Alliance-Network Externalities and Firm Innovation: Separating Endogenous from Exogenous Network Effects

We investigate whether the effect of network position on innovation is causal or spurious. Although empirical evidence demonstrates that certain structural positions in alliance networks (e.g. structural holes) affect firm innovation (Phelps, Heidl, and Wadhwa, 2012), it is hard to disentangle the factors allowing a firm to put itself in a certain position from the innovation outcomes that stem from being in that position. In other words, do firms innovate more because of their network position, or do they occupy that position because of their innovation strategies and capabilities? While this might appear to be an empirical issue, it is fundamentally a theoretical one because the resolution depends on how scholars conceptualize the underlying mechanisms by which interfirm networks arise and change (Shaver, 2020).

To help disentangle cause and effect in this line of research, we advance a theoretical concept—*alliance-network externalities*. We describe how this helps distinguish network changes that are intentional (i.e., ego-driven or endogenous) from network changes that are unintentional (i.e., alter-driven or exogenous to the focal firm). From this theoretical foundation, we develop a novel methodological approach to identify if empirical relationships between network position and innovation are causal. We apply this approach to re-evaluate the relationship between structural holes and firm patenting in the biotechnology industry.

THEORETICAL ARGUMENT

Innovation is a process of recombination, whereby firms obtain multiple bits of knowledge and remix them in original ways (Fleming, 2001). Networks factor into this process because the structural position a firm occupies affects the amount, variety, and uniqueness of the knowledge available for recombination. In studies of interfirm alliances, structural holes is the network property most commonly linked to innovation (Burt, 1992). The theory is well known (Burt, 2004). The more structural holes a firm bridges, the more disconnected partners it has. Disconnected partners expose the focal firm to distinct knowledge communities. Firms at the center of many disconnected partners have exclusive access to a large scope of unique knowledge bits. Therefore, brokers have a vision and timing advantage in access to non-redundant ideas. This theory has led to a significant amount of empirical research (see Phelps *et al.*, 2012).

Assessing Causality

A complication of assessing the relationship between network positions and firm-level outcomes, such as structural holes and innovation, is that the "network generating process" is not clearly theorized (Salancik, 1995). There is no generally accepted account of how firms end up in certain positions of interest (Ahuja, Soda, and Zaheer, 2012). And without understanding that process, it is hard to know if the effect of the network attribute on an outcome is causal or spurious. This is not a purely empirical consideration. Rather, it reflects that the *theoretical* mechanism explaining the relationship between the network position and the outcome could be driven by factors related to the process that led firms to end up in that position to begin with, rather than with the position itself. In the case of firms behaving with strategic intent, those factors are related to the organization's goals, capabilities, and opportunities.

We illustrate this for the case of structural holes, but the point applies more generally. To span many structural holes, a firm needs to have (a) many partners who are (b) disconnected from one another, representing (c) a diverse and non-redundant set of knowledge spheres. Further, once a firm spans structural holes the following needs to be true for innovation to happen (see Vasudeva, Zaheer, and Hernandez, 2013): (d) knowledge should flow from the partners to the broker and (e) the broker should be capable of absorbing and recombining the knowledge in creative ways.

What kind of underlying factors would lead a firm to end up in such an advantaged position? In terms of condition (a), firms that attract many alliance partners have strong technological capabilities, powerful brands, and high social status (Ahuja, 2000a). In terms of conditions (b) and (c), firms that establish alliances across a variety of knowledge spaces tend to follow diversified product and technological strategies (Hernandez and Shaver, 2019) and are often in dynamic industries (Tatarynowicz, Sytch, and Gulati, 2016). In terms of condition (d), firms that can motivate their partners to share knowledge probably have strong alliance management capabilities (Kale, Dyer, and Singh, 2002). And in terms of condition (e), firms that can absorb and recombine multiple sources of knowledge must have reasonably high absorptive capacity (Cohen and Levinthal, 1990).

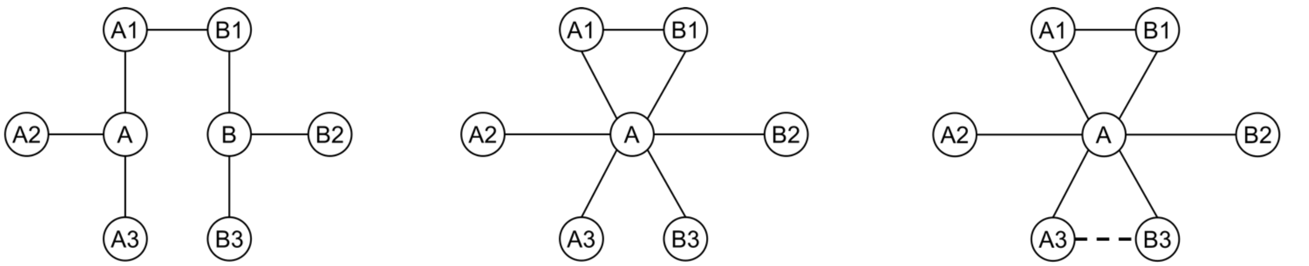
Because those factors allowing firms to obtain brokerage positions are also associated with enhanced innovation outcomes, separating the "network generating process" from the causal effect of structural holes on innovation is challenging. A solution to this problem would be to find a scenario in which the theoretical mechanism leading to the firm's network position is exogenous to its goals, actions, and capabilities. We propose and test such a mechanism.

