TIE DISSOLUTION IN MARKET NETWORKS:

A THEORY OF VICARIOUS PERFORMANCE FEEDBACK

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ABSTRACT

Managers need to periodically evaluate any exchange partner to decide whether to continue or dissolve the exchange tie. Despite the importance of exchange ties, how managers assess a partner's contribution to firm performance remains poorly understood. We argue in this paper that one way managers evaluate their exchange partners is by observing the performance trajectories of competitors who rely on the same exchange partner. We propose a theory of vicarious performance feedback and test it in the context of Formula One motor racing. We find that a firm building a Formula One racing car is more likely to end an exchange relationship with an engine supplier after that supplier's other customers experience an episode of poor performance relative to their historic track record. In line with an attention-based view of the firm, we find that this behavior occurs when the firm's own performance is below its aspiration level. We contribute to the literatures on vicarious learning, network dynamics, and performance feedback.

INTRODUCTION

A central theme in organization theory is that economic activity is embedded in a network of social relations, such as the exchange ties between suppliers and buyers within an industry (White, 1981; Uzzi, 1997). Networks of interorganizational relationships have been found to impact numerous important outcomes for firms, including innovation, value creation and value capture, and survival (Uzzi, 1996; Ahuja, 2000; Lavie, 2007; Gulati, Wohlgezogen, and Zhelyazkov, 2012). Understanding the dynamics of market networks is therefore a high priority for scholars of organization theory (Ahuja, Soda, and Zaheer, 2012; Sytch and Tatarynowicz, 2014). The formation and dissolution of exchange ties are managerial choices which turn on managers' evaluations of the potential gains from a given relationship. A large body of research addresses how managers evaluate potential exchange partners when making tie formation decisions (e.g., Gulati and Gargiulo, 1999; Podolny, 2001; Mitsuhashi and Greve, 2009). Much less research addresses how managers evaluate current exchange partners (Rivera, Soderstrom, and Uzzi, 2010).

At first glance, it appears that evaluating current exchange partners would be a straightforward matter: through their experience of working with a partner, managers discover private information which was unobservable before forming the tie (Fichman and Levinthal, 1991). However, research has shown that evaluating a given exchange partner is challenging (Sorenson and Waguespack, 2006; Azoulay, Repenning, and Zuckerman, 2010). Organizational experience—including experience working with a given exchange partner—is often deeply ambiguous (March, 2010). Causal ambiguity hinders managers' attempts to attribute organizational performance to the factors that underlie this performance (Mosakowski, 1997; King, 2007). A firm's performance depends on the interplay of its internal resources and the elements contributed by its exchange partners (Thompson, 1967), making the separable contributions of elements in the system hard to discern (Sterman, 1994). Furthermore, managers have a limited sample of direct experience with any given organizational partner with which to make an evaluation (March, Sproull, and Tamuz, 1991). In this paper we examine how organizations decide whether or not to dissolve a tie with a current exchange partner given such causal ambiguity.

Organizational learning research has found that when direct experience is insufficient for assessing the value of a technology or practice, managers can supplement it with vicarious observation of other organizations (e.g., Baum, Li, and Usher, 2000; Terlaak and Gong, 2008; Posen and Chen, 2013). Work on vicarious learning shows that despite the limitations of bounded rationality, managers attend and respond to salient information in their environment (Gavetti, Levinthal, and Rivkin, 2005; Baum and Dahlin, 2007; Mitsuhashi, 2012). Research has not yet addressed whether vicarious learning extends to the evaluation of existing exchange partners. When there is uncertainty surrounding an exchange partner's quality, vicarious observations could provide useful information that helps managers interpret their ambiguous experience.

In this paper, we develop the argument that firms learn not just from their direct experience with a given exchange partner, but also from other firms' concurrent experience with the same partner. For example, when two firms (A and B) procure the same component from a supplier (S)—a constellation we refer to as joint component usage—each firm can observe the other firm's performance and use such observations to supplement knowledge from its own direct experience with the supplier. We hypothesize that whether firm B performs above or below its aspirations will affect firm A's decision whether or not to dissolve the tie with the supplier S. We thus develop a theory of *vicarious performance feedback* (VPF), in which a focal firm's behavior is influenced by the performance trajectory of other firms to which it is indirectly tied.

We test this theory in the context of Formula 1 (F1) motor racing. In this industry, a set of firms—known as constructors—manufacture cars, hire drivers, and compete in F1 races (Grands Prix) (Jenkins, Pasternak, and West, 2005). A constructor can opt to develop and build an engine in-house or, more commonly, procure an engine from an external supplier. We examine the factors that lead constructors to dissolve their supplier relationship at the end of an F1 season. F1 exhibits several features which make it a particularly good fit with our research topic: joint component usage is prevalent (Aversa, Furnari, and Haefliger, 2015), firms' performance trajectories are readily visible to one another, and the annual design-build-race cycle of the F1 season allows us to relate one season's performance to the organizational changes made before the next season—an ideal scenario for testing performance feedback hypotheses. Scholars have previously used motorsports settings to shed light on the dynamics of interorganizational relationships (Castellucci and Ertug, 2010; Mariotti and Delbridge, 2012) and on organizational learning (Jenkins, 2014; Marino, et al., 2015; Hoisl, Gruber, and Conti, 2016), thereby validating the suitability of this setting for our research question. We propose—and find supporting evidence—that firms are more likely to dissolve a tie with a supplier if that supplier's other customers exhibit performance below their historic track records. We also investigate several moderating factors, address several alternate explanations, and supplement our quantitative analysis with interview research. Together, these additional analyses give us confidence that vicarious performance feedback is indeed the mechanism underlying our main finding.

This paper contributes to three areas of literature. First, we contribute to the literature on vicarious learning by establishing vicarious performance feedback as an important learning mechanism. The managerial inference process we theorize is more cognitively sophisticated than those examined in prior studies, which most often measure frequency-based and trait-based imitation (Terlaak and Gong, 2008; Greve, 2013) rather than outcome-based inferential learning. We find that managers react to vicarious performance feedback when the firm's own performance is below its aspiration level, highlighting the role of problemistic search in directing managerial attention to vicarious learning sources (Ocasio, 1997; Baum and Dahlin, 2007). Our research also shows that vicarious learning interacts with structural position, providing a novel test of the way structural equivalence in a network directs actors' attention to one another (Burt, 1987; Bothner, 2003).

Second, we contribute to the literature on interorganizational network dynamics. Market networks consist of distinct sets of buyers and suppliers, i.e., they are two-mode networks, meaning some mechanisms of tie stability that are well-established in the broader networks literature may be less relevant to market networks (Baker, Faulkner, and Fisher, 1998; Sorenson and Rogan, 2014). The theory of vicarious performance feedback describes a novel mechanism that applies to triadic (and larger) structures in market networks. It provides a nuanced account of how firm performance acts as an antecedent of network change (see also, Baum, et al., 2005; Shipilov, Li, and Greve, 2011; Zhelyazkov, 2018), which complements prior work that links network structure to performance outcomes (Gulati, Lavie, and Madhavan, 2011).

Third, we contribute to the literature on performance feedback. Building on recent work linking performance feedback with organizational structure and cognition (Gaba and Joseph, 2013; Joseph, Klingebiel, and Wilson, 2016), we conceptualize performance feedback as a more cognitively sophisticated process than has traditionally been depicted, in which a firm's and its competitors' performance trajectories are used as informational inputs to help managers deal with causal ambiguity (see also Posen, et al., 2018). Taken together, by developing theory at the intersection of behavioral theory and social networks, our study moves two of the most established strands of organization theory towards closer integration (Baum, et al., 2005; Gavetti, et al., 2012).

THEORY AND HYPOTHESES

Tie Dissolution in Market Networks

Prior work on the retention versus dissolution of interorganizational ties underscores the challenge managers face in evaluating their firm's current exchange partners. Even when a firm already collaborates with an exchange partner, managers may nevertheless face difficulty evaluating that exchange partner's contribution to their own firm's performance (Sorenson and Waguespack, 2006; Azoulay, Repenning, and Zuckerman, 2010). We lay the foundations of our theoretical development by summarizing the literature on tie dissolution and analyzing why causal ambiguity makes the evaluation of exchange partners difficult.

Tie dissolution has been linked to relational, structural, assortative, and proximity-based antecedents (Rivera, Soderstrom, and Uzzi, 2010). Table 1 provides an overview of the mechanisms studied in this literature. Relational antecedents of tie dissolution are particularly relevant to our research question as they concern how a manager's experience with an exchange partner affects their decision over whether to continue or terminate the partnership (Gulati, 1995a; Polidoro, Ahuja, and Mitchell, 2011). After a tie is formed, ongoing interactions reveal information about the partner and the quality of the match, leading the hazard of tie dissolution to initially rise—as dyads that discover a poor match dissolve—then fall, because the remaining dyads are better matched (Fichman and Levinthal, 1991). This nonlinear duration-dependent tie dissolution has been documented across numerous kinds of ties including marriage ties (Weiss and Willis, 1997; Kulu, 2014) and employment ties (Jovanovic, 1979; Mortensen, 1988) as well as interorganizational relationships (e.g., Levinthal and Fichman, 1988; Baker, Faulkner, and Fisher, 1998; Greve, et al., 2010). Social and emotional processes of interpersonal attachment also strengthen interorganizational ties over time (Seabright, Levinthal, and Fichman, 1992; Sorenson and Rogan, 2014), to the extent that the departure of top executives or exchange managers from an organization can lead to the dissolution of exchange ties (Broschak, 2004; Rogan, 2014; Bermiss and Greenbaum, 2016).

*** Insert Table 1 here ***

Surprisingly little work has explicitly studied firm performance as an antecedent of tie dissolution (exceptions include Baker et al., 1998). Instead, poor performance is *inferred from* the empirical observation of tie dissolution or, conversely, satisfactory performance is inferred from tie continuation (Park, S. H. and Ungson, 2001). The robust empirical finding that the number of partners' past interactions predicts their likelihood of collaborating in future (e.g., Gulati, 1995b) is consistent with the premise that satisfactory performance leads to the renewal of exchange relations. However, it "black boxes" the actual process of partner evaluation and it is largely agnostic to the degree of difficulty managers face when interpreting their experience of working with a given exchange partner (Ariño and De La Torre, 1998). Several studies suggest that evaluation of current exchange partners is challenging and that managers have difficulty inferring partner quality from their own performance outcomes. On the one hand, Sorenson and Waguespack (2006), in their study of the movie distribution industry, find evidence of a self-confirming positive bias in how distributors evaluate producers. On the other hand, in a study of the contract research sector, Azoulay and colleagues (2010) find a dynamic of negatively biased exchange partner evaluations leading to the phenomenon of embeddedness failure. How an exchange partner's inputs affect the focal firm's performance is subject to substantial causal ambiguity. Past research provides a rich conceptualization of causal ambiguity which constitutes one foundation of our theory of exchange partner evaluation.

