Management Science

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MANAGEMENT SCIENCE
Articles in Advance, pp. 1–20
ISSN 0025-1909 (print), ISSN 1526-5501 (online)

Acquisitions, Node Collapse, and Network Revolution

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Received: October 22, 2015
Accepted: October 6, 2016
Published Online in Articles in Advance: March 29, 2017

https://doi.org/10.1287/mnsc.2016.2691

Abstract. We explore a novel mechanism of network change that occurs when a firm acquires another one and inherits its network ties. Such "node collapse" can radically restructure the network in one transaction, constituting a revolutionary change compared with the incremental effect of tie additions and deletions, which have been the focus of prior research. We explore several properties of node collapses: their efficacy in helping firms achieve superior network positions, the externalities they impose on other network actors, and how they provide exclusive control over both internal and network resources. Using a simulation in which actors compete to acquire one another, we model network dynamics driven by node collapses. We find that node collapses directly affect the performance of the acquirer and indirectly that of other actors, and that the direction of network evolution hinges on the degree to which firms pursue internal versus network synergies through node collapses.

History: Accepted by Olav Sorenson, organizations.
Funding: The authors are thankful to the Wharton Dean's Research Fund for covering the cost of this project.

Keywords: networks • node collapse • mergers and acquisitions • competitive dynamics • simulations and agent-based modeling

Introduction

Interorganizational networks function as "pipes" through which firms obtain valuable resources (Gulati 1999, Podolny 2001, Zaheer and Bell 2005). The position a firm occupies in a network can be valuable because of how it facilitates access to those resources. Hence, the question of how firms obtain superior network positions is important (e.g., Ahuja et al. 2012, Hallen and Eisenhardt 2012, Ryall and Sorenson 2007). Despite many theoretical approaches to this issue (Barabási and Albert 1999, Lin 2001, Madhavan et al. 1998, Sytch and Tatarynowicz 2014), research almost exclusively focuses on two means of network change: tie additions and, to a lesser extent, tie deletions. These tie changes allow the firm to manage resources through its own direct ties but provide no control over the ties of other firms. We consider another mechanism of network change that can provide such control: acquisitions. From a networks lens, an acquisition consists of the collapse of two nodes by which the acquirer gains ownership of the target's ties, which creates unique strategic possibilities for acquisitions and network change.

These unique possibilities arise because node collapses have markedly different properties compared with tie modifications (additions or deletions). Acquisitions can radically restructure the network by modifying multiple ties in a single transaction, constituting a revolutionary change in the structure compared with the more evolutionary change from tie modifications. Node collapses also have an impact on the existence and distribution of ties for nodes not involved directly in the acquisition, resulting in potentially strong network externalities, whereas changes in individual ties tend to produce effects more localized to the two nodes forming or ending a tie. Furthermore, acquisitions allow actors to gain control over two types of resources: internal ones gained from ownership of the target's resources and external ones gained from inheriting the network ties of the target. The former may give rise to "internal synergies," as discussed by previous mergers and acquisitions (M&A) research (e.g., Haspeslagh and Jemison 1991, Shaver 2006), while the latter may give rise to "network synergies," a concept we introduce. Finally, many firms can form a tie to another firm and access its resources, but only one entity can gain exclusive control over another by acquiring it.

These differences allow firms to access and manage network resources in ways that tie additions or deletions cannot. Consider the following examples, which reflect the properties laid out in the previous paragraph. Node collapses provide access to networks in ways that tie additions could in principle accomplish but in reality are hard to achieve. For instance, suppose a firm could benefit from being tied to a set of other firms. This firm could theoretically establish ties with all or several of the desirable partners. But in reality, the firm may have insufficient influence to form ties (e.g., low status) or the potential partners may not have the capacity or desire to initiate additional collaborations. These barriers can be overcome through the acquisition of a target that already is linked to some or all of the desirable partners, keeping the existing network intact but under new ownership. The externality-inducing effect of acquisitions could be important in settings where firms compete for network positions, such as in high-technology industries where structural holes are valuable (Tatarynowicz et al. 2016). One strategic move in this context may be to undermine the networks of multiple rivals by eliminating their structural holes. While this may be possible (but hard to orchestrate) through a series of tie additions or deletions, it gives time for rivals to respond and neutralize the focal firm's actions. By contrast, a node collapse has the advantage of speed by affecting multiple rivals at once: a single transaction is more likely to affect the ties of multiple actors beyond the acquirer and target. These two examples get at how node collapses can increase the odds of achieving a superior network position in a competitive environment by both enhancing the focal firm's position and undermining that of its rivals.

Furthermore, some strategically beneficial network changes are only possible through node collapses. For instance, two firms may have ties to a similar set of partners, making them rivals for access to those partners' resources. Ideally, one firm would cause the other to eliminate all redundant ties to increase the exclusivity of its position (Ryall and Sorenson 2007), but this is impossible because firms cannot control others' ties. However, one firm can acquire the other and eliminate the overlapping ties because the acquisition grants legal control over the target's ties to the acquirer. As a final example, consider a cross-national scenario. Suppose a firm has valuable ties to a partner in a foreign country. Because of government restrictions, other firms are unable to also ally with or acquire the foreign actor. A focal firm wanting access to the foreign firm's resources could form a tie to the foreign firm's partner. But a rival of the focal firm could do the same and then both would be competing for indirect access to the desired resources. An acquisition of the partner of the foreign firm by the focal firm has two benefits: it grants exclusive access to the foreign firms' network resources, and it eliminates the option for a rival to access these network resources by forming a tie with the partner firm.

These cases illustrate some of the strategic possibilities afforded by node collapses when it comes to accessing and protecting network resources. An additional consideration is that acquisitions allow firms to also gain control over the internal resources of a target, as extensively discussed in prior research on M&A (e.g., Haspeslagh and Jemison 1991, Shaver 2006). As mentioned earlier, a unique issue raised by node collapses is that firms may strategically consider both kinds of resources when making acquisitions. And because each acquisition is likely to vary in the extent to which acquirers are concerned with internal versus network synergies, which types of resources firms pursue is important in explaining what kinds of network positions firms may seek via acquisitions and thus how networks evolve over time. Hence, the concept of node collapses brings novel insights to the study of both network dynamics and M&A.

We systematically explore how node collapses impact the evolution of networks and the performance of organizations. As a baseline, we consider whether acquisitions are an effective means for firms to obtain desired positions and improve performance. We focus on how collapses allow acquirers to improve access to resource-enhancing positions, such as centrality or structural holes (Anjos and Fracassi 2015, Buskens and Van de Rijt 2008). We then study how node collapses produce externalities—some positive, some negative—for the performance and network positions of those not directly involved in the acquisition. Finally, we analyze how the tension between seeking internal versus network resources through node collapses affects the evolutionary path of the network at both the ego and global levels (Lee et al. 2010, Tatarynowicz et al. 2016). Competition becomes a salient consideration when exploring these issues. The exclusive nature of acquisitions implies that multiple firms may simultaneously be seeking similar network resources through node collapses, and it is not clear what the implications of such behavior would be. Hence, we explore how the behaviors of individual firms seeking to acquire other nodes in a competitive context affect the dynamics of the network.

Since our objective is to observe the emergent properties of the network and develop theory rather than to test specific hypotheses, we adopt a simulation method (Davis et al. 2007, Buskens and Van de Rijt 2008, Tatarynowicz et al. 2016). In our multiperiod, multiagent simulation, actors receive a payoff in each period based on the amount of resource "bits" they accumulate (Reagans and Zuckerman 2008), which can be produced internally or accessed through the network. Acquisitions, or node collapses, allow the acquirer to gain control over the target, through which the acquirer can produce more internal resources, and to inherit the ties of the target, through which the acquirer can access more network resources. These acquisitions involve a competitive bidding process. We allow the system to unfold until no more collapses occur and observe how firm performance and the properties of the network evolve at both the ego and global levels. Additionally, we build another simulation in which actors similarly pursue resources but can only add ties to one another to improve their network positions. We compare some of the main findings to those produced by the tie addition simulation.

We observed a series of interesting results. Node collapses helped improve the performance of acquirers and, in the process of seeking more resources, resulted in higher centrality and greater access to structural holes for acquirers. These transactions tended to produce positive externalities on the performance of others but negative externalities on their centrality and structural holes. When firms could only add ties, the impact on the network per transaction was significantly weaker. The evolutionary path of the network depended on whether firms sought internal or network resources. We explored three factors that modified the relative importance of the two types of resources: the cost of managing a large firm, getting at diseconomies of size (Coase 1937); the importance of obtaining distant network resources, getting at the importance of novelty (Rosenkopf and Almeida 2003); and the frictions of resource transmission through the network, getting at the willingness of the firms to exchange resources with one another (Borgatti and Cross 2003). The simulation allowed us to vary each of these dimensions independently. When firms had inducements to favor internal resources, the network tended to become dominated by one or a few large firms and thus was characterized by high constraint at the ego level and low modularity at the global level. These tendencies were generally reversed with incentives to pursue network resources, with the network becoming more "egalitarian" and characterized by lower constraint and higher modularity. We also found that certain combinations of cost, distance, or transmission produced intriguing nonlinearities in these effects.

We make several valuable contributions by introducing a novel mechanism of network change. The idea that acquisitions can "collapse" nodes in interfirm networks raises the intriguing possibility of network revolution rather than incremental evolution from tie changes. We show that these collapses not only impact the focal acquirer but also produce network externalities for those uninvolved in the transaction. This suggests that the evolutionary path of a network modified through node collapses can have unique outcomes. To explain how that path unfolds, we distinguish between the internal versus external resource consequences of acquisitions. Scholars in the M&A literature have conceived of synergies as arising from the combination of acquirer and target resources that the firms own (Bradley et al. 1988, Capron and Pistre 2002). We raise the possibility of network synergies stemming from the structural recombination of the ties of the merging entities, and we demonstrate that the direction of network evolution depends on which of the two types of synergies firms pursue through node collapses. In doing so, we consider how competitive interactions shape the dynamics of both firm and industry networks. The findings raise novel strategic rationales for why firms make acquisitions and how such actions affect network change.

Background

Networks are composed of two basic elements: a set of nodes and an arrangement of ties among the nodes. Network change, at its most basic level, will involve the modification of one or both of these elements. Prior work on social networks has tended to emphasize change driven by actors adding or deleting ties over time. While tie changes capture a large amount of the ongoing dynamics of networks, organizations are able to modify nodes in ways that individuals cannot. Two individuals cannot "merge" with each other from one period to the next, and so, for example, a friendship network can only change when ties are modified. By contrast, mergers and acquisitions are one of the most ubiquitous corporate strategies for growth and competition. Thus, in interorganizational networks, two nodes can "collapse" into one, creating an alternative avenue for network change. Because the concept is novel, we begin by providing some grounding in real examples of how node collapses may help firms obtain resources.