Alliance-Network Externalities

Recent advances in the study of interfirm networks provide a means of identifying situations in which the network of a focal firm changes as a result of *other* firms' actions. We apply those ideas to distinguish between intentional and unintentional network change processes, which forms the conceptual basis to assess causal network effects.

A network is composed of nodes and ties; thus, network change is fundamentally about modifications in nodes and ties. Existing research overwhelmingly considers processes of network formation driven by modifications in ties. In interfirm networks, tie changes happen when two firms either form or end an alliance. Hernandez and Menon (2020) point out that firms also engage in corporate actions that modify ownership and existence of *nodes* in networks, including acquisitions ("node collapses"), divestitures ("node splits"), industry entry ("node appearance"), and industry exit ("node disappearance").

We are interested in one profound implication of this broadened notion of network change mechanisms: when a firm undertakes any of the various corporate actions (tie additions, tie deletions, acquisitions, divestitures, entry, exit), those actions can also give rise to network externalities that modify the structural positions of *other* network participants (Hernandez and Menon, 2018, 2020). The figure below offers some simple illustrations. The figure on the left shows the ego networks of firms A and B. The middle figure shows what happens after A and B merge and combine their networks. Previous research focuses on the implications of such a network combination from the perspective of the acquiring firm (A) (Hernandez and Shaver, 2019). But other firms are affected too, even though they are not parties to the deal. For example, after the acquisition, A1 no longer spans a structural hole between A and B1, and B3 now has a new link to A. Similarly, the alliance formation and deletion behaviors of one firm can impose network externalities on another firm. The right-most figure below, for instance, illustrates that if A3 and B3 form a tie they would "close" the structural hole that A used to span. These simple examples illustrate *alliance-network externalities* (Hernandez and Menon, 2020).



An example of an acquisition imposing network externality (A & B merges into A)

An example of an alliance imposing network externality (A3 and B3 form an alliance)

Intentional vs. Unintentional Ego Network Change

Suppose we observe that a firm's structural holes increased from one period to the next, and that its innovation subsequently increased. If the firm's position changed because of its own actions—say it formed new alliances or made an acquisition—it's difficult to isolate the strategy and capabilities behind those actions from the innovation outcome (i.e. we may be observing a treatment effect). In contrast, if the structural change was the unwitting result of *another* firm's actions—say an acquisition involving two proximate firms in the network results in more structural holes for the focal firm—we can plausibly claim to identify a treatment effect of structural holes on innovation.

Alliance-network externalities, thus, provide a theoretical foundation to separate intentional from unintentional network change. This, in turn, suggests an empirical approach to test the effects of network position on firm-level outcomes that better establishes causal inference. More generally:

Proposition: If a change in network position for a focal firm results from the alliance-network externalities created by other firms' actions, the effect of that change in network position on an outcome can be more confidently be considered causal. If a change in network position for a focal firm results from the focal firm's own actions, the effect of that change in network position on an outcome cannot be considered causal.

METHOD AND RESULTS

We apply the proposition to assess the relationship between structural holes and innovation because it is one of the most commonly studied relationships in interfirm alliance networks. To do so, we develop a novel empirical methodology, which we describe below.

Our first step is to replicate the findings of prior literature. To do so, we obtain data from a well-known context: biotechnology alliances (1995-2007) and patents (1996-2012). The most common innovation indicators linked to structural holes in alliance networks are patent counts and citation-weighted patent counts, typically observed in the five-year period following the observation of the network structure. Structural holes are usually measured through Burt's (1992) constraint indicator. And the canonical specification is a panel data analysis that regresses patent outcomes on network positions, with firm and year fixed effects. As the table below shows, we replicate previous findings and document a negative effect of constraint on patent outcomes (Models 1 and 2)—recall that lower constraint reflects more structural holes.[1]

Our next step accounts for all possible corporate actions that affect the network structure (alliance formation, alliance termination, acquisitions, divestitures, entry, and exit). Extant work primarily accounts for alliance formation,