Causal Ambiguity

When making calculative decisions under uncertainty, managers apply a logic of consequences (March, 1994). Managers rely on their cognitive models of cause-and-effect to try to anticipate the outcomes associated with each choice (Simon, 1996). They then select the choice they perceive as most likely fulfill whatever organizational goal(s) they are currently attending to (Cyert and March, 1963; Ocasio and Joseph, 2005). Managers' cause-and-effect models form through the accumulation of experience in similar circumstances (Huber, 1991; Gavetti, Levinthal, and Rivkin, 2005). Organization theorists have documented how ambiguity in the interpretation of past experience can lead to mis-specified causal models (Weick, 1995; March, 2010).

Causal ambiguity—defined as "basic ambiguity concerning the nature of the causal connections between actions and results" (Lippman and Rumelt, 1982: 418)—can arise from the tacitness, complexity, or specificity of the factors that contribute to firm performance (Reed and DeFillippi, 1990). In a seminal essay on causal ambiguity, Mosakowski (1997) provides a typology of levels of causal ambiguity based on the *ex ante* and *ex post* reducibility of uncertainty over causal relations and input quality. She notes that at the extreme of "fundamentally irreducible causal ambiguity," organizational learning is impossible: no amount of experience will generate useful causal knowledge (Mosakowski, 1997: 417). At the opposite extreme, if ambiguity is reducible *ex ante*, investment in information shifts the decision-making regime to one of risk (i.e., probabilities of outcomes are known) (Mosakowski, 1997).

In the theoretical development that follows, we focus on intermediate levels of causal ambiguity. Here, uncertainty regarding causal relations and input quality is reducible *ex post*. Managers can learn from experience, but they still face uncertainty over forward-looking decisions. This level of causal ambiguity arises when the environment is turbulent, which hinders the *ex ante* reduction of ambiguity, and when system-level complexity is moderate to high (Mosakowski, 1997). These qualities characterize the decision-making context of Formula 1—and many other industries—very well. [1]

Causal ambiguity has been studied at the intrafirm and the interfirm levels of analysis (King, 2007). Prior work at the intrafirm level shows that managers often face causal ambiguity over which factors contribute to their own firm's performance (King and Zeithaml, 2001; Denrell, Arvidsson, and Zander, 2004). Work at the interfirm level has highlighted the difficulty managers face in discerning the factors that underlie another firm's competitive advantage (Simonin, 1999; Argote and Ingram, 2000). We bring together the intra- and interfirm perspectives to argue that managers face causal ambiguity when assessing their exchange partners' contributions to their own firm's performance. In the next section, we proceed to consider how a firm's level of performance may influence how managers evaluate exchange partners, with consequences for tie dissolution in market networks.

Performance Feedback and Exchange Partner Evaluation

Performance feedback theory, grounded in the work of Cyert and March (1963), suggests that organizational change is triggered by performance below aspiration levels. Managers are suggested to satisfice: to maintain the status quo as long as organizational performance meets or exceeds their aspiration level (March and Simon, 1958). When performance falls below aspiration, managers engage in problemistic search. This leads to changes in organizational factors that might have caused the poor performance (Greve, 1998a) and managers become more open to taking risks, such as pursuing exploratory courses of action (Baum, et al., 2005; Kacperczyk, Beckman, and Moliterno, 2015). A growing body of empirical work supports performance feedback theory (Shinkle, 2012; Greve and Gaba, 2017; Posen, et al., 2018). By itself, this theory would lead us to expect a

[1] Environmental dynamism and system-level complexity are therefore scope conditions of to our theory. We revisit these and other scope conditions in the Discussion section below.

firm would change a key exchange partner after an episode of poor performance, purely as a matter of problemistic search for change.

This expectation is strengthened when we consider a firm's evaluation of an exchange partner, which is likely to shift negatively when the focal firm's performance is weaker. In a complex organization, performance depends on the interplay between many internal and external elements, making it difficult to decompose performance and attribute it to specific factors (Thompson, 1967; Sorenson and Waguespack, 2006). Because of the psychological tendency for individuals to make self-serving attributions (Staw, McKechnie, and Puffer, 1983)—which biases managers towards making external attributions for failure and internal attributions for success—the supplier of a key component is likely to face at least some of the blame when a firm underperforms. This leads us to a baseline expectation that the lower a firm's performance falls below its aspiration level, the more likely the firm is to terminate a supply relationship.[2]

Baseline hypothesis: The further a firm's performance falls below its historic and social aspiration levels, the more likely it is to end an exchange relationship with a key component supplier.

Vicarious Performance Feedback

When managers have difficulty interpreting their organization's experience, they may look to the other organizations in their immediate environment (Levitt and March, 1988). For example, when interpreting whether their organization's performance level should be considered satisfactory, they compare it to a social aspiration level through a process of social comparison with an appropriate reference group, such as their immediate competitors (Cyert

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[2] One of the 23 hypotheses in Baker and colleagues' (1998) study of tie dissolution suggests that an improvement in sales is negatively related to the hazard of dissolving a market tie. This provides an initial test of performance feedback behavior with a tie-dissolution dependent variable, despite not being presented in terms of this theory. Other authors relating performance feedback to network dynamics are Baum et al. (2005) and Greve et al. (2011), who show that performance below aspirations can stimulate a more distant search for *new* exchange partners.

and March, 1963; Mezias, Chen, and Murphy, 2002; Beckman and Lee, 2017). Additionally, managers are motivated to achieve a level of performance that affirms the organization's membership within its social reference group (Moliterno, et al., 2014). Although performance feedback theory has shown that managers pay attention to the performance of competing firms, it has not yet fully explored the range of inferences that managers might draw from observing that performance.

We argue that managers attend to competitors' performance in order to draw inferences about the value of commonly used resources. Competitor performance allows a focal firm to make inferences about the value of that competitor's choices, such as its strategy, practices, and exchange partners (Haveman, 1993; Haunschild and Miner, 1997). We suggest that when a focal firm engages with the same exchange partners as its competitors (as in joint component usage), it will compare the competitor's current performance to its historic track record in order to evaluate the shared exchange partner.

The first pillar of this argument is the network-theoretic notion of structural equivalence. Structural equivalence exists when two actors have the same structural relationship with respect to the other actors in a social network (Wasserman and Faust, 1994). Burt (1987) theorizes that this is an inherently competitive relationship which leads to mutual monitoring (see, e.g., Piezunka, et al., 2018). When two firms purchase a component from the same supplier, they are structurally equivalent with respect to that supplier, so we can expect the managers of these firms to pay heightened attention to one another. For example, Greve's study of the shipbuilding industry (2009) shows that structural equivalence in buyer-supplier networks influences managers' decisions to adopt a new technology. We argue here that structural equivalence focuses managers' attention on competitors' performance, which they then incorporate into evaluations of the shared exchange partner.

The second pillar of our theory is the organizational salience of competitors' historic performance. The relevance of a firm's own historic performance is a well-established element of performance feedback theory, forming the basis of the historic aspiration level. Competitors' *current* level of performance forms the basis of the social aspiration level. Competitors' *historic* track record, however, does not enter into conventional performance feedback models, nor has it received much attention in organization theory more broadly. We suggest that managers in fact pay attention not only to their own firm's historic track record, but also to that of its competitors. This is a result, in the first instance, of the managers' direct experience of competing in the market. It is supplemented by the market's social infrastructure, which often includes intermediaries—for example, stock analysts, consultants, and media pundits—who collect and analyze performance data, drawing attention to historical trends and making contemporary comparisons (Zuckerman, 1999; Espeland and Sauder, 2007).

The third pillar of our theory is the asymmetry between inferential learning from positive and negative performance. Prior work suggests that distinct processes underlie vicarious learning from others' failures versus others' successes (Dahlin, Chuang, and Roulet, 2018). Managers try to emulate success by adopting the practices of high performing firms (Haveman, 1993; Strang and Macy, 2001) and they try to avert failure by distancing themselves from a practice after observing negatively-valanced information relating to the practice (Greve, 2011; Gaba and Dokko, 2016). We suggest that in the context of tie dissolution, managers are particularly attuned to negative information. We expect that vicarious observation of negative deviations from past performance by structurally equivalent firms will weigh heavily on managers' decision to terminate an exchange tie. These negative performance deviations provide a salient informational input in the deliberate, cognitive process of supplier evaluation by managers (Ito, et al., 1998; Greve, 2013). Furthermore, observing other firms' negative performance deviations reveals to managers the precariousness of their own firm's position. As a result, they are likely to be motivated to take actions that might avert failure, even if those actions are risky (Bothner, Kang, and Stuart, 2007).

Together, these three pillars lead us to hypothesize a vicarious analogue to performance feedback, in which a focal firm's behavior responds to the track-record deviations of those firms that are also exchange partners of its own partners.[3]

Hypothesis 1 [VPF]: When a firm jointly uses a component, the further the other users' performance falls below their historic levels, the more likely the focal firm is to end an exchange relationship with the component's supplier.

Moderating Hypotheses

In this section we outline several factors that we expect to moderate managers' reactions to vicarious performance feedback. We assume throughout that managerial behavior is purposive, boundedly rational, and socially embedded. We expect factors that draw managers' attention towards the supplier or the firm's structurally-equivalent competitors will strengthen vicarious performance feedback. On the other hand, substitute opportunities for learning about the supplier should weaken vicarious performance feedback.

Interaction of Direct and Vicarious Performance Feedback

We expect managers to react more strongly to negative vicarious performance feedback when the firm's own performance is below its aspiration level. Cyert and March (1963) argue that a firm's failure to meet a goal on an important dimension will trigger a process of problemistic search. Problemistic search is described as follows:

[3] Vicarious feedback is introduced by Strang and Patterson (2014) in a study of US baseball teams hiring and firing managers. Hiring was found to be influenced by vicarious observation of the performance trajectory of teams with which the manager had previously been affiliated. We build on Strang and Patterson's theory by showing that direct and vicarious feedback operate simultaneously, by testing moderating factors, and by linking vicarious performance feedback with network structure.

> "Search is based initially on two simple rules: (1) search in the neighborhood of the problem symptom and (2) search in the neighborhood of the current alternative…When search, using the simple causal rules, is not immediately successful…the organization uses increasingly complex ("distant") search" (1963: 121–122)

We draw on this theory in three ways. First, the theory suggests that problemistic search focuses managers' attention on possible causes of the firm's disappointing performance (Cyert and March, 1963; Posen, et al., 2018). Managerial attention is a scarce resource and its allocation has a major impact on decision-making (Ocasio, 1997; Sullivan, 2010; Joseph and Ocasio, 2012; Piezunka and Dahlander, 2015). As performance decreases relative to aspirations, managers are likely to allocate more attention toward analyzing their suppliers' contribution to firm performance. The allocation of attention leads managers to engage in more cognitively sophisticated processes of supplier evaluation, such as drawing inferences by analyzing the performance of the supplier's other customers.

