings suggest the need for empirical studies to evaluate these hypotheses in ongoing work teams interacting in MTSs. A second future direction is the identification of interventions capable of nudging the emergence of divergent and convergent leadership networks to topologies that are more amenable to nurture innovation. The research reported here is primarily to understand the effect of space on leadership structures and, by extension, on innovation. We are generating hypotheses about what is likely to happen in MTSs. Once we have a better handle on the drivers of shared leadership emergence, a new avenue would be to use computational modeling as it is more commonly used in other areas of hard science and engineering: to optimize the assembly of MTSs based on members' personality characteristics and their prior network relations that are most likely to result in the emergence of shared leadership structures that will shepherd innovation.

Third, future research is needed to determine more precisely the impact of each of the five topological characterizations of shared leadership on innovation in MTSs. This research advances five topological aspects of leadership in MTSs, only some of which have been the subject of rigorous testing, e.g., leadership capacity. Investigations of the impact of newer forms such as leadership brokerage concentration on innovation represent an interesting avenue for future work.

Fourth, the results of the VE have offered several intriguing and in some cases, at least initially, counter-intuitive insights about the differential impact of space and time on shared leadership. However, the computational models do not offer insights into isolating the sources of these differences. As the complexity of ABM s increase both in terms of the number of variables directly, indirectly, and in loops influencing divergent and convergent behaviors, it becomes increasingly challenging for the human mind to mentally intuit and/or computationally isolate the specific sources of these differences. Indeed, one of the reasons to use modeling to examine the effects of space and time on leadership network structure was the complexity of tracing these effects. While computational models, including the one used in this study, are acclaimed for predicting unanticipated "emergent" behaviors that were difficult to intuit, computational modeling methods lag in their ability to isolate the sources of these emergent behaviors. From a methodological standpoint, this is definitely an area of future research.

5.5 Conclusion

Spurred by advances in digital technologies, novel forms of organizing with shared leadership at the helm is increasingly the coin of the realm in the 21st century. There is evidence that the structures of shared leadership—including both divergent and convergent behaviors—influence the innovativeness of teams and MTSs. While there is general recognition that space and time impact the emergence of shared leadership structures, we have not developed theoretical or empirical understanding about the nature of this impact. This study takes an important step in addressing this research question. Given the complexity of examining this phenomenon, this study showcases a novel methodological approach that combines the use of VE run on an empirically estimated agent-based computational model to deduce testable hypotheses about the differential impacts of convergent and divergent on five distinct topological characterizations of shared leadership networks. The results demonstrate the utility of this approach to reveal systematic and significant differences in the pace and magnitude of the impact of space and time on the emergence of convergent and divergent leadership behavior as characterized by their topologies. Findings, such as these, will be critical in helping build leadership interventions to advance innovation in teams and MTSs.

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Appendix: empirical validation of the ABM

Participants and procedure

We collected empirical data in order to estimate the model parameters that best fit a sample of MTSs engaged in an innovation task, separated by organizational and geographic space, interacting over time. Participants were students working on a semester long course project. Students were located at either Georgia Tech (GT),

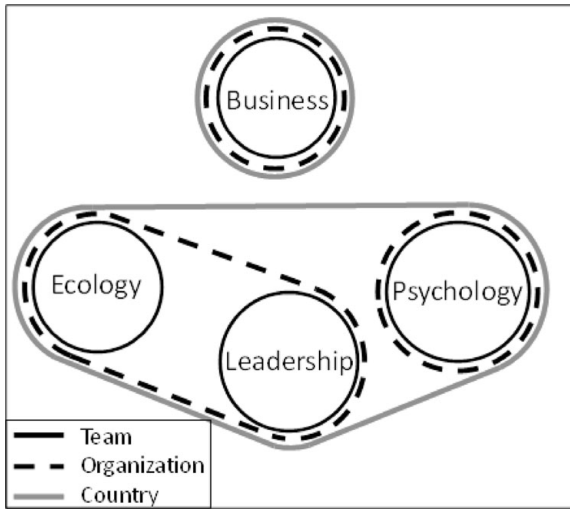

Fig. A.1. Configuration of the MTSs in this study.

George Mason University (GMU), or the Grenoble Ecole de Management (GEM) in France during the Fall semester of the 2012–2013 school year. The project lasted 47 days, or approximately 7 weeks. The sample consisted of 33 MTSs, each consisting of 9–12 students ($N = 326$). There were four component teams: Ecology, Business, Psychology, and Leadership. The MTS goal was to develop a plan for the use of a SmartCity technology that would improve environmental sustainability in a world city with a population of 3–5 million people. Each team was tasked with providing one type of functional expertise needed for the project. The Leadership and Ecology teams were students at GT, Social Psychology members were studying GMU, and Business teams were students at GEM. Each MTS was composed of students distributed across team, organizational, and national boundaries. A summary of the configuration of each MTS is shown in Figure A1.