Node Collapses and Resource Access

External ties are important when resources are widely distributed.[1] In such settings, a firm's network position impacts its performance by affecting its access to resources (Lavie 2006), and the systemic pattern of connections affects the distribution of resources across the industry (Anjos and Fracassi 2015). These conditions are common, for instance, in technologically dynamic industries (Baum et al. 2000, Tatarynowicz et al. 2016) and for firms operating across foreign markets where resources are embedded in local and global networks (Ghoshal and Bartlett 1990, Vasudeva et al. 2013). When networks matter for performance, firms are likely to be aware of the implications that acquisitions have for their network positioning.

One example is the 1999 acquisition of Allelix Biopharmaceutical from Canada by the U.S.-based NPS Pharmaceutical. The deal announcement considers the combination of the preexisting alliances of both firms: "Research and development efforts in the new organization will include currently partnered programs . . . with Amgen and Kirin, . . . with SmithKline Beecham, . . . with Eli Lilly, . . . with Janssen and . . . with Pharm-Eco. Proprietary clinical programs will be advanced by the new entity or partnered" (NPS Pharmaceuticals 1999). The mentioned partners came separately from the premerger networks of NPS and Allelix. Besides the combination of research and development (R&D) ties, the deal expanded the geographical reach of the two networks across the U.S. and Canada: "NPS and Allelix said that as a combined entity, they will be able to take advantage of the Canadian biotechnology industry and its associated technical and financial resources, 'while reaping the benefits of NPS' US biomedical industry connections"' (*The Pharma Letter* 1999).

Another case is the 1998 purchase of GeneMedicine by Megabios. The acquisition was in part justified by how the combination of the two firms' R&D networks was expected to be beneficial: "Megabios has corporate partnerships with Glaxo Wellcome ... and with Eli Lilly.... GeneMedicine recently expanded its corporate alliance with the Corange International Limited subsidiary ..." in addition to having other partnerships (Megabios Corp. 1998). The announcement further explains how the combination of these partnerships would help the new entity: "At the close of the merger, the combined company will have ... [several] ongoing corporate partnerships.... [T]his business combination should enable the combined company to leverage its collective scientific expertise, intellectual property and product development efforts *into additional corporate partnerships* and successful products ..." (Megabios Corp. 1998, emphasis added). Referring back to some of the general cases from the introduction, NPS and Megabios could have—in principle—established ties to each of the firms mentioned in the acquisition announcements. But this may not have been possible, and the purchase provided access to all partners through one deal.

These network-enhancing acquisitions are frequently contested because the acquirer's rivals may seek to purchase the same target. For instance, when Inamed announced the acquisition of Collagen in August 1999, it discussed its hopes to tap into Collagen's "longstanding ties with cosmetic physicians," but interest in purchasing Collagen was actually initiated when, five months earlier, Inamed's rival Mentor "made an unsolicited bid to acquire Collagen" (Rundle 1999). A more recent example in a different industry is VMware's acquisition of Nicira. Cisco expressed concerns about how the combination would affect its preexisting alliance with EMC as well as a separate alliance with Citrix and NetApp (Duffy 2012). Competition was an important factor in this case because Cisco had attempted to acquire Nicira before VMware succeeded (Damouni et al. 2012). The contestation of acquisitions reflected in these cases gets at the issue of exclusivity we considered in one of the examples from the introduction.

A recent study suggests that the network implications of acquisitions are more than anecdotal by demonstrating that diversifying deals help firms "[bring] together information scattered across the economy," which reduces the network distance between such information and provides performance advantages to diversified firms (Anjos and Fracassi 2015, p. 161). This underscores the importance of understanding how the mechanism of node collapse affects firms' acquisition strategies and how these strategies, in turn, affect network change and evolution.

Node Collapses vs. Tie Changes

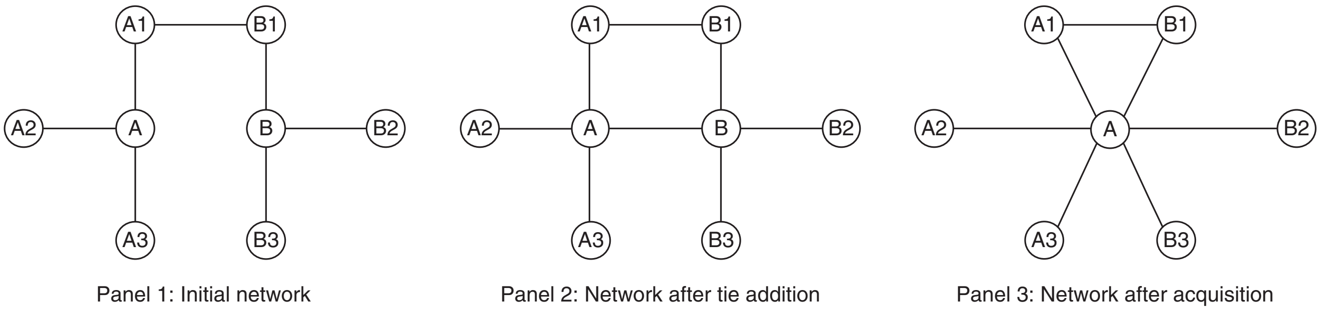
We see tie changes and node collapses as part of a tool kit that firms have at their disposal to modify their networks. Firms likely use different actions for different reasons or combine them according to their objectives. For example, some research shows that firms first establish ties to evaluate potential acquisition targets and then acquire some of those prospects (e.g., Higgins and Rodriguez 2006), and evidence suggests that such sequencing may improve acquisition performance (Porrini 2004, Zaheer et al. 2010). Tie deletions may help firms prune their networks of relationships that no longer provide valuable resources, making room for subsequent additions or node collapses (Hernandez et al. 2015, Kleinbaum 2017). This underscores the fact that each type of network change mechanism has unique properties and is thus likely to produce distinct performance and network outcomes. Because extant work has mostly focused on tie changes, and because the node collapse mechanism is novel to the literature, we focus this study on the unique properties of node collapses and their implications for network evolution.[2]

From a networks perspective, node collapses have four characteristics that differentiate them from tie changes.

Impact. Acquisitions allow a firm to access multiple relationships in one transaction—this, combined with the acquirer's existing ties, can help the new entity dramatically change its standing in the network. What an acquisition accomplishes in one transaction in terms of adding new ties or removing redundant ties, a firm would have to replicate via multiple separate tie formation and deletion transactions. Figure 1 illustrates this with a highly stylized example. If firms A and B establish a tie, they each increase their degree by one unit. If they delete a tie, they decrease their degree by the same amount. But if A collapses with B and inherits its ties, it increases its degree by three units. Hence, acquisitions have the potential to create network revolution rather than incremental evolution. While the differential impact per transaction may imply that node collapses are "supercharged" versions of tie additions or deletions (though that is not necessarily the case), the remaining properties are more unique to collapses.

Externalities. The structural consequences of an acquisition not only affect the parties involved in the acquisition but also indirectly impact other parties. Returning to Figure 1, the collapse of A and B has a spillover effect for those surrounding the acquirer and target (A1, B1, A3, and B3). For instance, A is able to increase its access to structural holes by becoming a broker between B1 and B2, B2 and B3, and A3 and B3 while A1 and B1 experience a decline in structural holes—in fact, their ego networks become fully

Figure 1. Tie Addition (A and B form a Tie) vs. Acquisition (A and B Merge)



closed in this simple case. Inasmuch as structural holes are valuable to access resources in this network, the acquisition produces a negative externality for several others. The ego networks of other parties are not structurally affected when A and B simply form or eliminate a tie with one another in this example, and the impact on the broader network structure is more limited.

Internal and External Resource Control. Research on M&A has focused on the internalization benefits of such deals—namely, the ability of the acquirer to take ownership and thus control of the target's resources. The literature uses the notion of synergy—a combination of assets that produces greater value together than separate—to explain how much value can be created from the transaction (Bradley et al. 1988, Seth 1990). While the definition of synergy allows for any kind of resource combination, research has emphasized those stemming from resources owned by firms, which we label "internal synergies."[3] But when viewed from a networks perspective, acquisitions as node collapses also bring with them some degree of control (or at least more influence) over the target's ties and thus enhanced access to external or "network resources" (Gulati 1999). For instance, an acquirer frequently takes over the contractual alliances of the target, as the biotechnology examples mentioned earlier show.

Hence, value could stem from both the oft-studied internal synergies as well as what we label *network synergies*—the improvement in the acquirer's network position resulting from the structural change in the network because of a node collapse. In Figure 1, when A acquires B, it internalizes B's resources but also gains access to novel external resources through ties to B1, B2, and B3. Tie formations and deletions modify access to external resources only. We anticipate that much of the uniqueness of node collapses for the performance of actors and for the evolution of the network stems from the relative importance firms place on internal versus external resources as they engage in node collapses.

Exclusivity and Competition. Because ownership of resources usually brings with it decision rights over the use of those resources, acquisitions provide firms with strong control over the target's assets. While one could argue that some resources are more controllable than others (e.g., patents versus human resources, internal versus network resources), node collapses provide greater control over another node's resources than tie additions. While only one actor can acquire another, many actors can form a tie to the same partner. Such exclusivity underscores why, frequently, mergers happen through competitive processes in which multiple suitors outbid one another. This exclusivity also underlies many of the strategic possibilities that only node collapses can offer (and not changes in ties), as illustrated in some of the introductory examples. From a networks perspective, inasmuch as the focal firm seeks to obtain an improved network position through node collapses, so would others in the same network facing similar incentives (Salancik 1995).

Research Goals

We are interested in how acquiring another firm to obtain resources within a competitive context affects the evolution of the network and the performance of network actors, whether directly involved in the node collapses or indirectly affected by it. To reflect the issues raised by the properties of node collapses described in the previous section, our study focuses on the following issues.

Objective of the Network Actors. We explore how actors behave as they seek to accumulate resources, under the assumption that resources affect performance. Firms may benefit from both the amount and the novelty of resources they obtain, with networks being instrumental in accessing both (Rosenkopf and Almeida 2003). As in many real-world settings, actors can generate their resources internally or obtain them from their network environment. Node collapses are one way to gain additional resources, either by internalizing another actor (and its resources) or by gaining additional ties by which to access others' resources through network ties.