Second, in situations with high causal ambiguity, problemistic search triggered by disappointing performance is likely to progress from simple rules to a more complex and distant type of search (Cyert and March, 1963). This point builds on prior work in several ways. Studies of organizational search for network partners find that performance below aspirations leads managers to increase the network range of their search (Baum, et al., 2005; Shipilov, Li, and Greve, 2011). In the context of tie dissolution, an increase in network range suggests that managers pay more attention to the partner's other partners when their firm's own performance is below aspirations. Additionally, studies of organizational learning suggest managers engage in more vicarious learning—a more distant source of knowledge than the firm's own experience—when the firm's own performance is below their aspiration level (Baum and Dahlin, 2007).

Third, a recent stream of work examines circumstances in which managers pay more or less attention to their competitors. Performance feedback theory incorporates an element of social comparison (Festinger, 1954): managers pay attention to a social aspiration level, which is based on the performance of competing organizations (Greve, 2003a). Blettner and colleagues find that firms whose own performance is very low pay more attention to their competitors' performance (Blettner, et al., 2015). In the context of vicarious performance feedback, this suggests that low performance may lead managers to draw more inferences from competitors' performances.

These cognitive mechanisms are coupled with the behavioral tendency to be more willing to make changes when firm performance is below aspirations compared with when it is above aspirations (Greve, 1998a). Performance below aspirations, we argue, both shifts managerial attention and shifts managers' tendency to act on the evaluations that result from this heightened attention. These proposed processes lead us to predict that firms exhibit a stronger response to vicarious performance feedback when their direct performance feedback is negative (i.e., below aspiration):

Hypothesis 2: The effect of vicarious performance feedback on the focal firm's decision to terminate its supplier relationship is stronger when its own performance is below its aspiration level.

Number of Joint Component Users as a Moderator of Vicarious Performance Feedback

We expect that managers are more likely to react to negative vicarious performance feedback when there are more other firms using the same component (i.e., joint component users) for them to draw inferences from. We have argued that vicarious performance feedback varies in strength depending on how much attention managers pay to structurally-equivalent competitors. Simply put, we expect managers to pay more attention to the performance trajectories of those competitors if there are more of them.

Prior work on vicarious learning finds that managers respond not only to the direction of vicariously-observed signals, but also to the number of firms from whom those signals arise (Rhee, Kim, and Han, 2006). Negative performance deviations by multiple joint component users provide a consistent signal about the possible cause of the poor performance (Gaba and Terlaak, 2013). The presence of multiple signals from multiple joint component users helps to reduce the causal ambiguity managers face in evaluating the supplier.

In our empirical analysis we study the main effect of vicarious performance feedback (H1) by taking the average of the joint component users' deviations from their historic record. Here, we suggest that for a given *average* level of vicarious performance feedback, managers will respond more strongly if that average is derived from a larger number of joint component users (Rhee, Kim, and Han, 2006). To the extent that the managers intuitively treat the mean performance of the reference group as a summary statistic, deriving this mean from a larger number of joint component users reduces the variance of the statistic and, thus, the risk associated with acting on this information.[4]

Hypothesis 3: The effect of vicarious performance feedback on the focal firm's decision to terminate its supplier relationship is stronger the more other firms use the same component.

Geographic Distance as a Moderator of Vicarious Performance Feedback

We expect that a firm which is geographically close to a supplier has alternate channels for evaluating the supplier, reducing the extent to which managers respond to vicarious performance feedback. It has long been recognized that knowledge flows more easily over shorter geographic distances (Audretsch and Feldman, 1996; Sorenson and Audia, 2000). Geographic proximity raises the likelihood of knowledge flowing through informal

[4] We thank an anonymous reviewer for this suggestion.

inter-personal ties and employee mobility (Henry and Pinch, 2000; Sorenson and Stuart, 2001). It also makes it easier for managers of buyers to visit the sites of suppliers and learn from face-to-face meetings with the suppliers' managers (Dyer, 1996). Knowledge acquired through proximity can influence strategic decisions, such as firms' adoptions of uncertain production technologies (Greve, 2008; Greve and Seidel, 2015). Amongst the different forms of knowledge, Tallman and colleagues (2004) suggest that component-related knowledge is particularly likely to spread within geographically localized industrial clusters, such as those in the motorsports industry (Jenkins and Tallman, 2010).

We reason that information gained from proximity to a supplier is likely to substitute for—rather than reinforce—the inferences managers draw from vicarious performance feedback. Information from vicarious performance feedback is inherently backward-looking. It helps managers interpret the ambiguity of past experience. Information gained from proximity to a supplier, on the other hand, has both a backward-looking and a forward-looking component to it. For example, the component buyer may learn through informal channels about the supplier's future plans; managers from the buyer may visit the supplier's premises and become aware of investments the supplier is making in next-generation technologies.

The role of geographic proximity in the sharing of forward-looking information is underscored by the finance literature on investment managers' proximity to portfolio firms (Coval and Moskowitz, 1999). Investment managers' decisions about what stocks to hold in their portfolio are intrinsically forward-looking. The finance literature shows that investment managers obtain superior investment returns when they invest in geographically proximate firms (Coval and Moskowitz, 2001), which is consistent with the proximity providing superior access to forward-looking information (Malloy, 2005). Since managers who are geographically proximate to suppliers may obtain forward-looking information on the suppliers' next product generation, this information could outweigh the backward-looking inferences they make from vicarious performance feedback.

In addition, to the extent that geographic proximity leads to inter-personal ties between managers of the focal firm and supplier firm, geographic proximity may imply a degree of social and emotional attachment, mutual obligation, or cultural solidarity between managers of the two firms (Powell, 1990; Laursen, Masciarelli, and Prencipe, 2012). Such embeddedness could make the focal firm's managers less likely to attribute negative performance deviations of joint component users to the supplier firm, lowering their sensitivity to vicarious performance feedback:

Hypothesis 4: The less the geographic distance between a focal firm and its supplier, the weaker the effect of vicarious performance feedback on the focal firm's decision to terminate its supplier relationship.

METHODS

Research Context and Sample

We test our hypotheses in the empirical setting of Formula 1 (F1) motor racing. Formula 1 is an annual racing series in which firms, known as *constructors*, build cars and hire drivers to race them in Grands Prix around the world. An F1 car is a complex system of interdependent components, including chassis, engine, gearbox, brakes, and electronic control unit (Marino, et al., 2015). In line with the rules set by the industry's governing body, the *Fédération Internationale de l'Automobile* (FIA), constructors must build the car chassis in-house but may procure other components from external suppliers. A constructor's relationship with its engine supplier is strategically significant because the engine is a material determinant of car performance (Castellucci and Ertug, 2010). While certain engine attributes, such as horsepower, are objectively measurable, the engine is interdependent with the other car components, so it is challenging to assess its impact on a constructor's Grand Prix performance. The supply structure for engines displays considerable variation amongst constructors and over time, with joint component usage a frequent arrangement. New engine models are developed each year to incorporate technical advances and to conform with F1's evolving rules. A constructor gains experience of the new engine primarily by using it in Grands Prix; this limits how much experience it can accumulate directly and raises the question of whether it can learn from other constructors' use of the same engine (Aversa, Furnari, and Haefliger, 2015)

F1's position at the frontier of automotive technology, a highly dynamic field, renders it very appropriate for studying organizational change (Marino, et al., 2015). Furthermore, the industry's temporal pacing makes it ideal for untangling questions of performance feedback. The F1 season in a given year starts in March and ends in October, November, or December. Constructors undertake an annual cycle of designing, building, and testing a car in the months leading up to the first Grand Prix of the season (Jenkins, Pasternak, and West, 2005). The performance of a constructor's car in a given year has therefore been observed by the time the constructor has to choose a supply arrangement for the following season.

Although the first F1 championship was held in 1950, in our dataset we focus on the period since 1981, when the sport was professionalized through the Concorde agreement between F1 constructors, the FIA, and the F1 administration. This agreement instituted a broad framework for the racing series, according to which constructors must build their own chasses but may acquire other components from external suppliers. While the detailed rules of F1 change annually, this broad framework has not changed since the signing of the agreement. We therefore choose as our sample period a 33-year window from 1981 to 2013.[5] The database we use is from Motorsportarchiv,[6] which, in turn, is assembled from data

[5] Where historic data is needed to construct independent variables, we use earlier data. We observe constructors' engine suppliers in 2014 in order to define the dependent variable for the 2013 season.
[6] Retrieved from http://www.motorsportarchiv.de on March 18, 2015

supplied by the FIA. These data were supplemented with records of organizations' addresses from the industry publication, *Who Works in Formula 1* (Grégoire, 2013). Article counts drawn from searches of the Factiva database were used to construct the status variable (see below). On average, 13 constructors compete each year, for a total of 432 constructor–years in our sample window.

To better understand the empirical setting and to enrich our evidence base, we carried out a program of qualitative interviews with Formula 1 professionals. We conducted 55 interviews with 46 different individuals between July 2016 and December 2018. These interviews were conducted in English, French, and German by one of the authors. We recorded 42 of these 55 interviews. We did not record the remaining 13 because the interviews were conducted on site, where recording devices were not allowed, or because the interviewees explicitly asked not to be recorded. For these interviews we took detailed notes. The average length of an interview was 42 minutes. Beyond these interviews we also had various informal conversations with employees during site visits.

Most of our interviewees were employed at F1 constructors or at F1 engine suppliers. We also interviewed journalists and industry experts. See Appendix A1 for a detailed overview of our interviewees. Given the global distribution of F1, most of our interviewees were based in the UK, France, Italy, Austria, and Japan. Overall, the 46 individuals we interviewed had more than 450 years of experience in Formula 1. We enjoyed the trust of our interviewees as most interviews resulted from a referral by a previous interviewee. Our relationships with the interviewees also benefitted from our increased understanding of the industry and people saw us as someone with whom they could "talk shop."

Our interviewees confirmed that assessing an engine—and, respectively, an engine supplier—constitutes an important and difficult challenge in Formula 1. One engineer pointed out that it would be easy to see that a car had a problem, but "finding the cause is, as you may imagine, definitely more difficult.” The technical head of an F1 constructor pointed out the need and challenge to “decompose performance into its constituents”. Our interviewees also outlined the specific challenges of decomposing performance: “it’s difficult to do because it’s hard to discriminate between an engine power and drag, aerodynamic drag.”