All variables included in the ABM were assessed using surveys collected at multiple points during the project. There were four time points at which data was collected. Individual characteristics and network properties were assessed at the project start. Leadership networks were assessed using sociometric items, "who do you rely on for leadership?", obtained at three points in time during week following a team or MTS deadline. There were three weeks between the project start and the first measure of leadership networks, and then one week between each subsequent survey measure.

Model implementation

Model initialization

The model starts with the initialization phase. First, the empirical data about MTSs is uploaded. The information put in to the model is the attributes of the members of each MTS and the relations between team members (information used for running the model), and the final divergent and convergent reliance networks (information used for parameter fitting). Additionally, the probabilities describing episodic influences are pre-calculated and stored in a file that is input for each MTS.

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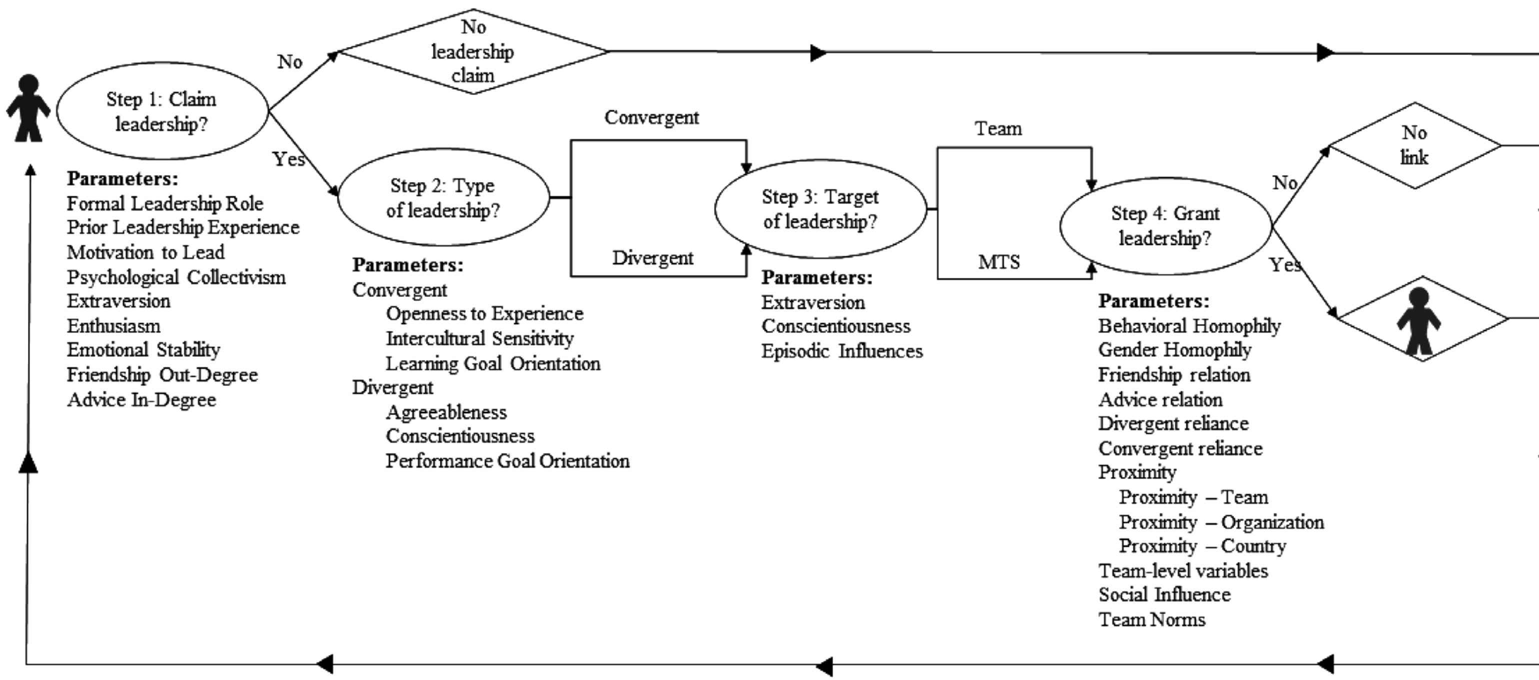

Fig. A.2. The process through which leadership reliance links are formed.