Outcomes of Interest. We focus on outcomes at the ego and global levels. At the ego level, we explore two types of factors: firm performance and network properties. Performance is a function of the resources that firms obtain, and we observe both the amount and the novelty of resources to which firms have access. Because network positions are the means by which firms access external resources, we observe the centrality and the constraint of firms' ego networks. Centrality is associated with influence and access to high resource amounts (Anjos and Fracassi 2015). Constraint is (inversely) associated with access to structural holes, whereby firms gain novel resources from bridging disconnected clusters (Burt 1992, Buskens and Van de Rijt 2008). Besides our interest in the level of these various factors for individual firms, we are also interested in their distribution (e.g., standard deviation) across firms in the network. This allows us to get at issues of performance and competitive advantage.

At the global level, the community structure of the network is an important indicator of the structure of the industry (Tatarynowicz et al. 2016). Community structure focuses on the way in which ties are distributed by capturing the modularity of the network. For instance, in industries with strong community structure, the network is composed of subgroups that are densely connected within but weakly connected to other groups (high modularity), whereas in industries with weak community structure, ties are more uniformly distributed such that subgroups are not readily apparent (low modularity).

Factors Affecting Outcomes. At the most basic level, we are interested in observing whether node collapses impact the performance and network position of the focal actor and of third parties. Thus, the most basic factor we care about is the impact on the aforementioned outcomes per node collapse. We are also interested in observing how acquirers' pursuit of internal versus network resources affects the outcomes of interest. While firms are unlikely to pursue only one type of resource from an acquisition, we consider three factors that affect the relative inducements to pursue internal versus external resources. We will discuss these parameters in significantly more detail below, but we mention them here to conceptually motivate the model parameters.

First, the cost of being a large firm will impose limits on the value firms can create from absorbing many nodes through acquisitions (Shaver and Mezias 2008). Growing large through mergers allows firms to have high rates of internal resource production, but when the cost of size goes up, the scales are tipped in relative disfavor of internal resources (Coase 1937). Second, the payoff to obtaining resources from "distant" parts of the network may be valuable in settings where novelty is an important aspect of performance (Rosenkopf and Almeida 2003). When incentives to pursue such distant resources are strong, firms will tend to favor network resources over internal ones. Third, relational or competitive factors may create frictions in the flow of resources through network paths (Borgatti and Cross 2003, Hernandez et al. 2015). This will affect the need to engage in node collapses to access resources. When frictions are low, acquiring other firms is less valuable because network resources are easily available; when they are high, acquiring other firms to internalize resources becomes a more valuable strategy.

Model

Because our objective is to observe emergent properties of the network to develop theory, we do not provide hypotheses like in a traditional empirical study. We instead follow a simulation approach, which has advantages over formal analytical modeling in our case. An analytical model would entail solving a highly complex multiperiod problem involving many interacting strategic agents. To achieve a closed-form analytical solution for such a system, the underlying model would have to be simplified to such an extent as to lose many crucial aspects of the problem. For instance, to bring the computational requirements to manageable limits, one might lower the number of actors to an extremely small number, reduce the number of periods (perhaps to even just two), impose very strong symmetric conditions across the players, and introduce other strong simplifying assumptions. But since we are interested in how networks of a large number of agents change over many periods, leading to significant asymmetries along the way, we opt for the simulation approach. We expect that the results of the simulation can be subsequently tested empirically.

Simulation Structure

The simulation executes the following steps:

Step 1. We initialize a random Erdős–Rényi (1959) network with n nodes and probability p that any two nodes are linked to one another. We set the network size to 25 nodes because the computational complexity is formidable and increases exponentially with the size of the network. Initially, all firms have a "size" of one node. As they acquire other firms, acquirers internalize the nodes of targets and thus grow in size, defined as the number of nodes possessed by the firm.

Step 2. Each node produces a "bit" of resources every period that is valuable for all firms (Reagans and Zuckerman 2008). The firm that owns a node has access to the resources it produces with a probability of 1 (Anjos and Fracassi 2015). Resources can get transmitted to other firms through network ties. The probability that a firm receives a resource through network transmission decreases the farther away it is in the network from the firm that owns the node that produced the resource (i.e., it decreases in the shortest path length between the two firms). A "transmission" parameter, $tr \in [0,1]$, determines how much friction there is in the flow of resources through the network. The probability that a firm i obtains access to resources from firm j is then given by $tr^{spl_{ijt}}$, where spl_{ijt} is the shortest path length from firm i to firm j at time t. Thus, at $tr = 0$, there is an infinite amount of friction, and no resource transmission occurs over the network. As tr increases, the resources start to flow more freely, up to $tr = 1$, where every firm j that has some network path to firm i is guaranteed to access its resources. If a firm has no network path to another, it cannot receive resources via network transmission. Thus, the more nodes a firm owns (i.e., the larger its size), the more resources it will produce internally and have guaranteed access to every period. The more ties it possesses, the greater will be the chances of accessing resources through network transmission. The smaller the shortest path length to other firms, the greater the likelihood of accessing network resources. As we discuss in more detail later, tr affects firms' inducements to pursue internal versus network resources.

Step 3. The objective of each actor is to maximize its performance, which is a function of the resources to which it has access at a given point in time. The profit for actor i in period t is given by

$$\pi_{it} = \sum_j (r_{ijt} \times (spl_{ijt} + 1)^d)^{1.5} - c(size_{it})^2. \qquad (1)$$

The first term of the equation captures the positive effect of resources, while the second term captures the negative effect of firm size. We describe each term in turn. On the resource side, r_{ijt} is the amount of resources firm i has access to from firm j in period t, spl_{ijt} is the shortest path length from firm j to firm i in period t, and d is a parameter that captures how much the distance that the resource has travelled across the network impacts performance. Thus, $(spl_{ijt} + 1)^d$ can be thought of as a distance-based weighting factor for the amount of resources, such that low values (e.g., $d = 0$) represent situations in which performance is driven solely by the amount of resources accessible by the firm, while high values (e.g., $d = 1$) represent cases in which resources that come from far across the network are more valuable. Note that if $i = j$, we define $spl_{ijt} = 0$, meaning that the distance-based weighting will be 1 for one's own resources, irrespective of the parameter d. The exponent of 1.5 captures a world with increasing returns to scale (results are robust to using other values >1). In a world where only "internal" synergies mattered (i.e., no resources are available from the network), for an acquisition to create more value than the status quo and thus, for both parties to find an agreeable price, one would need such increasing returns. Since prior literature on M&A focuses on value created through internal synergies, we use an increasing returns setup as our default, but we do consider simulation outcomes for decreasing returns as well.

On the cost side, $size_{it}$ captures the number of nodes "owned" by firm i in period t, and c is a parameter that determines how much firms are penalized for being large. When $c = 0$, there is no penalty for absorbing nodes through acquisitions. As c increases, firms are disincentivized from internalizing nodes to guarantee access to their internal resources, tipping the scales in relative favor of network resources. While Equation (1) has several components, we can reduce it to a very simple function where only the amount of resources affects performance by setting $d = 0$ and $c = 0$. As we explore the results, we always begin with this simple structure and later explore the implications of adding distance and cost considerations.

Step 4. At the beginning of each period, a firm is picked at random to choose a potential acquisition target. The chosen firm goes through the list of all remaining firms in the network and, for each firm, evaluates the expected payoff that will accrue to it if it were to acquire that firm. (Note that the firm calculates the expected value of the payoff since the transmission of resources through the network is a probabilistic process.) An acquisition causes the acquiring firm to inherit the node(s) of the target as well as its ties, resulting in a new network. The value of the potential target to the acquirer (VA) consists of the expected payoff that will accrue to the focal firm (the acquirer) in the next period based on the combined networks of acquirer and target, as determined by Equation (1) applied to the new network.

The acquirer is willing to make a bid for a target only if the VA to the firm exceeds what it would expect to get in the next period if the network remained unchanged (VU). $VA - VU$ will be the maximum that the firm will be willing to pay for the target. After making this calculation for each of the firms in the network, the focal firm chooses the one producing the highest $VA - VU$. At the same time, the target will accept a bid only if the bid is larger than the payoff it would get if it rejected the bid and stayed a separate entity (VT). Thus, the acquirer identifies the target that produces the highest $VA - VU$ and, if $VA - VU > VT$, makes a bid for that target. (In this setup, a bid can happen only if the joint value that is created by the acquisition is larger than the value created by the firms remaining separate, consistent with the classic notion of synergy.)

To simplify the bidding mechanism, we will assume that a firm always bids the maximum that it is willing to pay for a target. The bidding mechanism can be thought of as being similar to a second-price sealed-bid auction, where the winner of the auction pays the second-highest bid for the target (Fudenberg and Tirole 1991). This could result in some situations where a very small firm (say, an isolate) could acquire a much larger firm—an unrealistic scenario. To rule out such cases, we impose a constraint that the acquirer cannot bid on targets that are more than 150% of its own size. (The results are robust to relaxing this constraint, as discussed later.) Thus, the acquirer makes the bid for the target producing the highest $VT - VU$ given this constraint. In case no targets satisfy the constraint and/or generate a positive $VT - VU$, the firm simply does not make a bid, and the period ends with all firms receiving payoffs based on the existing network structure.

An important issue is what level of rationality we assume acquirers have when evaluating potential targets. Bounded rationality suggests that firms are unlikely to observe and evaluate large numbers of potential acquisition targets. While this would become a significant issue in a general model with a large number of nodes (since actors evaluate all firms in the network), the network size in our current setup is kept rather small (25 nodes including the focal firm) and shrinks with each node collapse. This implicitly keeps the computational complexity manageable without requiring extreme levels of cognitive capability.

Step 5. Once the focal firm has made its bid, the remaining firms in the network (except the target for whom the bid has been made) enter into a competitive bidding process for that potential target. Following the same logic as the focal firm above, they each submit a bid. Once all bids are entered, the firm with the highest bid wins the target, pays the price offered by the second-highest bidder (as explained above), and the acquisition is completed. The network is reconfigured to reflect the acquisition. The fact that others become aware of the acquirer's intention of merging with the target is borne out by prior research (e.g., James and Wier 1987) and illustrated by some of our earlier examples.

Step 6. At the end of the period, all firms receive a payoff per Equation (1) reflective of the state of the network at that point in time. We assume that the firm pays off all of its profits for the period to its "shareholders" at the end of each period, and thus we avoid affecting the dynamics due to intertemporal issues that might result from firms carrying over profit balances.

Step 7. Steps 2–6 are repeated for a certain number of periods until we observe convergence (i.e., no more node collapses are occurring, as discussed below). A variety of metrics are calculated at the end of each period to assess how the network is evolving over time.

In addition to the primary simulation, focused on node collapses, we generated an additional simulation in which actors could only add ties to each other. This served as a comparison for some of the results of the main simulation. The tie addition simulation is identical to the main one in Steps 1–3 and Steps 6 and 7. Instead of Steps 4 and 5, where the acquisition target is selected, a firm is randomly chosen to establish a tie with another node. The focal firm considers all possible new partners and picks the one that maximizes the objective function, subject to the condition that the new partner's performance is also better off by establishing the tie.[4] When comparing tie additions to node collapses, we set $c = 0$ to avoid assumptions about the relative costs of forming ties versus acquiring nodes that could drive any differences in the comparison.