Figure 1 depicts the two distinct supply arrangements in which multiple F1 constructors are supplied with the same engine. In the first configuration, the supplier is a third-party engine manufacturer that sells engines to multiple customers, labeled X_1 and X_2. In the second configuration, there is a vertically integrated constructor, labeled Y, which produces engines for its own use and also sells engines to customer constructors labeled Z_1 and Z_2. We define a constructor’s set of joint component users on the basis of structural equivalence: firm X_1’s joint component users are X_2, X_3, etc., and firm Z_1’s joint component users are Z_2, Z_3, etc., but not firm Y.

Insert Figure 1 about here

Measures

Dependent variable. We measure the dependent variable of whether the tie is dissolved at the constructor-supplier-year level of analysis. We code for termination of a supplier relationship with a dummy variable set to 1 if a constructor uses a different engine supplier in the following season than in the current season. Thus, our dependent variable measures dissolution between year *t* and year *t+1*. We learned in our interviews that the decision to terminate the collaboration is generally made by the constructor. One interviewee with many years of experience across multiple constructors pointed out “99% of the time I put my money on it that it was the team.” Also, a senior manager who was directly involved in such a decision pointed out that “normally it is the team.” Our interviewees also pointed out multiple reasons why suppliers would generally not terminate the relationship with a constructor. We document these in Appendix A2.

Independent variables. The independent variables in our main analyses are defined at the end of the season in year *t*. To create our variables for performance-aspiration gaps, we first specify a performance measure. We use the constructor's total number of points scored in the World Championship in the focal year (i.e., the sum of points awarded in each Grand Prix) divided by the total points awarded to all teams, in order to normalize for differences in the scoring scheme between years (Castellucci and Ertug, 2010).

Focal performance-aspiration gap (Baseline). We create measures of aspiration level for the focal firm (*i*) using a weighted average of social and historical aspiration level (Greve, 2003a). The social aspiration level is calculated as the mean performance level, which is, by construction, the reciprocal of the number of constructors in the World Championship in the focal year. The historic aspiration level (L_t) is calculated using an exponential updating function of the focal constructor's past performance (P_{t-1}) (Greve, 2003a):

$$L_{it} = \alpha_1 L_{it-1} + (1 - \alpha_1) P_{it-1}$$

The updating parameter α_1 specifies the weight placed on past aspirations versus the weight placed on recent performance, so that lower values of α_1 correspond to faster updating. In line with the literature, we set the updating parameter based on the best model fit ($\alpha_1 = 0.5$) and test for robustness to a range of values on either side (Greve, 2003a).[7] Similarly, when specifying the relative weights of historic and social aspirations, we base the parameter on the best model fit and test for robustness.[8] The focal constructor's performance-aspiration gap in the focal year is calculated by subtracting its weighted average aspiration

[7] Our results are robust to setting α_1 between 0.3 and 0.7.
[8] We define the mixed aspiration level with 0.9 weight on the historic aspiration and 0.1 weight on the social aspiration. Our results are robust to setting a weight on the social aspiration between 0 and 0.3. When new constructors enter the panel, we have insufficient data to calculate historic aspiration levels; thus, in the first year in which a constructor appears we use the social aspiration level.

level from its performance and using a spline specification to separate performance below aspirations from performance exceeding aspirations. The negative part of the spline is reverse-coded to ease interpretation of the coefficients: that is, so that our baseline hypothesis corresponds to a positive coefficient.

Vicarious performance-aspiration gap (H1). With this variable, we aim to capture the deviation of the focal constructor's joint component users (denoted $j = 1, \ldots, N$) from their historic levels of performance, as perceived by the focal constructor. We therefore calculate a distinct "vicarious" aspiration level (V_{jt}). We do not see any *a priori* reason that managers' own historic aspirations and vicarious expectation over competitors' performance should update at the same rate. For this reason, we allowed those two parameters to vary independently. We calculate the historic aspiration level as outlined above, with an updating based on best model fit ($\alpha_2 = 0.6$).[9] This aspiration level is subtracted from the joint component user's performance to create a vicarious performance-aspiration gap. When there is more than one joint component user (other than the focal firm), these are aggregated by taking the mean value:

$$VPF_{it} = \frac{\sum_{j=1}^{N}\left(P_{jt} - V_{jt}\right)}{N}$$

This vicarious performance-aspiration gap is subjected to a spline transformation about zero, and the negative component of the spline is reverse-coded to ease interpretation. For constructors with no joint component users, this variable is coded as zero.

Moderating Variables

*Direct * Vicarious interaction.* We test the interaction between direct and vicarious performance feedback by interacting the continuous measures of vicarious performance feedback with dummy variables indicating whether the firm's own performance is above or

[9] Our results are robust to setting α_2 between 0.5 and 0.8. See Appendix B for details of parameter selection for the performance feedback and vicarious performance feedback variables.

below its aspiration level. This allows us to directly compare the strength of vicarious performance feedback in the domains where direct performance feedback is satisfactory (i.e., above aspiration) or unsatisfactory (i.e., below aspirations, predicted to trigger problemistic search).[10]

Number of joint component users. This variable is a count of the number of structurally equivalent constructors who use engines from the same supplier as the focal firm. As depicted in Figure 1, for firm X_1 this variable is a count of firms of type X with the same supplier, and for firm Z_1 it is a count of firms of type Z with the same supplier.

Geographic proximity. We calculate the geographic distance between the focal firm and its engine supplier, in units of 1000 km, based on the latitude and longitude associated with the organizations' addresses recorded in *Who Works in Formula 1*. We take log of this variable to reduce skewness. To test hypothesis 3, we standardize this variable in our interaction terms, which eases the interpretation of coefficients.

Control variables. We control for numerous factors that have been linked to interorganizational tie dissolution in prior research. We control for supplier relationship length and its squared term to capture the nonlinear duration-dependence in the fragility of interorganizational ties (Levinthal and Fichman, 1988). We code relationship length in years, capping the variable at five years so that a small number of very long relationships do not distort the coefficient estimates.[11] We use three dummy variables to control for the main effect of a constructor's engine supply configuration: the first is set to one for constructors that produce their engine in-house, the second is set to one for constructors that procure an engine from one of those vertically integrated teams, and the third is set to one for constructors with an exclusive relationship with a third-party supplier.

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[10] We check the robustness of our findings to other interaction specifications, i.e., interacting two continuous variables or interacting two dummy variables, and we find consistent results (see Appendix Table C2).
[11] Without this cap, the results show the same pattern of statistical significance, but the model fit is substantially worse, with adjusted R^2 of 17.4% instead of 20.1% in the full model.

Prior work finds that interorganizational ties with a larger status inequality between members are less stable (Rowley, et al., 2005). We therefore control for the status difference between a firm and its supplier. We measure a constructor's status as described and validated by Castellucci and Ertug (2010): we use the count of its press mentions in the previous year, based on searches of the Factiva database, which is then residualized on its performance. Supplier status is defined to be the mean status of the constructors it supplies (Castellucci and Ertug, 2010). We control for a firm's tendency to switch exchange partners often by including a measure of supplier churn: the number of terminated relationships in the preceding five years (Baker, Faulkner, and Fisher, 1998). Because prior work finds that tie breakage is more likely if a firm has more "outside options," we control for the number of engine makers active in the focal year (Greve, Mitsuhashi, and Baum, 2013).[12]

Prior work finds that personnel mobility, such as the departures of key decision-makers and exchange managers, often precedes interorganizational tie dissolution (Broschak, 2004; Rogan, 2014; Bermiss and Greenbaum, 2016). We have collected personnel data for a subset of our panel, for the years between 1994 and 2013, from the annual publication *Who Works in Formula 1* (Grégoire, 2013). [13] This publication lists names and job titles of senior managers and selected technical employees for both constructors and engine suppliers. We assembled a list of job titles and qualitatively coded which job titles refer to decision-makers who influence whether to dissolve a supplier tie. We then identify, for each constructor-year, the set of managers at the constructor who are likely to be the key decision-makers. To control for personnel mobility, we define a variable, *constructor decision-maker exits*, as a

[12] Our results are robust to specifications that weight these "outside options" according to the supplier's performance. This gives us confidence that our results are not an artifact of constructors dissolving ties in order to form a new tie with a better-performing engine supplier.
[13] Because we have incomplete data on exchange manager mobility, we create a dummy variable that is coded one when data is missing.

count of decision-making managers who departed the constructor between the prior year and focal year of analysis.[14]

Model Specification

We follow the literature on dissolution of interorganizational ties (e.g., Rowley, et al., 2005) by specifying a discrete-time hazard model. Constructors make decisions about their engine supplier as part of an annual cycle of designing a car for the following F1 season. Our unit of analysis is therefore the constructor-supplier-year. In order to control for time-invariant tendencies for constructors to change suppliers, we use constructor-level fixed effects. Consequently, we use the linear probability model (LPM), rather than the logit or probit models, in order to circumvent the incidental parameters bias that can afflict nonlinear models with fixed effects. Standard errors are clustered by constructor and by supplier to address the non-independence of error terms introduced by repeated observations of the same actors (Cameron, Gelbach, and Miller, 2011).

Descriptive statistics are reported in Table 2. The mean value of the dependent variable is 0.25, indicating that, on average, a constructor changes its engine supplier about every four years.

*** Insert Table 2 here ***

RESULTS

We first provide a visualization of our data that provides preliminary, nonparametric evidence in support of the baseline hypothesis and hypotheses 1 and 2. We then present the results of our quantitative analysis followed by several robustness tests. Following this, we report qualitative findings that enhance our understanding of the phenomenon.

[14] Our findings are robust to specifications that control for contemporaneous decision-maker mobility, and to the inclusion of an analogous mobility variable relating to managers at the engine supplier.

Data Visualization

Figure 2 displays a scatter plot of all the observations in our data where a constructor has at least one joint component user. The horizontal axis depicts the constructor's own performance versus aspirations, and the vertical axis depicts the vicarious performance feedback that the constructor might observe. Points in the scatter plot are color-coded: black represents a constructor–supplier tie that was dissolved, while grey represents a constructor–supplier tie that was retained. It becomes visually apparent from this plot that black points appear disproportionately to the left of the vertical axis, where own performance is below aspirations (31% dissolve, compared to 12% above aspiration). This provides some non-parametric evidence in support of the baseline hypothesis. Dissolutions also appear disproportionately below the horizontal axis, where vicarious performance feedback is negative (28% dissolve compared to 23% above the axis). This provides some non-parametric support for hypothesis 1. Further, we note that dissolutions appear disproportionately in the lower-left quadrant, where the firm's own performance and vicarious performance are both below aspirations (34% dissolve), providing some non-parametric evidence in support of hypothesis 2.