Table A.1. *Description of the ABM parameters and rules.*

Parameter	Description	Rule	Citation/studies
Step 1: A member decides whether or not to claim leadership			
Individual variables			
Motivation to lead	Individual difference which describes an individuals' proclivity to assume leadership training, roles, and responsibilities; captures both the intensity of effort at leading and persistence as a leader.	Members high on motivation to lead have an innate drive to lead making them highly likely to claim leadership.	(Chan & Drasgow, 2001)
Psychological collectivism	The degree to which a member is concerned with developing norms and goals within the team.	Members high on psychological collectivism are likely to recognize when leadership is needed, put forth the extra effort required to provide leadership and thus be engaged in claiming leadership.	(Jackson et al., 2006)
Leadership biodata	The extent to which an individual has participated in leadership activities in the past.	If an individual has participated in leadership activities in the past, it is more likely that he or she will claim leadership.	(Mumford et al., 1993)
Enthusiasm	The degree to which members are excited about the task at hand.	Members who are more enthusiastic about the project are more likely to claim leadership.	(Lee-Davies et al., 2007)
Extraversion	The degree to which individuals are active, outgoing, emotionally positive, energetic, and eager.	Extraverts are more likely to be engaged with the project and to claim leadership.	(Judge et al., 2002)
Neuroticism	The tendency of individuals to experience poor emotional adjustment and other negative emotions such as anxiety, insecurity, and hostility.	Members who are high in neuroticism are less likely to claim leadership.	(Judge et al., 2002)
Formal leadership	Assignment to the role of leader.	Members of the leadership team feel more responsibility to provide direction and more comfort in claiming leadership.	(DeRue & Ashford, 2010)

Table A.1. *Continued.*

Parameter	Description	Rule	Citation/studies
Relational variables			
Friendship out-degree	The number of people a person considers to be a friend within a certain context.	Members who have higher friendship out-degrees relative to their component team are more likely to claim leadership.	(Carson et al., 2007)
Advice in-degree	The number of members who indicate that they go to a particular member for advice on work-related issues.	Members who have relatively more popularity than others in terms of advice relationships may be more likely to claim leadership.	(Carson et al., 2007)
Step 2: If the member decides to claim leadership, she/he must determine whether to claim divergent or convergent leadership.			
Divergent influence			
Openness	The extent to which an individual is oriented toward active imagination, nonconformity, and autonomy.	Individuals high on openness are more likely to claim divergent leadership.	(Bledow et al., 2009; Judge et al., 2002)
Intercultural sensitivity	The degree to which an individual is motivated to understand, appreciate, and accept differences between cultures.	Members high in intercultural sensitivity are more likely to claim divergent leadership.	(Chen & Starosta, 2000)
Learning goal orientation	Individuals' desire to enhance one's abilities by mastering new skills and situations.	Members with high learning goal orientation are more likely to encourage opening behaviors and claim divergent leadership.	(Gong et al., 2009)
Convergent influence			
Agreeableness	The degree to which individuals are pleasant, cooperative, and caring.	If agreeable members are compelled to provide leadership, they are much more likely to claim convergent leadership.	(Bledow et al., 2009; Judge et al., 2002)
Conscientiousness	The degree to which individuals are hard-working, persistent, organized, and responsible.	Conscientious members are more likely to claim convergent leadership.	(Judge et al., 2002)

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Table A.1. *Continued.*

Parameter	Description	Rule	Citation/studies
Performance goal orientation	The individual tendency to prove and validate competence by pursuing positive judgment and avoiding unfavorable feedback.	Members with high performance goal orientation are more likely to claim convergent leadership.	(VandeWalle et al., 1999)
Step 3: If the member decides to claim leadership, she/he must determine whether to claim leadership of the team or MTS.			
Broadcast level			
Extraversion	The degree to which individuals are active, outgoing, emotionally positive, energetic, and eager.	Members high on extraversion are more likely to claim leadership over the entire MTS rather than just their component team.	(Judge et al., 2002)
Conscientiousness	Extent to which individuals are diligent, organized, and strive for achievement.	Members high on conscientiousness are more likely claim leadership over the entire MTS than just their own component team.	(Judge et al., 2002)
Episodic influence	The proximity of an impending deadline.	Members will try to claim leadership over the entire MTS rather than just their component teams in periods preceding MTS-wide deadlines.	(Marks et al., 2001)
Step 4: Members who have received the leadership claim must decide whether or not to grant leadership.			
Relational variables			
Behavior homophily	The degree to which the leadership claimant has the same preferences towards either divergent or convergent behavior as the member granting leadership.	Leadership reliance links are more likely to form when the person claiming leadership has similar references as the person granting leadership.	(McPherson et al., 2001)
Gender homophily	Whether the sender and receiver are the same gender.	If the receiver is the same gender as the sender, the receiver is more likely to accept the sender's influence attempt.	(McPherson et al., 2001)