[1] For simplicity of exposition, the results shown in this abstract are based on models not including control variables. However, the findings remain materially unaltered in models including controls typical of prior studies.

alliance termination (usually by assuming that alliances last five years), firm entry (by incorporating new firms that establish alliances), and firm exit (by eliminating firms that do not establish alliances for a predetermined time period, usually five years). However, it does not account for acquisitions and divestitures. We account for the first by reassigning the alliances of acquired firms to the acquirer (see Hernandez and Shaver, 2019). Divestitures are harder to account for in the network because there is no information on how pre-existing alliances get allocated between the parent and the divested firm. Therefore, we identify all firms involved in divestitures and eliminate them from the sample (results are robust to keeping them). The full details of the procedures we followed are beyond the scope of this brief proposal, but available from the authors. Accounting for all possible network change mechanisms allows us to develop more precise measures of network position. When doing so, we continue to find a negative effect of constraint on patent outcomes (Models 3 and 4, table below). With the more precise network data, the magnitude of the effects decreases slightly and the p-values of the coefficient estimates increase.

	Firm FE Model				**First-Difference Model**	
Model #	**1**	**2**	**3**	**4**	**5**	**6**
M&A and Divest.?	**No**	**No**	**Yes**	**Yes**	**Yes**	**Yes**
Dependent Variable	**Pat. Count**	**CW Pat. Count**	**Pat. Count**	**CW Pat. Count**	**Pat. Count**	**CW Pat. Count**
Network Constraint	-2.746***	-8.091***	-2.616***	-7.898*	-0.657***	-3.074***
	(0.554)	(3.004)	(0.880)	(4.095)	(0.182)	(1.134)
Year fixed effect	Y	Y	Y	Y	n/a	n/a
Firm fixed effect	Y	Y	Y	Y	Y	Y
Observations	42,242	42,242	39,840	38,299	32,603	32,442
Number of firms	7,910	7,910	7,794	7,607	6,826	6,807
R-squared	0.014	0.033	0.006	0.02		

*** p<0.01, ** p<0.05, * p<0.1 (robust standard errors in parentheses)

As a third step, we adopt a different panel estimator than the standard firm fixed-effects specification. Because the panel is long (12+ years), we are concerned that unobservable effects are not constant, which is the assumption underlying the fixed-effect estimator (i.e., no serial correlation in the error structure). Therefore, we adopt a first-difference specification, where all variables are subtracted from the values of the previous year's observation. This model has the less restrictive assumption that changes in unobservable effects follow a random walk (Wooldridge, 2001). Models 5 and 6 (table above) present these estimates. We continue to find a significant negative effect of network constraint on the two patent outcomes. However, the magnitude of the coefficients is much smaller: about a quarter the size for the patent count measure and less than half the size for the citation-weighted patent count measure. Note also that the sample size is smaller because the first year of observation is lost (subtracted away).

Our final step is to distinguish between instances of intentional vs. unintentional change in structural holes (constraint). Recall that changes resulting from the focal firm's own actions (e.g. acquisitions, alliances) can be considered intentional, whereas those resulting from others' actions can be considered unintentional. Ideally, we could separate the portion of the network constraint measure resulting from the firm's own actions from the portion resulting from others' actions. That is not doable because it is impossible to identify exactly which of the focal firm's vs. others' actions lead to modifications in each individual tie comprising the focal firm's ego network. However, we know for each year of observation whether the firm was subject to one of four categories of network changes: (1) no change, (2) endogenous change (affected only by the firm's own actions), (3) exogenous change (affected only by others' actions), or (4) both exogenous and endogenous change.

		Endogenous Network change by *self-initiated alliance or acquisition*		
		No	Yes	Total
Exogenous change from *3rd-party's alliance or acquisition*	No	3,572 (No change)	428 (only endogenous change)	4,000
	Yes	15,173 (Only exogenous change)	20,398 (Both endogenous & exogenous change)	35,571
	Total	18,745	20,826	39,571

Thus, we can categorize each firm-year as falling into one of those four conditions. We can then interact constraint with each of the categories to assess the effect of structural holes on innovation under each of the four conditions. The coefficient of *constraint X exogenous change* can be interpreted as the exogenous effect of structural holes on innovation, while the other interactions provide the effect of structural holes on innovation under purely endogenous or mixed conditions that cannot be interpreted as causal.