Insert Figure 2 here

Main Regression Analyses

Table 3 reports the results of the linear regression models. Model 1 contains control variables and the direct performance feedback variables testing the baseline hypothesis. Model 2 tests hypothesis 1; models 3 through 5 test hypotheses 2 through 4 separately. Model 6 tests all hypotheses together, using two-way interaction terms. Model 7 tests whether direct performance feedback (H2) interacts with the other two moderating variables.

*** Insert Table 3 here ***

Coefficients on the control variables are fairly consistent in magnitude across the seven models. Five of the control variables have statistically significant coefficients. The linear and quadratic variables for *supplier relationship length* are significantly positive and negative, respectively, generating an inverted-U-shaped duration dependence with an inflection point at approximately 3.7 years. This finding is consistent with prior work suggesting that interorganizational ties exhibit a “honeymoon period” followed by a “liability of adolescence” (Levinthal and Fichman, 1988; Fichman and Levinthal, 1991; Baker, Faulkner, and Fisher, 1998). A constructor supplied by a competing team is less likely to dissolve that tie than constructors with other supply arrangements. A constructor’s recent level of *supplier churn* is negatively related to the risk of subsequent supplier tie dissolution. This coefficient might reflect strategic deceleration of supplier tie dissolution (Beck, Brüderl, and Woywode, 2008), or it may be picking up “regression to the mean” in the panel data. The number of other constructors using an engine is negative related to tie dissolution in the baseline model, though this coefficient is non-significant in the other models.

The coefficient on the variable for direct performance feedback when performance is below aspiration is in line with our baseline hypothesis: the further a constructor’s performance drops below its aspirations, the more likely it is to dissolve its supplier tie. The effect is economically significant, with a one-standard-deviation drop in performance below the aspiration level associated with a 7.1-percentage-point increase in the likelihood of a supplier tie dissolving.

Model 2 tests hypothesis 1 using the coefficient on the variable *vicarious performance feedback below historic level*. The positive and significant coefficient on this variable supports hypothesis 1. The farther that firms using the same engine component as the focal firm drop below their historic performance levels, the more likely the focal firm is to dissolve its supplier tie. A one-standard-deviation drop below historic levels is associated with a 1.9-percentage-point increase in the likelihood of tie dissolution, an economically-significant effect size roughly one quarter the magnitude of direct performance feedback.

Hypothesis 2 predicts that vicarious performance feedback is stronger when a firm's own performance is below its aspiration than when it is above its aspiration. Model 3 tests hypothesis 2 by interacting the vicarious performance feedback term with a pair of dummy variables: one captures own performance below aspiration (*Direct* (-)), and the other captures own performance above aspiration (*Direct* (+)). The interaction term with own performance below aspiration is significant and positive, while the interaction term with own performance above aspiration is non-significant. A Wald test finds that the difference between the two coefficients is significant ($p < 0.01$), providing support for hypothesis 2. Moreover, the non-significant coefficient on the interaction term with own performance above aspiration places a boundary condition on vicarious performance feedback. It suggests that managers respond to vicarious performance feedback only when their own experience is below aspirations. Figure 3 displays the effect size associated with vicarious performance feedback. It plots predicted probabilities of tie dissolution for constructors whose own performance is above or below aspirations for a range of values of vicarious performance feedback. The main finding in support of hypothesis 2 is represented by the solid line rising as vicarious performance declines below zero.

Insert Figure 3 here

Hypothesis 3 predicts that vicarious performance feedback is stronger when more other constructors are using the same engine as the focal constructor. Model 4 tests hypothesis 3 using an interaction term between vicarious performance feedback and (standardized) number of engine users. The positive and significant coefficient on this interaction term supports hypothesis 3. This coefficient size indicates that when the number of engine users is one standard deviation above the mean level (i.e., six firms use the engine), the constructor is roughly 2.8 times as sensitive to vicarious performance feedback as when the number of engine users is at the mean level of three.

Hypothesis 4 predicts that vicarious performance feedback is weaker for constructors that are geographically proximate to their supplier. Model 5 tests hypothesis 4 using an interaction term between vicarious performance feedback and (standardized) geographic distance. The positive and significant coefficient on this interaction term supports hypothesis 4. It suggests that if a constructor is one standard deviation above the mean distance from its supplier, the constructor is roughly 1.8 times as sensitive to vicarious performance feedback, compared to a constructor at the mean distance.

Models 6 and 7 test the three moderating hypotheses simultaneously. Model 6 uses two-way interaction terms; it tests number of engine users and geographic proximity as moderators of the main effect of vicarious performance feedback. Model 7 provides an interacted model which tests the moderating effect of number of engine users and geographic proximity in the context of the finding that vicarious performance feedback is contingent on direct performance feedback being negative. This is our preferred model, as it is both flexible—in the sense of imposing few constraints on how variables interact—and comprehensive—in the sense that it includes all three moderators of vicarious performance feedback. Model 7 provides support for hypotheses 2, 3, and 4, and supports the contingent nature of vicarious performance feedback. Model 7 has the highest explanatory power of our models, with an adjusted R^2 of 20.1%, compared to a value of 12.5% in the baseline model.

Figure 4 displays the moderating effects measured in model 7. Figure 4a depicts the interaction between vicarious performance feedback and the number of engine users; figure 4b depicts the interaction between vicarious performance feedback and the geographic distance between constructor and supplier.

Insert Figure 4 here

Robustness to Alternate Explanations

The results presented thus far are consistent with our proposed mechanism that managers make inferences about supplier quality based on the performance of the supplier's other customers. The moderating factors we point to help support the argument that this is the underlying mechanism. To support our reasoning even further, we would ideally like to rule out—or control for—a number of possible alternate explanations.

Imitation

First, we consider imitation, a well-known factor that can lead organizations to exhibit correlated behaviors. Interorganizational imitation has been studied in both institutional theory, under the label of mimetic isomorphism (DiMaggio and Powell, 1983), and in competitive strategy as a strategic move that laggard firms can employ to catch up to leaders (Lieberman and Asaba, 2006). If the dissolution of supplier ties is subject to imitation, then we might erroneously attribute to vicarious performance feedback what is, in fact, the result of a combination of direct performance feedback and imitation. For example, assume firms A and B share a supplier S and that A's performance drops below its historic level. Direct performance feedback would make B more likely to dissolve its tie to S. If firm A imitates the tie dissolution, we would observe a pattern of data that resembles vicarious performance feedback but is not driven by our proposed mechanism.

To help rule out imitation as a possible explanation for our results, we exploit a feature of our empirical setting: engine supply decisions are negotiated separately by constructors during the preceding F1 season. This negotiation process takes place confidentially, with the outcomes gradually becoming public knowledge toward the end of the season. Imitation is therefore unlikely to be a major factor midway through a season, although it could plausibly happen at the end. We therefore re-run our regression models using the constructor's performance at the end of the eighth race in the season, roughly halfway through, to construct the performance feedback variables. Model 1 in table 4 displays the results of this model, still finding significant support for vicarious performance feedback.

Insert Table 4 here

A further approach to ruling out imitation as an alternate explanation is by directly controlling for other firms' behavior. We create a variable counting the number of firms with the same supplier which dissolve that tie after a given year.[15] This is a particularly stringent specification as it controls for any correlation in behavior between customers of the same supplier, whether the correlation is ultimately caused by imitation or by vicarious performance feedback. Results with this additional control variable are reported in model 2 in table 4. Hypotheses 2 and 4 are supported at the 5% significance level. The coefficient testing hypothesis 3 is non-significant, likely because the *No. of engine users* moderator is correlated with *Count of other component users that terminate supplier relationship*. The coefficient on the new variable is not statistically significant. Vicarious performance feedback thus has stronger explanatory power than imitation in accounting for constructors' tie dissolution decisions.

Underlying Engine Quality

A second possible alternate explanation is what we might call a "mere quality" effect. We have argued that managers' quality inferences are based on their observations of competitors' performance, which they then compare to the same firms' historic track records. One premise of our theory is that an engine component's quality is hard to assess directly because it functions within a complex product system. However, if managers were able to assess quality more directly, we would still expect dissolution of supplier ties to be correlated with poor performance. Ideally, we would therefore like to control for the absolute level of underlying component quality when testing our hypotheses. Engine quality is multi-

[15] Results are robust to controlling for the proportion of joint component users who dissolve a supplier tie instead of the count of such users.

dimensional with some unobservable aspects to it. In the absence of a single, unified measure of engine quality, our “next best” approach is to develop multiple proxies for engine quality from observable data.

We develop proxies for engine quality based on championship performances, engine reliability, and vehicle speeds. To operationalize the (absolute) championship performance of an engine supplier, we take the World Championship points share of the best-performing team that the engine maker supplies (similar results are found if we take the average). To operationalize engine reliability, we analyze records published by the *Fédération Internationale de l’Automobile* (FIA), which specify the reasons why a driver fails to finish a Grand Prix. From these records we code the instances when drivers’ withdrawal from a race was due to engine failure. We count the engine failures attributed to each supplier in a given year; we then divide this by the total number of engine failures that year to account for the broad trend of increasing reliability over time. To operationalize vehicle speed, we use records of lap times from the practice and qualifying sessions that take place on the first and second days of each Grand Prix weekend. We calculate the average speed of each driver’s fastest qualifying lap. From amongst these, we find, for each year, the best average speed achieved by any driver using a given engine.

Model 3 in table 4 enters the championship performance variable alongside the control variables; model 4 adds the direct performance feedback variable; and in model 5, we add the vicarious performance feedback variables. In the absence of our performance feedback variables, there is a significant negative correlation between absolute performance and tie dissolution, as expected. Once the performance feedback variables are added, the coefficient on absolute quality drops below significance and adjusted R^2 increases, indicating that the performance feedback variables better capture managerial tendencies to dissolve the supplier tie than the “mere quality” measure. A similar pattern of results is obtained for the other two proxies of engine quality (reported in Appendix C1). Model 6 enters all three proxies of engine quality alongside our theoretical variables. Hypotheses 2, 3, and 4 remain supported even with this multi-dimensional approach to controlling for absolute engine quality.

Locus of Decision-Making

A third possible alternate explanation for our pattern of results draws on the possibility that the engine supplier makes decisions to dissolve a constructor–supplier tie. If suppliers act as key decision-makers behind tie dissolution, then poor performance by a supplier in a given year might trigger the supplier's managers to make changes to the portfolio of customers it sells to. This could lead to a pattern in the data that resembles vicarious performance feedback but which is generated by a different mechanism.