Table A.1. *Continued.*

Parameter	Description	Rule	Citation/studies
Friendship relation	Whether the receiver of the influence attempt has indicated that he or she has a friendship relationship with the sender.	If a receiver reports a friendship relation with the sender, the receiver is more likely to accept the sender's influence attempt.	(Carson et al., 2007)
Advice relation	Whether the receiver of the influence attempt has indicated that he or she goes to the sender for advice on work-related issues.	If the receiver reports an advice relationship with the sender, the receiver is more likely to accept the sender's influence attempt.	(Carson et al., 2007)
Divergent reliance	Whether the receiver already relies on the sender for divergent leadership.	The existence of a divergent reliance relation influences the acceptance of the sender's future divergent influence attempts	(DeRue & Ashford, 2010)
Convergent reliance	Whether the receiver currently relies on the sender for convergent leadership.	If the receiver has already accepted convergent influence attempts from the sender in the past, he will be more likely to accept convergent influences from the sender in the future	(DeRue & Ashford, 2010)
Proximity	The categorical boundaries that separate members: organization, country, and team membership.	The more proximate the sender and receiver are, the more likely it is that the receiver will accept the sender's influence attempt.	(Connaughton et al., 2012; Mortensen, 2013)
Team-level variables			
Social influence	The degree that the actions of others change or influence the actions of another individual.	If other members have accepted an influence attempt, then social influence implies that there will be pressure on those who have not yet decided to accept the attempt as well. The same is true for rejection of attempts.	(Marsden & Friedkin, 1993)
Team norms	The informal rules that are used by teams to regulate the behaviors of members.	A team that has a norm of accepting divergent influence attempts will be more likely to accept future divergent attempts, while a team with convergent norms will be more likely to accept convergent influence attempts.	(Hunter et al., 2007)

Table A.2. *ABM parameters estimated across MTSs from the empirical data ($N = 326$).*

S1. Claiming leadership	**Estimate**
Inertia	0.09
Motivation to lead	0.19
Psychological collectivism	0.96
Leadership biodata	0.90
Enthusiasm	0.70
Extraversion	0.98
Emotional stability	0.27
Leadership team membership	0.94
Friendship out-degree	0.62
Advice in-degree	0.33
Influence of individual factors	0.54
S2a. Claiming divergent leadership	
Openness	0.44
Intercultural sensitivity	0.74
Learning goal orientation	0.99
S2b. Claiming convergent leadership	
Agreeableness	0.33
Conscientiousness	0.03
Performance goal orientation	0.07
S3. Broadcast level	
Extraversion	0.61
Conscientiousness	0.51
Influence of tasks (episodic)	0.70
Decay parameters	
Divergent norms	0.45
Convergent norms	0.16
Divergent reliance	0.86
Convergent reliance	0.71
S4. Granting leadership	
Behavior homophily	0.92
Gender homophily	0.82
Friendship with sender	0.47
Advice from sender	0.53
Divergent reliance	0.87
Convergent reliance	0.75
Proximity	0.86
Proximity–team	0.68
Proximity–organization	0.83
Proximity–country	0.59
Team norms	0.73
Social influence	0.00

The attributes of the members uploaded from the empirical data are: motivation to lead, psychological collectivism, leadership biodata, enthusiasm, extraversion, formal leadership, emotional stability, openness, intercultural sensitivity, learning goal orientation, agreeableness, conscientiousness, performance goal orientation, and gender. Three relation types are uploaded from the empirical data: the prior advice and friendship relations between them, and the proximity relationship (same team, country, and organization).

Process overview (steps)/Individual rules

The model runs for the 47 days of the project. This process is recursive; therefore, leadership reliance relations that are updated or formed after one member claims leadership will influence the outcome of the next member's leadership claim. A summary of the process is shown Figure A.2 and the individual rules are shown in Table A1.

Parameter fitting (analysis)

The parameters were fit using the BehaviorSearch tool (Stonedahl & Wilensky, 2010, 2011). This tool allows for the specification of an objective function that is minimized according to some set of constraints in order to calibrate the model. In their paper, Thiele et al. (2014) specify that BehaviorSearch tool is a powerful and robust for parameter estimation (for an example use, see Radchuk et al., 2013).The objective function chosen for this model was the mean squared error between simulated leadership reliance relations and empirical leadership reliance relations. The mean squared error was calculated separately for divergent and convergent reliance relations then multiplied together to ensure the error was minimized for both types of relations simultaneously.

The constraints on the parameters were designed to range between 0 and 1. The BehaviorSearch software then has the ability to use several search algorithms to find the optimal combination of variables that most closely minimize this error term. To find the parameters for this model, each of the different search algorithms were tested, with the genetic algorithm yielding the best results. Table A2 presents the results of the parameter fitting.