Measurement

As mentioned earlier, we track a variety of metrics to assess how node collapses affect the performance of firms and the structure of the network. The description of the simulation provided the formula for metrics such as performance, resource amounts, or resource distance. The network measures of interest are as follows.

Ego Level. We capture the degree centrality of each actor as the number of ties it possesses in each period (Wasserman and Faust 1994). We follow prior work by measuring structural holes based on network constraint (Burt 1992): $c_i = \sum_j (p_{ij} + \sum_q p_{iq} p_{qj})^2, i \neq q \neq j$, where p_{ij} is the proportion of i's total network ties represented by j, p_{iq} is the proportion of i's total network ties represented by q, and p_{qj} is the proportion of q's total network ties represented by j. Recall that low values of constraint represent networks rich in structural holes while high values capture networks with high closure or density.

Global Network. We capture community structure using Girvan and Newman's (2002) approach to finding the modularity of the network, as $Q = 1/e \cdot \sum_k (e_{kk} - \{e_{kk}\})$, where e is the total number of ties in the network, e_{kk} is the number of ties in the kth community, and $\{e_{kk}\}$ is the expected average number within the communities in the network. There are many algorithmic approaches to estimating Q, of which we adopt the "Louvain" approach (Blondel et al. 2008) because it has been shown to have a good balance of accuracy and computational efficiency (Fortunato 2010).

Results

We organize our analysis into three parts that follow the conceptual claims of the paper. First, we briefly show that node collapses meaningfully affect the performance and network structure of the acquirer. Second, we explore the effects of node collapses on firms not directly involved in the transaction (i.e., network externalities). Third, we consider how factors that motivate actors to pursue internal versus network resources (d, c, and tr) affect the evolution of the network structure. For the results presented below, we initialized a network of 25 nodes with default values of $tr = 0.5$ and of $p = 0.15$, corresponding to a realistic scenario of a relatively sparse interfirm network with a moderate likelihood of resource transmission through network ties. Furthermore, for the baseline results, we set $c = 0$ and $d = 0$—that is, a world where there are no costs of being large and where only the total amount of resources matters for profit (and not the distance-weighted amount). We subsequently vary these parameters to assess their individual effects on the evolution of the network.

Each simulation was repeated 1,000 times for a range of several values of the parameters of interest. The computational complexity is formidable. In each period, a firm must assess the future payoff to an expected network for each potential acquisition target. If the firm makes a bid on a target, all other firms must make a similar calculation. This process repeats itself in each time period, and the sequence of steps runs 1,000 times for every single parameter value of interest. Obtaining the results reported below took a significant amount of time—multiple days—on a High Performance Computing Cluster. The computing time scales exponentially with the number of nodes in the network.

Convergence. We consider the simulation to have reached convergence when no more node collapses occur (or they occur very infrequently) because actors do not deem they can profit anymore from acquiring others. Figure 2(a) depicts the number of firms remaining in the network after each period for the default case ($p = 0.15$, $tr = 0.5$, $c = 0$, $d = 0$). As expected in a world with increasing returns to scale, when there is no constraint on firm size, the network eventually shrinks to a few nodes that have absorbed all others. This happens after roughly 400–500 periods (not necessarily at the rapid pace one would expect, as we will discuss shortly). The pattern of network shrinkage remains with slight variations in cases where c and d vary, as we will discuss later. Also, network shrinkage occurs but is delayed in supplemental models with moderate rates of new firm entry and reverses in models where the rate of entry is high. However, the relationships between the parameters of interest, discussed in more detail below, do not change much when we allow for entry. Hence, we present our main results without entry but discuss their sensitivity to entry later.

The main objective of our study is to understand the dynamics of the network and how certain parameters affect those dynamics, rather than to observe convergence or equilibrium structures. Once the network reaches a steady size, observations do not reflect how node collapses affect the network anymore. Thus, the focus of the results that follow will be on the periods when collapses are occurring.

Baseline

The most basic claim of the study is that node collapses are an effective means for firms to achieve network-related objectives. We explored the average impact of

Figure 2(a). Number of Firms Remaining Over Time (Default)

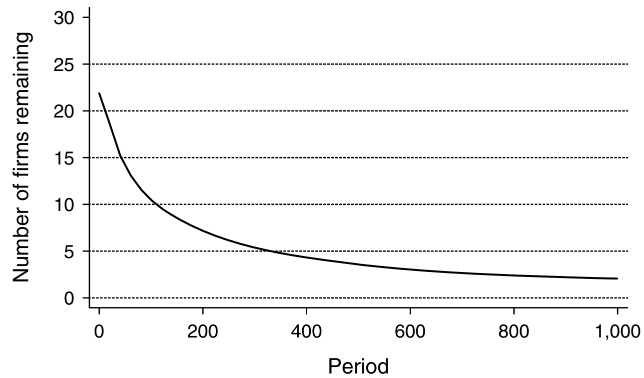


Figure 2(b). Performance Change (Focal Firm) per Node Collapse

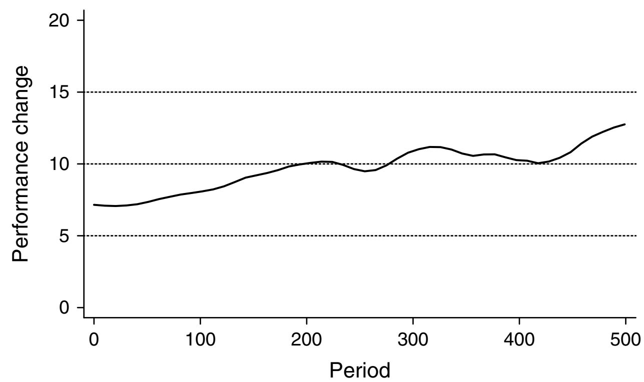
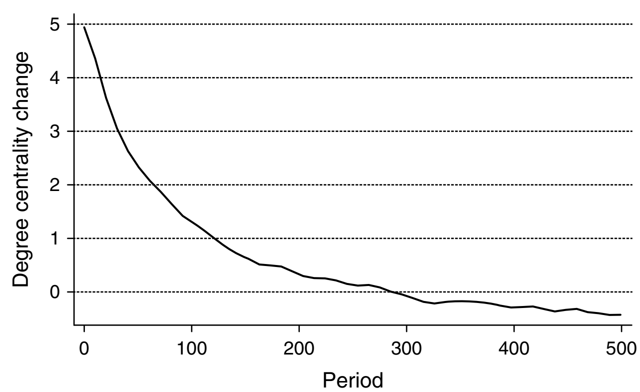


Figure 2(c). Degree Centrality Change (Focal Firm) per Node Collapse



a node collapse on a series of metrics, depicted in figures in which the vertical axis captures the *average change* per collapse and the horizontal axis captures the periods of the simulation (up to period 500, when convergence happens). Figure 2(b) shows that node collapses always increase performance for the focal firm (i.e., the acquirer), which is to be expected given the objective function. We observed that degree centrality generally increased for the acquiring firm with each node collapse in Figure 2(c), such that actors increased

Figure 2(d). Constraint Change (Focal Firm) per Node Collapse

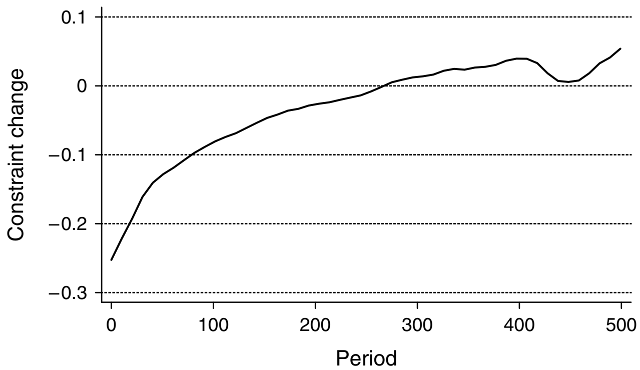


Figure 2(e). Modularity of Network Over Time

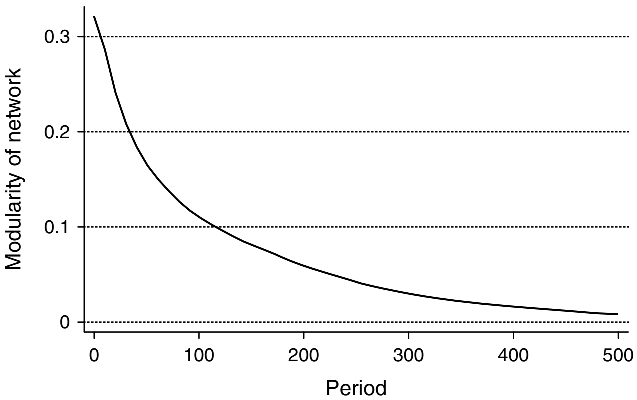
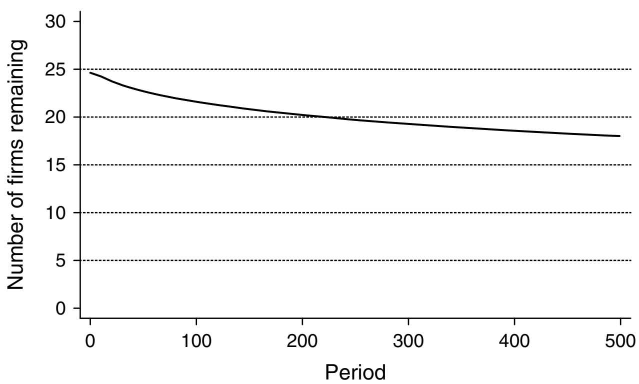


Figure 2(f). Number of Firms Remaining Over Time (Decreasing Returns)



the number of ties significantly to be exposed to more channels through which resources flow. However, in late stages (period > 300), acquisitions slightly decrease degree centrality, a mechanical artifact of the extremely small network size at that point. Network constraint in Figure 2(d) generally declined with each transaction, suggesting that the pursuit of network resources was associated with increasing access to structural holes. Once again, the exception was that constraint increased in very late periods because, by that point, the network is extremely small and actors are densely linked to each other. In the tie addition simulation, degree centrality increased and constraint decreased on average, but the rate at which they did so was much smaller compared with the node collapse simulation (graphs depicting this shown later).

To illustrate how node collapses affect the evolution of a global network property, Figure 2(e) shows that the modularity of the network decreases over time. This means that the process of competitive node collapses to obtain greater amounts of resources leads to a decreasing number of distinct clusters in the network. The results reported in this section remain qualitatively unaltered in a model where entry occurs. We summarize as follows.