Our qualitative evidence—described above and in Appendix A2—strongly indicates that suppliers are *not* the decision-makers behind tie dissolution in Formula 1, and that the locus of decision-making rests with the top managers of F1 constructors. To further validate our approach, model 7 in table 4 provides a direct, quantitative test of whether engine supplier-level performance feedback influences tie dissolution. Engine maker performance is operationalized as the World Championship points share of the best performing constructor the engine maker supplies.[16] We generate engine supplier aspiration levels following the same procedure described above for constructors. We subtract suppliers' aspiration level from their performance to calculate a performance-aspiration gap; we then use a spline specification and reverse-code the negative part of the spline. These two variables, for engine maker performance below and above aspirations, are entered in model 7. Coefficients on these variables are non-significant, and our theoretical variables in support of hypotheses 2,

[16] We find the same pattern of results if we define engine supplier performance as the average performance of the constructors it supplies (results available from the authors on request).

3, and 4 remain significant, providing some quantitative assurance that engine makers are not important decision-makers in the dissolution of constructor–supplier ties.[17]

Alternate Dependent Variable

As a further test of our proposed mechanism, we examine an alternate dependent variable: whether or not the constructor changes its driver roster in the subsequent F1 season. We earlier reasoned that managers have difficulty attributing performance among underlying organizational resources. We argued that vicarious observation of declines in performance at other constructors using the same engine supplier allows managers to attribute their own performance to that supplier. A corollary of this is that the constructor's drivers are less likely to be blamed for any perceived underperformance of the overall organization. We would therefore expect that negative vicarious performance feedback would be associated with a *lower* likelihood that the driver roster will change after a given F1 season. We run a linear regression model with *change in driver lineup* as the dependent variable and use our direct and vicarious performance feedback measures as independent variables. Results of this analysis are reported in model 8 in table 4. Consistent with standard behavioral theory, constructors are more likely to change their driver lineup the farther their own performance falls below aspirations. Also, consistent with our theory, constructors are less likely to change their driver lineup after negative vicarious performance feedback at the engine level.

Other Robustness Tests

We have tested the robustness of our findings to alternate variable specifications. Appendices C2 and C3 report these analyses. First, while our main analysis aggregates the vicarious performance feedback of multiple joint component users by taking the mean value, our findings are robust to taking the median. Also, similar results are obtained using simple

[17] In the appendix we report analyses of the performance trajectories for engine suppliers after ties with constructors dissolve. We find that these trajectories tend to be negative, implying that suppliers do not regularly break ties with weak constructors in order to form ties with better-performing constructors.

count variables of the number of joint component users whose performance is above or below their historic performance. Second, the interaction between direct and vicarious performance feedback, tested in hypothesis 2, is robust to alternate specifications, including interacting two continuous variables or interacting two dummy variables. Third, the main effect of a firm's own performance feedback (the baseline hypothesis) is robust to alternate specifications, such as taking the median instead of mean performance to define the social aspiration level. We find strong support for the baseline hypothesis when a firm's own performance feedback is operationalized using a historically-based social aspiration threshold (HiBSAT) as described in work by Moliterno and colleagues (Moliterno, et al., 2014 see appendix for details). Additionally, we find support for our hypotheses when controlling for other engine makers' performance to capture the attractiveness of a firm's outside options.

Qualitative Evidence

The qualitative data we collected corroborates and enriches our quantitative analyses. Across our interviews it became evident that, in line with our baseline hypothesis, a constructor's decision to dissolve the collaboration with its engine supplier depends on performance feedback. For example, the chief operating officer of an F1 constructor pointed out: "The reason why we moved away from [name of prior engine supplier] to [name of new engine supplier] was very simple: performance. I mean, [name of prior engine supplier]'s engine was so bad that you were simply not competitive if you were running a [name of prior engine supplier] engine."

Our interviews also provided strong evidence that managers assessed an engine by studying the performance of all constructors using that same engine. When asked about the relative performance of the Mercedes and the Ferrari engines, a vehicle modeling engineer pointed out: "You should look not just at the Mercedes team and the Ferrari team but [also] at the customer teams." Another interviewee pointed out: "You look at performance by engine, so obviously for [the] Mercedes [engine] that's all the teams they supply." When studying the performance across teams, our interviewees considered performance relative to historical performance. As a vehicle performance engineer explained to us: "If you look at a team that was using another engine manufacturer, and then when they switched to Mercedes with a new engine, you could all of a sudden see a jump in performance." It also became evident that managers draw conclusions about component quality based on vicarious performance feedback. Discussing the reasons why the constructor our interviewee was employed by performed below their target level, he outlined: "Listen, Red Bull is using the same engine and look at them, they're winning races. It's not the engine."

Our interviews also corroborated our quantitative evidence on H2 that managers learn from vicarious performance feedback particularly when their organization performs below aspirations. As the former CEO of an F1 constructor pointed out: "You monitor the competition all the time. […], when you think about switching your engine supplier, which is a major decision you only make if your performance is not where you want it to be, you look at other teams using the same powertrain you already have and check whether they do better or worse than you would expect." A comment by a performance vehicle engineer also reveals when management pays attention to vicarious performance feedback: "I collect data on all the teams all the time. What changes is to what degree that data is requested by the top management. For example, in 2017, the worse we did, the more data they requested on Red Bull and Toro Rosso [other constructors using the same engine as the constructor employing the interviewee]."

The qualitative evidence also helps us to understand why managers pay more attention to vicarious performance feedback when more firms rely on the same component. More firms relying on the same component increases the amount of data—and thus managers' ability to learn from vicarious performance feedback and to reduce causal ambiguity. As one of the test engineers we interviewed pointed out: "the more cars use your engine, the more samples you have, the more accurate your data are, and the easier it is to assess what's the performance of your engine compared to your competitors." The chief designer on the power unit of an F1 constructor underscored how having more constructors using the same component has a positive effect: "Statistics increase significantly. This is the most important thing, statistics. If you have two cars [it's one thing], but if you have six cars, it's something different. It really makes a difference." The strong need for more information was pointed out by the technical head of one of the F1 constructors: "Those are statistically shallow data sets and so you have to do everything you can to try and improve the quality of the statistical significance of the information by looking at all teams."

Our interviews also clarified what kind of alternative information managers gain when they are geographically close to a supplier. We suggested that managers engage in forward-looking reasoning. Being geographically close allows managers to learn about the supplier's development efforts regarding future components. As one high-ranking manager pointed out: "you literally need to go and talk to them. See what sort of pathway they're on for the future, because you're not really buying an engine for this season." Being on site also allows learning about the progress the supplier makes regarding the future component. One of the interviewees who was regularly on site replied, when asked how he would use the state of development on the future component to assess the supplier: "Do they already have a prototype on the dyno?[18] I think that would be a very clear indicator that they will do better."

DISCUSSION

In this paper, we developed the theory of vicarious performance feedback to explain how organizations evaluate an exchange partner in the presence of causal ambiguity. We found that when evaluating an exchange partner—and deciding whether to renew or dissolve that

[18] An engine dyno is a testing rig used to measure engine performance while in development.

interorganizational tie—a firm reacts not only to its own performance relative to aspirations, but also that of other organizations that share the same exchange partner. Our paper makes important contributions to three areas of organizational scholarship.

Contributions to Research on Vicarious Learning

At the core of the literature on vicarious learning is the idea that when managers make strategically important decisions, they incorporate inferences derived from observation of other firms (Terlaak and Gong, 2008; Greve, 2013). Work on vicarious learning has identified a hierarchy of inferential mechanisms of increasing sophistication (Haunschild and Miner, 1997; Baum, Li, and Usher, 2000). At the base of the hierarchy is frequency-based inference, in which a focal firm's adoption or abandonment of a practice, strategy, or technology depends on the count of prior adoptions or abandonments in the population (e.g., Fligstein, 1985; Greve, 2011). A more sophisticated form of learning underlies trait-based inference, in which organizations give more weight to learning from organizations that are large or successful (e.g., Haveman, 1993; Haunschild and Miner, 1997) or that are similar to themselves (e.g., Greve, 1998b; Baum, Li, and Usher, 2000). More sophisticated still is outcome-based inference, in which managers assess the value of a practice by observing its impact on other firms' performance (Haunschild and Miner, 1997). Although frequency-based and trait-based mechanisms are well-researched, surprisingly little work has directly addressed outcome-based vicarious learning. By showing that firms evaluate their suppliers by examining how other organizations that rely on the same supplier perform relative to their aspirations—that is, based on vicarious performance feedback—we provide one of the first empirical tests of outcome-based vicarious learning (cf. Strang and Patterson, 2014). Our confidence that outcome-based learning is occurring is strengthened by the robustness tests which found that vicarious performance feedback remains significant when we control for frequency-based imitation.

We also add to the vicarious learning literature by examining how vicarious learning depends on the organization's structural position (Beckman and Haunschild, 2002). Prior studies on vicarious learning in diffusion of practices and innovations has shown that network proximity to prior adopters is an important factor in a focal firm's adoption decision (Haunschild, 1993; Davis and Greve, 1997). A related literature on reputation shows that locally cohesive networks can spread second-hand information about the quality or reliability of a prospective exchange partner (Coleman, 1988; Greif, 1993; Zhelyazkov and Gulati, 2016). These findings are consistent with network ties acting as pipes through which information about a practice or a prospective partner flows (Haunschild and Beckman, 1998; Podolny, 2001).

We depart from work on social ties as conduits of information to instead depict competitive relationships as attention-focusing devices. Prior work argues that actors in networks direct attention towards structurally equivalent actors—those with whom they share direct ties—and to imitate adoption decisions due to social comparison (Burt, 1987). Prior interorganizational research, such as Bothner's (2003) study of the sixth-generation Intel Pentium chip and Greve's (2008) study of shipbuilding innovations, has found that structurally equivalent buyers in a buyer–supplier network appear to influence each other's technology adoption decisions. However, these studies do not discern whether the underlying mechanism is the attention being paid to structurally equivalent competitors or the flows of information through the network ties from a common supplier. In our paper, the use of tie dissolution as the dependent variable makes the latter mechanism less likely, as we can assume that the supplier does not act as a conduit for negative opinions about itself. We thus show that managers are paying attention to the performance trajectories of structurally equivalent competitors. We show that structural equivalence, and not just network proximity, is an important basis for vicarious learning.

A further area to which we contribute is the question of how vicarious and experiential learning interact (Haunschild and Beckman, 1998; Tuschke, Sanders, and Hernandez, 2014). Work on this question has put forward various mechanisms by which vicarious and experiential learning may be substitutes for one another (e.g., Schwab, 2007; Simon and Lieberman, 2010; Yue, 2012) and other mechanisms by which they are complements (e.g., Madsen and Desai, 2010; Posen and Chen, 2013). We find that managers react to negative vicarious performance feedback when their firm's own performance is below aspiration. This suggests vicarious performance feedback might operate through a two-stage process, in which managers initially attend to internal information sources, then look externally for validation.[19]

Our findings are consistent with Baum and Dahlin's (2007) argument that sub-aspiration performance leads firms to increase their locus of search for information. We build on their study by measuring vicarious learning using a performance feedback framework in which we examine how organizations pay attention to the performance—relative to aspiration—of other organizations that collaborate with the same exchange partner.