Before showing the results, it is important to consider a few issues pertaining to the four conditions. First, we determine that a firm is subject to an exogenous network change when it is within two degrees of separation from an acquisition (whether tied to the acquirer or target), and within one degree of separation from an alliance formation or termination event (tied to either of the allying parties). The analysis leading to this determination is available upon request. Second, there are a meaningful number of purely exogenous changes (15,173 or 38% of firm-years), so that it is not a rare condition. The table above shows the incidence of all four conditions in our data. Third, both endogenous and exogenous events produce meaningful changes in network constraint from year to year. Expectedly, endogenous actions (i.e. firms' own alliances and acquisitions) create bigger average changes in constraint than exogenous actions, but the variance in changes produced by exogenous actions is larger than the variance produced by endogenous actions (results available upon request). This alleviates concerns of our findings being driven by a lack of variance in some of the network change categories. Fourth, firms experience different network change conditions over time, and they tend not to experience the same type of network change in consecutive years [i.e. it is atypical for a firm to consistently experience only one kind of change (e.g. purely exogenous) for several years in a row]. This is important because it determines the appropriate empirical specification. When firms change categories over time, a traditional firm FE model is inappropriate because the deviation from the within-firm "trend" makes little sense—there is no trend in categories of network change. But the first-difference model does make sense because it accounts better for year-over-year switches in the condition that led to the observed change in structural holes.

Model #	7	8	9	10	11	12	13	14	15	16
Dependent Variable	**Patent Count**					**Citation-Weighted Patent Count**				
Network Constraint X No Change	0.0765				0.0989	0.108				0.202
	(0.385)				(0.387)	(0.908)				(0.922)
Network Constraint X Only Endogenous		-0.455*			-0.489*		-2.312*			-2.463*
		(0.256)			(0.258)		(1.322)			(1.323)
Network Constraint X Only Exogenous			1.368**		1.369**			2.998		3.001
			(0.657)		(0.657)			(2.097)		(2.101)
Network Constraint X Both				-0.704***	-0.706***				-3.219***	-3.229***
				(0.197)	(0.197)				(1.243)	(1.243)
Year fixed effect	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	32,603	32,603	32,603	32,603	32,603	32,442	32,442	32,442	32,442	32,442
Number of firms	6,826	6,826	6,826	6,826	6,826	6,807	6,807	6,807	6,807	6,807

*** p<0.01, ** p<0.05, * p<0.1 (robust standard errors in parentheses)

With these considerations in mind, the above models reveal the results of the first-difference estimation. Reassuringly, constraint exhibits no effect on innovation outcomes under conditions of no network change. The consistently significant result, when comparing across specifications using patent counts and citation-weighted patent counts, is that constraint exhibits a negative effect on innovation only under conditions including *endogenous* network change. The effect is most significant in the theorized direction when both endogenous and exogenous mechanisms modify the network ($p < 0.01$), followed by conditions when only endogenous mechanisms affect the network ($p < 0.10$). We do not find the expected negative effect when network change is driven by exogenous mechanisms (externalities): constraint *positively* affects patent counts ($p < 0.05$), but has no effect on citation-weighted patent counts.

DISCUSSION

Our results show that the mechanism leading firms to occupy structural-hole-spanning positions plays a crucial role in explaining why that network position affects firm-level innovation. In other words, we do not find evidence that network position, per se, affects innovation outcomes. We found that network changes driven by self-initiated corporate actions—acquisitions and alliances—were most consistent with the canonical expectation that structural holes (low constraint) would increase innovation. There is something inherent to the strategies, capabilities, and objectives that lead firms to pursue interfirm partnerships that correlates with firms' ability to produce patent-related innovations. In contrast, we found no clear effect of structural holes on innovation when the mechanisms that change firms' network positions are alter-initiated. The positive effect of constraint on patent counts replicates some prior research making the case for closure—the opposite of structural holes—as the driver of innovation productivity (e.g. Ahuja, 2000). However, the lack of an effect in either direction for citation-weighted patents, and the sensitivity of this effect to the window in which we define the variable (not shown), makes us cautious in concluding that the exogenous effect is positive.

The main conclusion of this study is not to simply state that network effects on innovation are not causal. Rather, because there is consistent empirical evidence that network structure correlates with innovation, it is important to advance theories and tests that better identify the underlying causal mechanism (should it exist). Researchers need to theorize about potential “network generating processes” that would lead firms to end up in the position of interest. This is just as important as, and inseparable from, theorizing about the mechanisms by which the position—once obtained—affects the outcome of interest. In parallel, research designs need to account for and potentially discriminate between different network generating processes. This affects what data are gathered, how network positions are measured, and what empirical specification is most appropriate to account for how firms change positions over time.

In conclusion, by advancing the theoretical concept of alliance-network externalities and devising a research design to take advantage of this concept, we evaluate the relationship between structural holes and innovation. Replicating the approach of existing research, we find that increases in structural holes are associated with more innovation. However, the effect is manifested only when network change is induced by a firm’s own corporate actions and not when the change is induced by others’ actions, which prevents us from concluding that the effect is causal. We hope this finding can help direct theoretical and empirical work in this domain.

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