Result 1. *Node collapses undertaken by firms in a competitive context to increase resource access will tend to increase the degree centrality and decrease the constraint of the focal firm. They will also lead to a less modular network over time.*

Recall that our default simulation is one with increasing returns to scale on the amount of resources accessed by firms. Thus, it was designed to give significant incentives to acquire, consistent with the concept of synergy. In a world where only internal resources existed, one should expect this system to collapse very quickly to a single firm that has acquired everyone else—especially in a small network starting with only 25 nodes. Instead, we see a gradual decrease in the number of acquisitions; that is, the collapsing force of the increasing returns is resisted by a competing force—namely, that of network synergies. As the network evolves over time, the relative importance of network synergies increases, slowing the rate of network collapse at an increasing rate.[5] Thus, in a world of increasing returns to scale, network synergies provide a force that balances against rapid or complete network collapse.

By contrast, in a world of decreasing returns to scale, firms would rather remain separate if the only resources available were internal ones because an acquisition would actually destroy total value. However, allowing for network synergies in this world can actually cause some firms to undertake acquisitions driven by the possibility of increasing access to network resources to an extent that more than compensates for the value loss due to decreasing returns. We can see this in Figure 2(f), which tracks the total number of firms remaining in the network in a decreasing returns world, where the exponent on the resources term in the profit function was changed from 1.5 (default) to 0.75. Thus, network synergies can actually facilitate node collapses and network shrinkage, while there would be none in their absence under decreasing returns to scale.

Result 2A. *In a world of increasing returns to scale, network synergies can ameliorate the tendency of firms to quickly acquire others, slowing network shrinkage.*

Result 2B. *In a world of decreasing returns to scale, network synergies can facilitate node collapses and lead to network shrinkage.*

For the rest of the results, we focus on the default simulation of increasing returns to scale because that is the typical scenario in M&A, where internal synergies are valuable.

Externalities

The next claim of the study is that node collapses have a significant impact on actors not directly involved in the transaction. We will consider externalities through a series of plots, each comparing the total externality, meaning the average impact of the node collapse on all firms except the acquirer and target, to the average impact of a node collapse on the acquirer.

We begin with performance in Figure 3(a). Node collapses tend to have a positive effect on the performance of the rest of the network, and this effect decreases over time. Collapses create positive externalities for two reasons. First, they allow the acquirer to internalize and control one additional "bit" of resources, and thus the acquirer will transmit more of its internal resources to those to whom it is linked. Second, collapses tend to shrink the distance between the target's partners and the acquirer (unless the acquirer and the target's partners were already tied), thereby increasing the odds that resources will flow to the acquirer's partners, to those existing partners' connections, and so forth. The inheritance of new connections through node collapses is more likely in earlier periods, when the network is sparser, explaining why the positive externality tends to decline over time. Figure 3(d) compares the performance externality produced by node collapses to that produced by tie additions. To make the two comparable, we scaled the performance produced by each simulation by the size of the network (recall that the network shrinks with node collapses but not tie additions).[6] The graph shows that node collapses produce significantly stronger positive performance externalities (per firm) than tie additions. Note also that the effect on the focal firm is much stronger for node collapses.

Result 3A. *Node collapses tend to create a positive externality on the performance of the other actors.*

Figure 3(b) shows the negative externality of node collapses on degree centrality. The degree centrality of a third party (i.e., neither acquirer nor target) can never increase after a node collapse because such transactions do not create new ties in the network—they only reassign the "ownership" of existing ties. Degree

Figure 3(a). (Color online) Performance Externality per Node Collapse

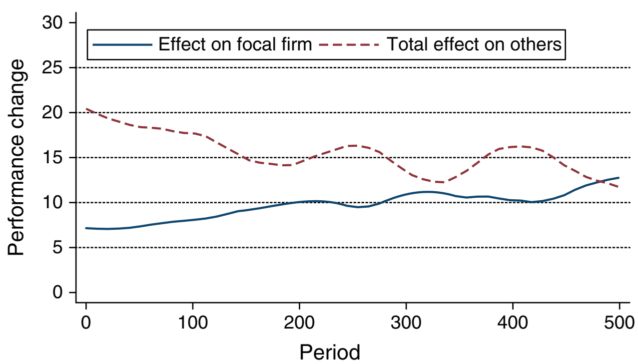


Figure 3(b). (Color online) Degree Externality per Node Collapse vs. Tie Addition

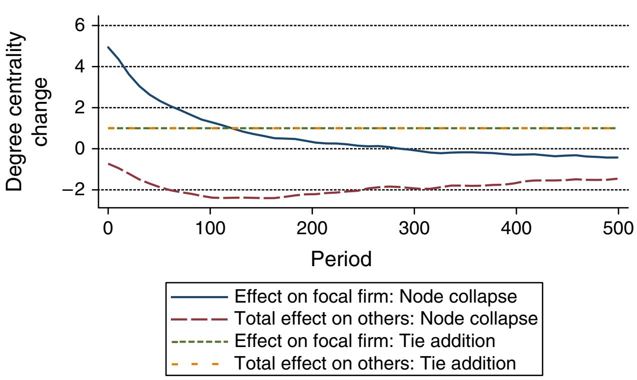


Figure 3(c). (Color online) Constraint Externality per Node Collapse vs. Tie Addition

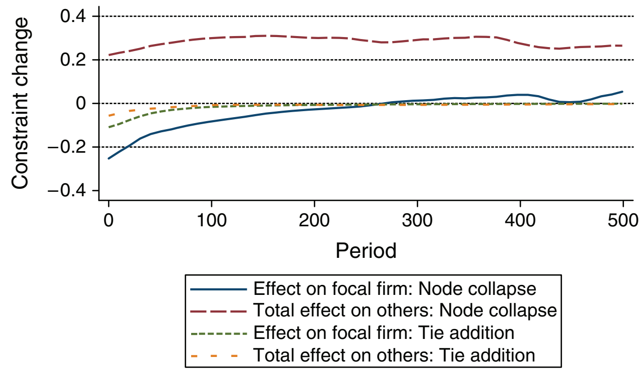
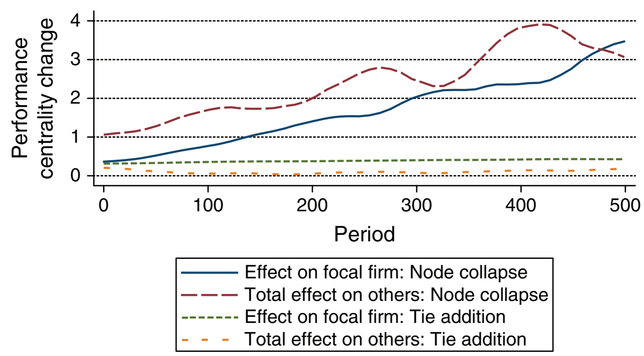


Figure 3(d). (Color online) Performance Externality (Normalized by Total Number of Firms) per Node Collapse vs. Tie Addition



will decrease only when the third party was tied to the two merging nodes. The reason that the externality becomes increasingly negative over time initially is that, as the network becomes less modular and denser with time (see Figure 2(e)), the odds of third-party ties among dyads increases too. Hence, collapses will decrease the degree of other actors more with time. However, in the later stages, the externality gradually becomes less negative as there are fewer firms remaining and thus fewer common third-party ties. (In the very late stages, when the focal firm itself decreases its degree centrality with every acquisition, the negative effect on others could be argued to be a positive externality, though we view this as an unrealistic scenario.) Figure 3(b) also contrasts this result with the degree of externality produced by the tie addition simulation. Each new tie mechanically increases the focal firm's degree by one tie, but there is no externality: the new partner also increases its degree by one tie, but no other firms are impacted.

Result 3B. *Node collapses create a negative externality on the degree centrality of actors.*

Figure 3(c) depicts the externality effect of node collapses on network constraint. Recall that constraint consistently declined as a result of node collapses for the acquirer seeking more resources (see Figure 2(d)), so the increase in constraint for all others is therefore a negative externality (except, once again, when the network shrinks to a very small size in late stages). The reason node collapses produce increases in constraint for others when the focal actor seeks to decrease constraint is best illustrated by referring again to Figure 1. If A and B establish a tie, they both increase in structural holes (more precisely, decrease in constraint). But that transaction has no effect on A1 or B1—their constraint value remains the same as before (A1 spans a structural hole between A and B1, while B1 spans a structural hole between B and A1). By contrast, if A acquires B and inherits its network, there are two effects. First, A's structural holes will increase (constraint decreases). Second, there will be a negative spillover on A1 and B1 because the "collapse" of A and B causes them to not span structural holes anymore—they are now part of the fully closed triad A–A1–B1. Thus, node collapses tend to indirectly close the network ties of parties formerly affiliated with the acquirer and target, resulting in decreased constraint—at least in scenarios in which actors seek to increase structural holes through collapses. Figure 3(c) also contrasts the constraint externalities produced by node collapses to those generated by tie additions. While both actions decrease the focal firm's constraint, collapses do so much more strongly. Interestingly, additions produce a slightly positive constraint externality (by increasing others' access to structural holes), whereas collapses produce a strong negative externality.

Result 3C. *Node collapses create a negative externality on the structural holes of other actors (i.e., increases others' constraint) when the focal actor seeks to increase structural holes (i.e., decrease its own constraint).*

Internal vs. Network Synergies

We expect that whether firms pursue internal or network resources through node collapses will have distinct effects on how the network evolves. We focus on three parameters that allow us to vary the relative importance of internal and network resources. We first explain how each parameter affects actors' valuation of internal versus network resources and summarize that explanation in an "observation." Then, we show how the relevant parameter affects a variety of network attributes, consistent with the observation. Because these considerations are unique to node collapses (tie additions or deletions have no impact on firms' access to internal resources), a tie addition simulation cannot be compared to a node collapse simulation for this set of findings.

Diseconomies of Size. The first parameter of interest is the cost incurred by the firm in managing an internal portfolio of nodes, which applies only to actors that absorb others and internalize their resources. By definition, the direct performance increase that results from gaining control over another actor's internal resources declines as cost increases.

Observation 1. As cost increases, the value of internal resources relative to external resources decreases.

We capture the implications of this observation in a variety of outcomes. The plots in this section have the outcome of interest on the vertical axis, the parameter of interest on the horizontal axis, and three lines corresponding to different preconvergence time periods in the simulation (early (period = 20), middle (100), and late (400)). Hence, effects over time can be seen across the lines. One clear emergent pattern is that, under very low cost, the network becomes dominated by one or a few large firms that absorb many nodes because the internal resource incentives overpower the network resource incentives—something similar to a "monopolist" effect. As cost increases, this tendency changes and gives way to a more "egalitarian" network composed of several medium firms because the relative value of external resources goes up. This can be seen in various results. Figure 4(a) shows that the number of firms remaining in the network increases with cost (i.e., fewer node collapses happen as cost increases), while it decreases over time. Figure 4(b) shows that the standard deviation in the average firm size decreases with cost and, when cost is low, increases dramatically over time as more node collapses happen to produce highly nonegalitarian structures with one or a few large central firms and a few small peripheral firms.