Contributions to Research on Network Dynamics

A major project within organization theory is to understand the dynamics of social networks, which entails untangling the microdynamics that apply when actors form, maintain, or dissolve a tie (Ahuja, Soda, and Zaheer, 2012). Prior work has shown that network changes depend on the current network structure, so that network evolution is, at least partially, an endogenous process (e.g., Gulati and Gargiulo, 1999; Beckman, Haunschild, and Phillips, 2004). We build on and complement this work by pointing to a, so far, neglected mechanism.

[19] We are grateful to an anonymous reviewer for suggesting this possibility.

We contribute to the literature on the dynamics of market networks (Baker, Faulkner, and Fisher, 1998; Broschak, 2004; Rogan, 2014). Market networks typically consist of distinct sets of buyers and suppliers, i.e., they are two-mode networks (Vernet, Kilduff, and Salter, 2014), meaning some mechanisms of tie stability well-established in the broader networks literature may be less relevant to market networks. For example, it is not clear whether or how the mechanism of structural embeddedness, which stabilizes closed triads in one-mode networks, would apply to buyer–supplier networks (Shipilov and Li, 2012). In this paper, we document vicarious performance feedback as a mechanism that most naturally applies to two-mode networks such as buyer–supplier networks. We extend the literature on tie stability to better understand the dynamics of triadic and portfolio-level structures at the interorganizational level of analysis (see, e.g., Ozcan and Eisenhardt, 2009; Sytch and Tatarynowicz, 2014; Davis, 2016; Zhelyazkov, 2018).

Our theory also advances network dynamics research by incorporating firm performance as an antecedent factor in network change. By going beyond endogenous network evolution to consider how structure interacts with the performance—or "fitness"—of network actors, we get closer to a picture of the market network as a complex evolutionary system characterized by variation, selection, and retention (Anderson, 1999; Hodgson and Knudsen, 2010). We validate the basic notion that strong performance makes an agent more likely to retain network ties, with the caveat that the agent's perception of performance is relative to its aspiration level. Moreover, we find that performance outside the focal dyad can impact that dyad's stability, which paints a more complicated picture and suggests that network evolution studies that focus narrowly on dyads may miss important interactions between the dyad and elements of its network neighborhood (see also, e.g., Hallen, Katila, and Rosenberger, 2014; Hernandez, Sanders, and Tuschke, 2015; Li and Piezunka, 2019).

Contributions to Research on Performance Feedback

We contribute to the literature on the relationship of performance feedback to social structure. The existing performance feedback literature depicts managers as social comparators, benchmarking their firm's performance against a set of social referents, which may or may not have network ties to their own firm (Greve, 2003a). However, beyond this, "the interface [between network research and] the Behavioral Theory of the Firm is not well explored" (Gavetti, et al., 2012). In this paper, we address that gap, theorizing a variant of performance feedback that can occur when two organizations both have ties to a common exchange partner. Our findings suggest that managers keep in mind not only their own organization's aspiration level, but also a vicarious analogue corresponding to the performance expectations of their competitors. We thus depict performance feedback as a more deliberative, cognitively sophisticated process than it is traditionally conceived as (see also, Joseph, Klingebiel, and Wilson, 2016; Posen, et al., 2018). This forges a link between performance feedback behavior and the epistemic perspective on social networks, which is gaining increasing attention in organization theory (Moldoveanu and Baum, 2014). The managers in our study appear to be "putting themselves in the shoes" of the managers of competitor firms, using someone else's (vicarious) evaluation of an exchange partner to inform their own judgment.

Adding to this perspective on performance feedback as a cognitive process, we find evidence that vicarious performance feedback guides managers' causal attributions about performance. This, in turn, addresses another issue that performance feedback theory faces: it predicts that firms make changes when performance is below aspirations, but it does not predict what those changes will be. Prior work links performance feedback to a wide range of dependent variables, such as R&D expenditure (Greve, 2003b), market position (Greve, 1998a), product portfolio decisions (Gaba and Joseph, 2013; Joseph, Klingebiel, and Wilson, 2016), and technology sourcing strategy (Gaba and Bhattacharya, 2012; Lungeanu, Stern, and Zajac, 2016; Eggers and Kaul, 2018). However, when there are multiple things that could be changed, it is not clear which one managers will focus on (Greve, 2018). Our vicarious performance feedback theory shows one way to resolve this. When multiple factors—such as the firm's supplier and its employees—could have caused sub-aspiration performance, vicarious observation of poor performance at the supplier's other customers allows managers to narrow down their causal attribution. We show for F1 constructors that when their supplier's other customers underperform with respect to their historic track records, the constructors are more likely to dissolve their tie to the supplier and *less* likely to change their driver roster.

While vicarious performance feedback has a cognitive component, we emphasize that it retains a central, behavioral feature of performance feedback theory: managers respond to relative performance (i.e., performance relative to an aspiration level) rather than to absolute performance. The importance of the direct and vicarious aspiration thresholds is evident in Figure 2, which makes visible a discontinuous change in the rate of tie dissolution at these thresholds. The robustness tests that control for an array of observable measures of engine quality further illustrate the importance of relative performance, rather than absolute performance, in managers' decision-making. Vicarious performance feedback thus has both a *cognitive* aspect (i.e., managers observe competitors' performance and try to understand what factors contribute to that performance) and a *behavioral* aspect to it (i.e., managers change firm strategy when firm performance and vicarious performances fall below aspirations).

Boundary Conditions for Vicarious Performance Feedback

A number of boundary conditions apply to the theory of vicarious performance feedback that we propose. We make these conditions explicit to guide our understanding of the settings to which we expect the theory to generalize. One straightforward scope condition of the theory is that the component or input provided by the shared partner must have a substantial impact on the customer's performance. A shared supplier of a standardized, mass-produced component is therefore unlikely to be a subject of vicarious performance feedback. Second, the firm's environment should be dynamic; otherwise, the relative attractiveness of each exchange partner will become known and a stable hierarchy of assortative matches between partners is likely to result.

A third scope condition is that competitors' historical performances are documented and salient. In sports settings this is clearly the case, as fans, pundits, and employees maintain a collective "memory" of producers' trajectories (Day, Gordon, and Fink, 2012). Many other organizational fields have analogous systems of institutional memory, such as public firms' trajectories tracked by stock analysts (Zuckerman, 2000), professional service firms and universities tracked in annual rankings (Askin and Bothner, 2016), or transportation companies tracked by regulators (Madsen and Desai, 2018). Vicarious performance feedback is unlikely to be found in settings that lack shared, observable performance measures or settings in which participants focus only on how organizations perform in the moment.

A fourth condition limits the circumstances under which observation of a structurally equivalent competitor helps managers to evaluate a shared partner: the system-level complexity governing organizational performance—conceptualized as the extent of interdependencies between components—should be in some intermediate range (Schilling, 2000; Rivkin, 2001). In other words, vicarious observation is not informative if system-level complexity is either low or very high. At low complexity, managers can accurately evaluate a partner based on their own experience with the partner. Causal ambiguity is low, and so vicarious observations hold no additional information. At very high complexity, vicarious performance feedback is uninformative because meaningful attribution of the competitors' performance to its contributing factors is impossible. The "landscape" is so rugged—the interdependencies so dense—that it is impossible to reduce system-level behavior to its separate constituent factors (Rivkin, 2000).

While this reasoning places a bound on the conditions under which vicarious performance feedback *should* (normatively) be undertaken, it does not necessarily describe how managers in fact behave. In practice, managers may react to vicarious performance feedback even when system-level complexity is high, despite the fact that competitors' performances would be uninformative. This would constitute a form of superstitious inferential learning (cf. Denrell, 2003). The goal of the present study is descriptive rather than normative, and future research might tease out whether managers' reactions to vicarious performance feedback are functional or superstitious.

While we developed our theory of vicarious performance feedback at the interorganizational level of analysis, the theory might have implications for inter-personal tie dissolution (Burt, 2000; Schwab and Miner, 2008; Kleinbaum, 2018). When a mentor or manager supervises multiple subordinates, those subordinates—who are structurally equivalent with respect to the mentor—likely monitor one another's performance (i.e. career) trajectories. To the extent the subordinate can choose to switch mentors, they may be inclined to do so after one or more other subordinates has a negative career shock. Future work might investigate whether the mechanisms extend to one-mode collaboration networks, in which a person monitors the productivity (e.g. patenting rate) of their collaborator's other collaborators, and questions whether to renew a collaboration tie if a structurally equivalent individual's productivity declines. Future work could also investigate whether the mechanisms extend to cross-level person–organization networks, in which "crowd" complementors might monitor how organizations engage with *other* contributors when deciding whether to contribute in future (Boudreau, Lacetera, and Lakhani, 2011; Zhu and Liu, 2018; Piezunka and Dahlander, 2019; Pan Fang, Clough, and Wu, 2019).

Implications

The main managerial implication we draw from this work relates to the supplier, rather than to the customers. Our work highlights how customers of the same supplier pay close attention to one another, which negatively impacts the supplier if the inferences drawn from this observation are unfavorable (Sa Vinhas, Heide, and Jap, 2012). The supplier may well be able to mitigate these negative comparisons through strategic communication. First, if a customer suffers an episode of poor performance after a string of successes, it is in the supplier's interest to carefully frame this occurrence as a result of external factors when communicating with other stakeholders. Second, and more subtly, the supplier can attempt to downplay the customer's historic record of success, so that the comparison against this record looks less surprising. In either case, the supplier should be aware of the heightened risk of losing multiple customers after one of them has a failure and should increase its client retention efforts for all customers, not just the focal one.

Our empirical setting provides an appropriate first test of our theory, but it brings with it several limitations. We measure and control for a variety of factors that can impact tie dissolution, but several dyadic factors that may be theoretically relevant—such as the prices at which various transactions take place, the contractual terms governing the engine supply arrangements, the extent of partner-specific investments, and the level of trust between the two partners—lack visibility (Williamson, 1985; Mayer and Argyres, 2004). For example, firms in our empirical context sometimes sign multi-year supply agreements but are also known to terminate these contracts before expiration. Since we do not have access to the original supply agreements, we cannot control for contractual penalties for breaking off a long-term arrangement. Future empirical work in settings where prices and contractual terms are measurable would help to strengthen the foundations of our theory.