Figure 4(a). (Color online) Number of Firms Remaining Over Cost

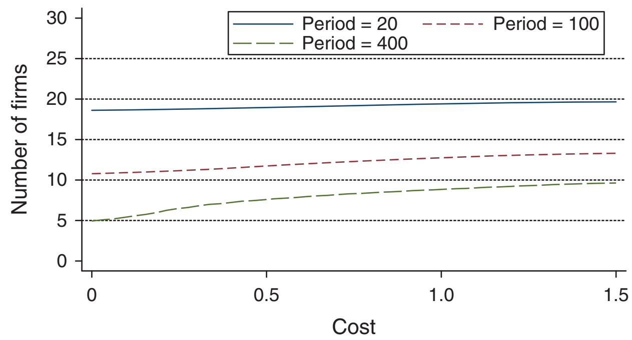


Figure 4(b). (Color online) Standard Deviation of Firm Size Over Cost

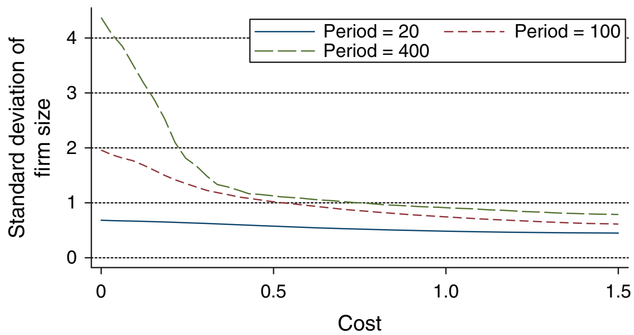


Figure 4(c). (Color online) Constraint Over Cost

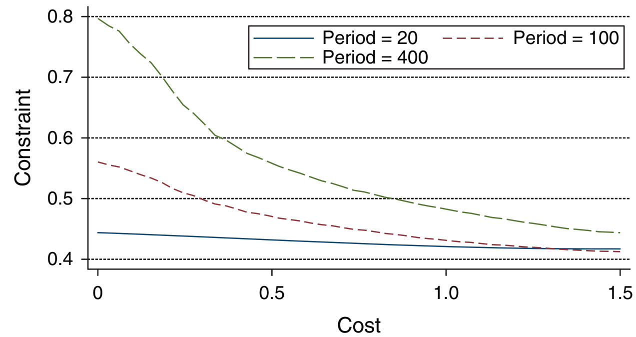
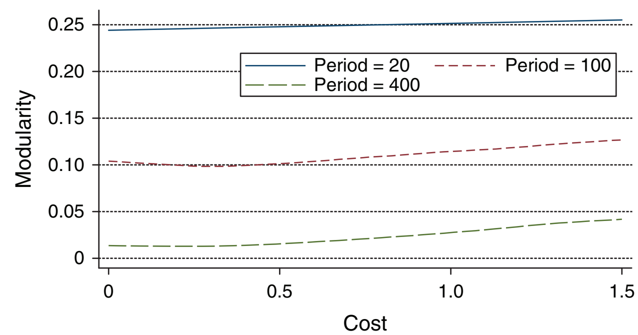


Figure 4(d). (Color online) Modularity Over Cost



The net effect of this pattern for the structure of the network can be seen in two plots. At the ego level, we observe in Figure 4(c) a significant decline in constraint (a move toward more open networks) as cost rises. When cost is low, constraint increases over time rather quickly, while this increase is much lower as cost rises. Consistent with this, Figure 4(d) reveals that at the global level, modularity increases as cost rises because cost prevents a "monopolist" from devolving the network into a single component, although modularity decreases over time as already shown in Figure 2(e).

Result 4A. *When actors seek to increase the amount of resources accessed through node collapses and cost is low, the network becomes dominated by one or very few large firms and evolves toward a structure characterized by high constraint (high closure) at the ego level and low modularity at the global level.*

Result 4B. *As cost increases under the conditions in Result 4A, the network is characterized by small to medium-sized firms and evolves toward a structure characterized by lower constraint (more structural holes) at the ego level and higher modularity at the global level.*

Distance. The second parameter that affects the relative value of internal and external resources is the impact on performance of the distance traveled by the resources to which the firm has access, embodied in d.

To recap, in our model, internal resources have a distance of zero, while network resources arrive to the focal firm via the shortest path length separating the focal firm from the owner of such resources. These considerations result in the following.

Observation 2. As inducements to pursue distant resources increase, the value of external resources relative to internal resources increases.

We will focus on two main patterns. The first is the expected effect of network actors having a disincentive to shrink the network too quickly because it eliminates the benefits of having access to distant resources ("dispersion" effect). The second effect is slightly counterintuitive: because firms get a performance boost as a result of the distance factor, targets that would not have been attractive based on the amount of resources alone are now able to clear the acquisition hurdle rate because they bring with them access to network resources, whose value increases as d increases ("hurdle rate" effect). This hurdle rate mechanism takes effect mainly in late periods, after deals that would have easily cleared the hurdle rate anyway have already been done. Also, it applies under significantly high values of d because the performance boost from even very small network synergies is strong enough to make deals worthwhile. The dispersion effect will slow down the shrinkage of the network, while the hurdle rate effect will slightly facilitate it. We present a series of plots supporting these ideas.

Figure 5(a). (Color online) Number of Firms Remaining Over Distance

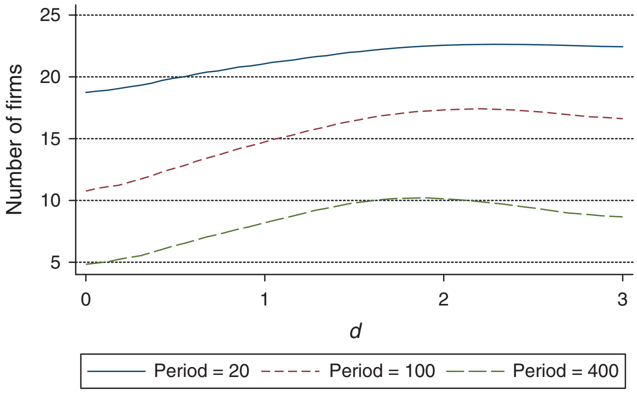


Figure 5(b). (Color online) Standard Deviation of Firm Size Over Distance

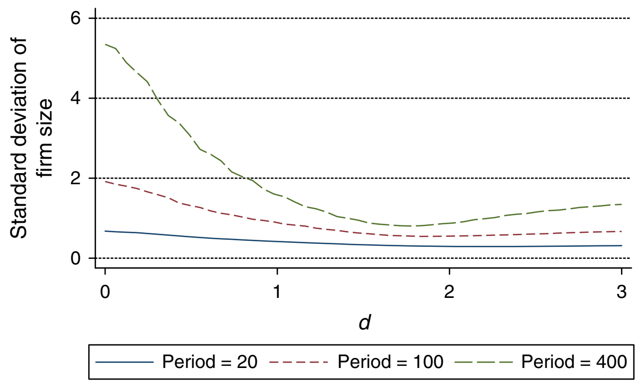


Figure 5(a) depicts the number of firms remaining in the network. As d rises, the number of firms remaining tends to increase, consistent with the dispersion effect. However, for very high values of d (approximately > 1.8), the size of the network tends to fall in d particularly for late periods, consistent with the hurdle rate effect. Figure 5(b) shows that the standard deviation of firm size tends to decline in d, moving the network to a more "egalitarian" structure, but it tends to rise again at very high d in late periods. The dispersion and hurdle rate effects are also manifested in the structure of the network. Figure 5(c) depicts the average constraint of the network actors, which tends to decline in d. Furthermore, constraint initially declines over time (from period 20 to period 100) at very high d because structural holes are particularly attractive because of the high value placed on distant or novel resources. But at very high d and in late stages, the hurdle rate takes effect and pushes the network toward higher constraint. Finally, Figure 5(d) shows the effects of distance on modularity. As expected, the importance of distant network resources pushes the network toward higher modularity initially as d increases. But at very high d at late stages, this tendency is slightly

Figure 5(c). (Color online) Constraint Over Distance

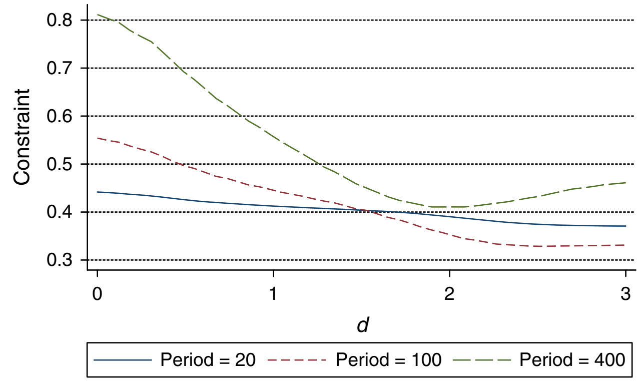
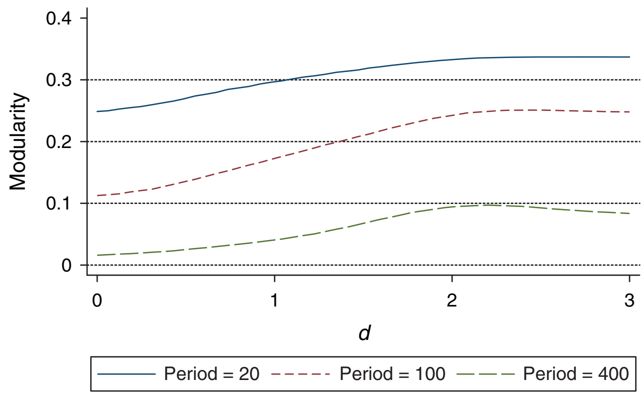


Figure 5(d). (Color online) Modularity Over Distance



reversed because of the additional deals driven by the hurdle rate effect.

Result 5A. *As the importance of distance-weighted resources increases up to moderate levels, the network is increasingly characterized by small to medium-sized firms and evolves toward a structure characterized by lower constraint (more structural holes) at the ego level and higher modularity at the global level.*

Result 5B. *As the importance of distance-weighted resources increases from moderate to very high levels, in late periods there is a mild amelioration the effects in Result 5A: the variance in firm size slightly increases and the network evolves toward a structure characterized by slightly higher constraint (fewer structural holes) at the ego level and mildly lower modularity at the global level.*

Transmission. The ease with which resources flow through network ties affects the efficacy of node collapses and, through that mechanism, the relative importance of internal and network resources. We embody the frictions to resource flows in the tr parameter. At one extreme, in a world with insurmountable frictions ($tr = 0$), no resources make it to the firm through network paths—that is, no network resources are available. Here node collapses are crucial because they are the only means by which resources possessed by other actors can be obtained. But these resources can only be gained through internalization; collapses do not provide access to network resources. As frictions to resource transmission ease to moderate levels (e.g., $tr = 0.5$), internal resources become less crucial as network resources become increasingly available and important. Under these conditions, collapses become useful to access network resources because they allow the acquirer to shorten the distance between itself and valuable resource providers. As transmission increases, therefore, internal resources become relatively less important than network resources. At the other extreme, in a perfectly frictionless world ($tr = 1$), all resources in the network arrive to the focal firm as long as there is a path to the resource owner. Here, internalizing resources has no value except when a node collapse allows the firm to take control of or link to a previously disconnected actor. At the same time, network resources are guaranteed to arrive, so node collapses are not valuable to obtain these either. Thus, we have the following.

Observation 3. As transmission increases, the availability of network resources relative to internal resources increases.

Observation 3A. As transmission increases, the relative importance of node collapses as a means of acquiring internal resources decreases.

Observation 3B. As transmission increases, the relative importance of node collapses as a means of acquiring network resources increases initially and then decreases.

Thus, transmission should affect the evolutionary path of the network in interesting ways. Because transmission affects both internal and network resources simultaneously per Observations 3, 3A, and 3B, varying transmission alone makes it hard to isolate the two types of resources. However, because increases in cost suppress the payoff to pursuing internal resources only (per Observation 1), we compare the effects of transmission across low and high values of cost ($c = 0$ and $c = 1$, respectively). We note that the effects are highly similar whether firms are pursuing only resource amounts ($d = 0$) or distance-weighted amounts ($d > 0$), so we present only the results for the former. Figure 6(a) shows that, under low cost, the number of firms remaining increases as transmission increases. Note that in the absence of any network synergies at $tr = 0$, the increasing returns to scale of our simulation quickly force the network to collapse into a single firm, providing further evidence of how the network synergy was the force that was keeping the network from collapsing before (see Result 2A). Under high cost, the importance of internal resources is suppressed, and we observe that transmission has a nonlinear effect on the number of remaining firms, with the highest number of node collapses occurring at moderate transmission levels per Observation 3B.

Figure 6(a). (Color online) Number of Firms Remaining Over Transmission

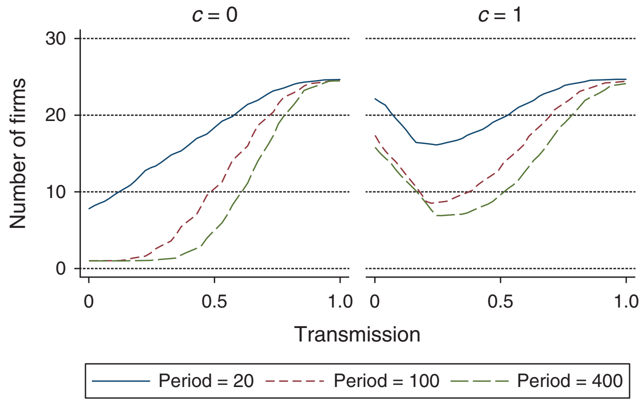


Figure 6(b). (Color online) Standard Deviation of Firm Size Over Transmission

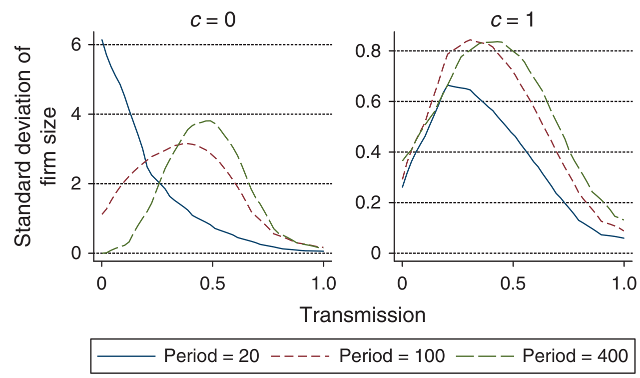


Figure 6(b) demonstrates that in the initial periods, the distribution of firm size becomes more egalitarian as transmission increases in a low-cost regime, whereas it exhibits a nonlinear pattern under a high-cost regime—with the most unequal distribution at moderate values of transmission. Note, however, that under the low-cost regime and at very low transmission levels, the strong incentives for resource internalization drive the network to very quickly devolve into a single firm, as was seen in Figure 6(a) as well. This explains the dramatic fall in standard deviation of firm size at low transmission levels over time, explaining the nonlinear pattern across transmission levels for middle and late stages.

Figure 6(c) reveals that constraint tends to decrease as transmission increases when cost is low (mainly in late periods, as expected) but that when cost is high it has a nonlinear relationship with transmission—with the highest values of constraint, or ego networks exhibiting the highest levels of closure, at moderate

Figure 6(c). (Color online) Constraint Over Transmission

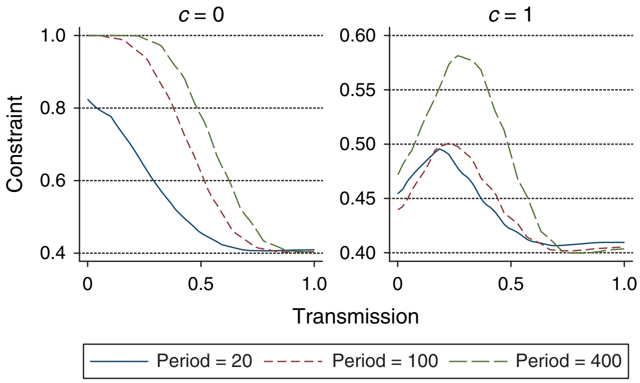
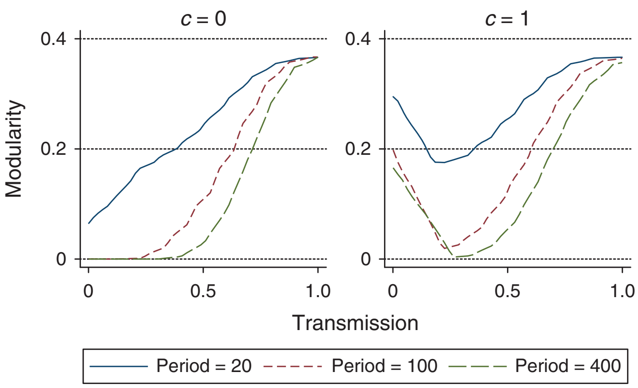


Figure 6(d). (Color online) Modularity Over Transmission



transmission as a result of the significant number of deals that take place then. Figure 6(d) plots the effect of transmission on the modularity of the network. We observe that modularity increases over transmission when cost is low but that it exhibits the expected nonlinear relationship in which modularity is lowest at moderate transmission levels when cost is high.

Result 6A. *As transmission increases in a low-cost scenario, fewer node collapses happen, the network is characterized by a more egalitarian distribution of small to medium-sized firms, and the network evolves toward a less constrained and more modular structure.*

Result 6B. *As transmission increases in a high-cost scenario, the number of node collapses initially increases and then declines, the egalitarianism of the network initially decreases and then increases, the constraint of ego networks initially increases and then decreases, and the modularity of the network initially decreases and then increases.*

Robustness Tests

The findings remain qualitatively similar in a series of additional tests. We conducted simulations allowing for different rates of entry of new firms into the network. These simulations had two important features: (1) the rate of entry was determined by a probability that one new firm entered the network in each period (we ran models ranging from 10% to 30%), and (2) the new entrant was endowed with the average number of ties of the initial network (determined by p). The relationships between the key parameters (c, d, and tr) and the outcomes of interest remained qualitatively similar. The only difference, unsurprisingly, is that the point of convergence (i.e., no more deals are happening) happens later as the entry rate increases and that the network increases in size over time when the entry rate is high.

One arguably strong assumption we made in the main models is that the acquirer inherits all of the network ties of the target. The benefits of node collapses may dissipate if ties are lost systematically. To address this, we introduced a parameter m that captures the proportion of the target's ties that remain postacquisition (i.e., a fraction $1 - m$ ties of the target are randomly dropped). In the main simulation, the default value of $m = 1$. We found substantively similar results using 0.50 and 0.75 as alternative values. We reasoned that losing more than half the ties is unlikely in most scenarios. While we do not expect the m parameter to embody all scenarios under which ties may be lost, it helps provide a sense that the results are robust to at least one assumption of tie loss.

We also checked the sensitivity of the results to the assumption that firms cannot acquire targets that more than 1.5 times larger. We relaxed this constraint by running models allowing acquirers to purchase targets up to 2 and 3 times as large, as well as without restrictions on target size. The results are, once again, qualitatively similar.

Discussion

This paper studied an underexplored mechanism of network evolution based on changes in nodes. We focused our attention on some of the key features of this mechanism that make it distinct from changes in network ties. In this section, we comment on some of the main patterns that emerged from the simulation and their implications for research on networks, acquisitions, and organizations. We also attempt to explicitly point out empirically testable implications as we discuss the main patterns.

A unique aspect of node collapses is that they allow firms to both internalize a target's resources and increase access to a target's network resources. M&A research has long focused on the former but not explicitly considered the latter. We suspected that the relative importance of pursuing internal versus network resources through acquisitions would have a significant bearing on the direction of network evolution. The general pattern is that conditions motivating firms to pursue internalization of resources lead to networks dominated by a monopolist and structurally characterized by low modularity at the global level and high constraint at the ego level. By contrast, conditions motivating firms to pursue network resources lead to a more egalitarian distribution of small to medium firms, where the network is structurally characterized by high modularity and low constraint. Empirical work could test these implications by observing how heterogeneity in the types of resources firms seek through M&A activity affects the structure of interfirm networks. These patterns from the simulation were revealed by varying three factors that affect the relative weight placed on the two types of resources: the cost of being a large firm, the value of distant resources, and the ease of transmission through network ties. Each of these parameters map onto real-world applications and important empirical literatures.

Incentives to pursue resource amounts versus distance-weighted resources may correspond to different types of industries. In settings where resources are not very differentiated and performance is driven by size or market power (e.g., oil, transportation), firms may be more motivated to pursue high resource amounts. We note that such industries are, consistent with our findings, characterized by higher levels of concentration (akin to a "monopolist" effect) and tend to place less emphasis on external collaboration. By contrast, in industries where differentiation and innovation are more germane to performance (e.g., biotechnology, electronics), the network distance of resources may be important. Those industries also show network patterns consistent with our findings because they tend to place more importance on external collaboration and thus have larger networks of firms interacting with each other.

Consistent with this latter observation, we found that node collapses produce negative externalities on the structural holes spanned by firms, which are frequently associated with access to novel resources (Burt 1992). This speaks to the issue of innovation through networks, which is of interest to many scholars (Ahuja 2000, Phelps et al. 2012). In empirical work, Tatarynowicz et al. (2016) demonstrated that firms are more likely to pursue structural holes as the technological dynamism of the industry (a proxy for the need for novelty) rises. A study motivated by the concept of node collapses could take this a step farther and test whether firms select acquisition targets that enhance access to structural holes in technologically dynamic industries but prefer those that enhance network density in technologically stable industries.

The transmission parameter applies to several empirical examples of factors affecting the process of interorganizational knowledge transfer. The nature of the relationships between network participants is one such factor, with trust facilitating resource flows (Zaheer et al. 1998) and competition impeding them (Hernandez et al. 2015). The institutional context also plays a role because it affects partners' mindsets and motivations to share knowledge (Powell et al. 2005, Vasudeva et al. 2013). The nature of the resources being exchanged (e.g., tacit versus codifiable) is also relevant (Szulanski 1996). Any of these could impact transmission and provide empirical scenarios in which to test a common implication of our simulation: as the frictions to knowledge flows via networks are high, firms are more likely to engage in acquisitions versus tie formation to obtain desired resources. These empirical scenarios could also be used to test whether settings with increasing knowledge transfer frictions affect the density and modularity of interfirm networks.

Our exploration of the cost parameter revealed an intriguing result that speaks to the literature on firm boundaries. The network does not simply devolve to a single, massive firm because the benefits of network synergies countervail the incentives of purely internal production (Result 2A). Coase (1937) suggested that firms would not grow indefinitely large because diseconomies of size would make managing extremely large organizations challenging. We indeed observe this effect—as cost increases, the network stops short of collapsing to a single firm. But we also observe that, even in the absence of diseconomies of size ($c = 0$), firms do not grow indefinitely due to the value of network resources. This provides an additional limit on firm size not anticipated by transaction cost theories. Empirical research could get at issues surrounding the cost of firm size by taking advantage of technological transitions that make vertical or horizontal integration more or less valuable, and such research could see whether the pattern of effects on network dynamics (and the choice to use acquisitions to collapse nodes) holds in real-world data.

While node collapses have significant effects on the networks of acquirers, one of the hallmarks of this mechanism is the strong externalities it imposes on actors not involved in the transaction. We found positive externalities on performance and negative ones on centrality and access to structural holes. This is somewhat paradoxical because the two structural properties enhance access to resources. In our simulation, acquisitions always increase the potential resources available to others because they increase the resources of acquirers, who in turn are more likely to transmit more to those they are connected to. Hence, even if they worsen others' structural positions, acquisitions do not decrease access to resources and thus improve others' performance. We recognize that this may not be realistic because actors are likely to differentially transmit network resources to others depending on whether they are collaborators or rivals (e.g., Hernandez et al.

2015). Future work could develop this with more nuance than we have.

Because node collapses only happen in interorganizational networks (not in interpersonal ones), they most commonly occur through mergers and acquisitions. Hence, the findings have significant repercussions for the literature on that subject. Only recently have network considerations begun to seep into the literature (Anjos and Fracassi 2015). We introduce the important idea that acquisitions, by collapsing nodes, generate two kinds of synergies: internal ones based on owned resources and network ones based on relational resources. The increasing returns conditions of the model produced outcomes consistent with internal synergies as discussed by prior work—firms have strong reasons to internalize others to become more productive. But as we illustrated with some of the introductory examples, understanding node collapses provides an explanation for acquisitions not considered previously.

We suggest three types of deals uniquely motivated by node collapses. The first would help the firm rapidly improve its network position in a way that tie changes cannot. This may be the case when a single acquisition provides the ability to tie with many new partners at once at a lower cost than separately establishing formal or informal ties to each desirable new partner. The second type of deal would be motivated by imposing an externality on other network participants. Our results provided one example: firms can eliminate the structural holes of others through node collapses, which may limit their ability to access novel resources. The third type of deal would be motivated by control, such as blocking a rival from partnering with a valuable target or protecting a bit of valuable knowledge. This may happen, for instance, when the firm wants to eliminate a rival from the network to reduce competition for a certain network position (e.g., take out a structurally equivalent node).

Each of these cases cannot be explained by the concept of internal synergy alone. Indeed, node collapses may help explain otherwise odd deals where no significant owned assets seem to be in play. This may be helpful in addressing the perennial issue of why firms engage in acquisitions despite evidence that the stock market reacts negatively to them (Giliberto and Varaiya 1989, Haspeslagh and Jemison 1991). Perhaps considering network synergies may explain variance in acquisition performance above and beyond internal synergies and even identify cases in which network synergies compensate for negative internal ones. We believe that future empirical work could document the various kinds of synergies to understand different sources of value for acquirers. For instance, the difficulty of relying on tie formation to access desirable network resources varies across firms with low versus high status. Because the former may not be able to control tie formation as much, perhaps they rely on acquisitions more than high status firms to gain access to network ties. Or a study getting at the externalities created by node collapses could assess whether firms involved in innovation races, where preventing rivals from accessing novel ideas is crucial, engage in acquisitions offering few internal synergies but producing high negative network externalities (such as closing others' structural holes).

While the application that motivated our initial interest in node collapses is mergers and acquisitions affecting interfirm alliance networks, the mechanism of node collapse occurs in other settings. Within an organizational context, reorganizations frequently involve the combination of departments or other subunits to streamline operations. These events can be conceptualized as node collapses that alter the structure of formal and informal ties among employees and reassign rights and responsibilities over intraorganizational resources. Marriages may have some features of node collapses because they combine the assets (social and economic) of families and allow access to new social groups. The degree of instrumentality we assume in corporate mergers may not apply to many modern marriages, but in the past, marriages have served significant political and economic roles that may be understood from a node collapse angle (Padgett and Ansell 1993). Not all of the assumptions we have made in our simulation may apply to these other instances of node collapses.

Earlier we described a test indicating that the results are robust to node collapses resulting in a loss of a certain fraction of ties chosen at random. It might be the case that the loss of target ties is nonrandom but instead skewed toward exactly those ties that bring in certain types of resources. These would be important boundary conditions of our results. Some previous research has shown that firms may lose client ties in nonrandom ways after a horizontal merger (Rogan 2013, Rogan and Greve 2014), and Rogan and Sorenson (2014) bring up the fact that sometimes the social capital embodied in organizational networks is controlled by individuals rather than organizations, which may lower the efficacy of node collapses in obtaining desired resources. This may be captured in the low transmission scenario of our model if what individuals do is reduce flows between firms.

Given the novelty of node collapses to research on network change, we felt it was important to focus on a world in which that is the only process at play, with a simple comparison to tie additions for some of the primary results. One limitation of the study is that we have put aside other mechanisms by which the network evolves: (1) tie deletions, (2) entry and exit of nodes, and (3) node splitting (e.g., divestitures). A joint study of these processes would be a valuable next step, with several issues worth addressing. At a basic level, comparing the impact of the various mechanisms on specific outcomes can provide a sense of which means are most effective in helping firm accomplish certain goals. One issue in such a study could be the relative cost of various types of mechanisms in producing a desired outcome. For instance, a single tie addition or deletion is likely to be less expensive than a node collapse or split. Another issue may be under what conditions certain mechanisms may be functionally equivalent, such as when a strong tie may be as useful for resource access as a collapse and when it may not. As we mentioned earlier, these mechanisms are likely to work together as part of a tool kit. Understanding the sequencing of various actions would be important—for instance, firms may divest to make room for network renewal and then use a combination of additions and mergers to obtain new resources.

We have pointed out that node collapse is a frequent occurrence but that its effects on network evolution and on acquisition strategy has been unexplored. Given the prevalence of acquisitions and the documented effects of network positions on firm performance, exploring the implications of this mechanism has theoretical and practical value. Because a single collapse transaction can have a much larger impact on the network compared with tie additions or deletions, it has the ability to produce network revolution rather than incremental change. Moreover, node collapses uniquely allow firms to access both internal and external resources, and which of the two resources firms pursue impacts the direction of network evolution. A few of the effects of these issues were glimpsed in the results of this paper, but the subject raises many implications that remain to be studied.

Acknowledgments
The authors thank Olav Sorenson and the editorial team at *Management Science*. Matthew Bidwell, Emilie Feldman, David Knoke, Michael Leiblein, Xavier Martin, Ethan Mollick, Myles Shaver, Aks Zaheer, and Sri Zaheer provided helpful comments. The authors appreciate feedback from anonymous reviewers at the 2015 Strategic Management Society Conference, where this paper was runner-up for the Best Paper Award. Supritha Ravikumar provided valuable programming assistance. The authors are thankful to Wharton Computing for allowing them to use their High Performance Computing Cluster. The usual disclaimers apply.

Endnotes
[1] We define resources broadly as including any tangible or intangible factors that may affect firm performance. We are interested in resources that can be transferred or accessed through network ties (e.g., Gulati 1999, Lavie 2006), so factors such as machinery that do not move through networks are beyond the scope of this study. While the bulk of networks research tends to focus on information or knowledge, and such resources may be the dominant type that flows through networks, we use the broader term "resources" for generalizability.

[2] See Hernandez and Menon (2016) for a study of the effect of multiple network change mechanisms, including tie and node changes.

[3] Existing work on market power has also considered "external" consequences of acquisitions, such as eliminating a rival or taking greater control over suppliers (Devos et al. 2009). Or a transaction may also impact ties to clients (e.g., Rogan and Sorenson 2014). While the focus of those studies is on external considerations, here we are concerned with effects on the structure of the ego and global networks in which the acquirer is embedded, and the performance implications thereof.

[4] We did not generate a tie deletion simulation because the objective function in our case does not create any incentives to remove ties, and it was important to use comparable objectives across the simulations.

[5] Backing for this point comes from Figure 6(a), to be discussed later, when all network synergies are turned off at transmission levels of 0. In that scenario, given the absence of a network force to counteract internal synergies, we do indeed see that the network rapidly devolves into a single large firm driven by increasing returns to scale.

[6] This scaling is necessary when it comes to comparing performance because the total amount of network resources changes with the number of firms in the network. Hence, performance comparisons across node collapse and tie addition simulations are not meaningful without scaling. This is not an issue when comparing structural metrics such as degree and constraint (see Figures 3(b) and 3(c)).

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