Conclusion

Managers face a daunting challenge in attributing organizational performance to the numerous factors that contribute to it. We have argued—and provided supporting evidence—that managers use the performance trajectory of their exchange partners' other partners when evaluating whether to continue or terminate an exchange tie. We cannot tell, from the present study, whether this behavior is functional or whether the attributions resulting from vicarious performance feedback are biased. Not all of the questions raised by this intriguing direction for future research have answers yet. Nevertheless, we believe we have made valuable advances in three important streams of literature—vicarious learning, performance feedback theory, and network evolution—and on how they relate to one another.

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TABLES AND FIGURES

Table 1. Overview of the literature on tie dissolution in market networks

High-level mechanism categories	Definition	Example findings	Illustrative studies
Relational mechanisms	Relational mechanisms refer to the history of interaction between two partners. Interaction reveals information about the partner and leads to social and emotional attachment between partners.	• Hazard of tie dissolution duration follows an inverted-U shape relationship with tie duration	Levinthal and Fichman (1988) Baker, Faulkner, and Fisher (1998) Greve *et al.* (2010)
		• Departures of top executives or exchange managers raise the hazard of tie dissolution	Broschak (2004) Rogan (2014) Bermiss and Greenbaum (2016)
		• Trust and reputation affect how well a tie withstands a dispute or an adverse event	Malhotra and Lumineau (2011) Park and Rogan (2019)
Assortative mechanisms	Assortative mechanisms refer to the way in which attributes of exchange partners make them more or less compatible.	• Social similarity and resource complementarity can generate cohesion which makes the relationship more stable	Rowley *et al.* (2005) Greve *et al.* (2010)
		• Resource differences can lead to inefficiency which raises the hazard of tie dissolution	Greve *et al.* (2010)
		• Overlap in product-market scope can cause competitive tension and thereby weaken the tie between the partners	Park and Ungson (1997)

Structural mechanisms	Structural mechanisms refer to the ways in which the broader social network, beyond the dyad itself, can stabilize or destabilize a tie.	• Ties to common third parties (i.e. *structural embeddedness)* lowers the likelihood of tie dissolution	Polidoro, Ahuja, and Mitchell (2011)
		• Structural status or power differences can strain a relationship, raising the hazard of dissolution	Rowley *et al.* (2005) Piskorski and Casciaro (2006) Greve *et al.* (2010)
		• Networks with dispersed tie strengths may contain subgroups of actors with fragile "faultlines" between them	Heidl, Steensma, and Phelps (2014)
		• Outside opportunities to form ties can raise the hazard of dissolving the current tie	Greve, Mitsuhashi, and Baum (2013)
Proximity-based mechanisms	Proximity mechanisms derive from actors' closeness in social, cultural, and geographic	• Country-level cultural proximity lowers the hazard of dissolution of international joint ventures	Park and Ungson (1997) Barkema and Vermeulen (1997); Hennart and Zeng (2002)
		• Geographic proximity may reduce the likelihood of tie dissolution	Xia (2011)

Table 2. Descriptive statistics and correlations

		Mean	S.D.	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1)	Change of engine supplier	0.24	0.43	0	1	1														
(2)	Change of driver line-up	0.62	0.49	0	1	0.22	1													
(3)	Supplier relationship length (years, max 5)	1.93	1.97	0	5	-0.2	-0.17	1												
(4)	Engine supplied by competitor	0.11	0.31	0	1	-0.09	-0.09	-0.06	1											
(5)	Vertically integrated constructor	0.18	0.39	0	1	-0.24	-0.17	0.42	-0.17	1										
(6)	Exclusive third-party supplier	0.31	0.46	0	1	0.13	0.11	-0.11	-0.24	-0.32	1									
(7)	Status difference	0.63	0.94	0	7.84	0.18	0	-0.27	0.04	-0.16	-0.15	1								
(8)	Supplier churn (5 years)	0.98	1.17	0	4	0.23	0.18	-0.5	0.03	-0.36	0.26	0.2	1							
(9)	Number of engine makers	7.58	1.79	4	10	0.19	0.16	-0.15	-0.32	-0.09	0.33	0.03	0.24	1						
(10)	Constructor decision-maker exits	0.26	0.63	0	4	-0.01	-0.12	0.03	0.18	0.1	-0.06	0.06	0.05	-0.16	1					
(11)	Distance to engine maker ('000 km)	0.81	2.01	0	9.87	0.16	0.07	-0.21	-0.08	-0.17	0.28	0.03	0.27	0.16	0.01	1				
(12)	Number of constructors using engine	2.74	3.10	1	12	-0.02	0.11	0.03	-0.14	-0.27	-0.38	-0.01	-0.14	-0.21	-0.16	-0.09	1			
(13)	Performance below aspirations	0.02	0.03	0	0.22	0.15	0.05	-0.03	-0.05	0.04	-0.06	0.24	-0.12	0.03	-0.07	-0.03	-0.06	1		
(14)	Performance above aspirations	0.02	0.04	0	0.30	-0.19	-0.2	0.2	0	0.15	0.03	-0.1	-0.06	-0.02	0.09	-0.09	-0.14	-0.3	1	
(15)	Vicarious performance below historic level	0.01	0.02	0	0.23	0.13	-0.08	-0.12	0.16	-0.12	-0.26	0.39	0.09	-0.06	0.04	-0.05	0	0.07	0.07	1
(16)	Vicarious performance above historic level	0.01	0.02	0	0.29	-0.03	-0.04	0.03	0.09	0.02	-0.17	0.06	0.03	-0.15	0	-0.05	-0.04	0.1	-0.05	-0.09

Table 3. Linear regression of *change of engine supplier*, 1981–2013

	Model 1 Baseline	Model 2 Test H1	Model 3 Test H2	Model 4 Test H3	Model 5 Test H4	Model 6 Full	Model 7 Full interaction
Supplier relationship length (years, max 5)	0.15**	0.15**	0.13*	0.14**	0.14**	0.12+	0.13*
	(0.05)	(0.05)	(0.06)	(0.05)	(0.05)	(0.06)	(0.06)
Supplier relationship length^2	-0.04**	-0.04**	-0.03**	-0.04**	-0.04**	-0.03*	-0.03*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Engine supplied by competitor	-0.23*	-0.19+	-0.21+	-0.20	-0.18+	-0.22+	-0.21+
	(0.11)	(0.11)	(0.11)	(0.12)	(0.11)	(0.12)	(0.13)
Vertically integrated team (0/1)	0.00	0.04	0.01	0.03	0.02	-0.01	0.01
	(0.14)	(0.14)	(0.14)	(0.17)	(0.15)	(0.18)	(0.20)
Exclusive third-party supplier	-0.02	0.02	-0.00	0.01	0.03	-0.01	-0.02
	(0.13)	(0.13)	(0.13)	(0.14)	(0.13)	(0.15)	(0.16)
Status difference	0.04	0.02	0.02	0.01	0.02	0.02	0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Distance to engine maker	0.01	0.01	0.01	0.01	0.00	0.00	-0.03
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Supplier churn (5 years)	-0.11*	-0.12*	-0.12*	-0.11*	-0.12*	-0.12*	-0.14**
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.06)	(0.05)
Number of engine makers	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Number of constructors using engine	-0.02*	-0.02+	-0.02+	-0.03	-0.02+	-0.03	-0.02
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.03)
Constructor decision-maker exits	0.04	0.04	0.04	0.03	0.04	0.03	0.01
	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.06)
No data on constructor decision-maker (0/1)	0.02	0.02	0.03	0.00	0.01	0.00	-0.01
	(0.07)	(0.07)	(0.08)	(0.07)	(0.07)	(0.08)	(0.07)
Performance below aspirations	2.14*	2.08*	1.46+	2.07*	2.10*	1.53+	1.55+
	(0.93)	(0.94)	(0.84)	(0.97)	(0.94)	(0.90)	(0.94)
Performance above aspirations	-1.26*	-1.42*	-0.72	-1.35*	-1.35*	-0.67	-0.59
	(0.57)	(0.63)	(0.65)	(0.64)	(0.63)	(0.66)	(0.76)
Direct feedback (-) (0/1)			0.05			0.04	0.03
			(0.06)			(0.06)	(0.07)
Direct (-) * No. of engine users							-0.09
							(0.06)
Direct (-) * Distance to engine maker							0.11*
							(0.05)

Table 3. Continued from previous page	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Vicarious performance below historic level		2.61**		2.89**	2.74**		
		(0.92)		(1.05)	(0.72)		
Vicarious performance above historic level		-1.04		-1.36	-0.74		
		(1.05)		(1.81)	(2.81)		
Vicarious performance below historic level * Direct (-)			3.61**			3.81**	2.14*
			(1.01)			(0.97)	(1.03)
Vicarious performance above historic level * Direct (-)			-0.62			-1.81	1.26
			(0.94)			(2.68)	(2.35)
Vicarious performance below historic level * Direct (+)			-3.16			-2.35	-2.60
			(1.98)			(2.28)	(2.01)
Vicarious performance above historic level * Direct (+)			-3.24*			-4.75	-4.87
			(1.48)			(3.78)	(4.03)
VPF below historic level * No. of engine users				5.19**		5.03**	
				(1.20)		(1.31)	
VPF above historic level * No. of engine users				-1.38		-2.35	
				(8.49)		(8.55)	
VPF below historic level * Distance to engine maker					2.16*	1.85+	
					(0.97)	(0.95)	
VPF above historic level * Distance to engine maker					0.92	-2.89	
					(10.46)	(10.74)	
VPF below historic level * Direct (-) * No. of engine users							6.01**
							(1.87)
VPF above historic level * Direct (-) * No. of engine users							3.37
							(6.27)
VPF below historic level * Direct (+) * No. of engine users							8.48
							(7.96)
VPF above historic level * Direct (+) * No. of engine users							-7.07
							(10.07)
VPF below historic level * Direct (-) * Distance to engine maker							3.34**
							(1.05)
VPF above historic level * Direct (-) * Distance to engine maker							-4.00
							(4.22)
VPF below historic level * Direct (+) * Distance to engine maker							-3.01
							(3.93)
VPF above historic level * Direct (+) * Distance to engine maker							-1.57
							(6.12)
Observations	432	432	432	432	432	432	432
Number of constructors	57	57	57	57	57	57	57
Adjusted R-squared (within constructor)	0.125	0.141	0.165	0.154	0.141	0.176	0.201
Constructor fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses, clustered by constructor and engine supplier. ** $p<0.01$, * $p<0.05$, + $p<0.1$

Table 4. Robustness tests: Linear regression models for *change of engine supplier* (models 1–7) and *change of driver line-up* (model 8), 1981–2013

	Model 1 Mid-season	Model 2 Imitation	Model 3 Quality	Model 4 Quality	Model 5 Quality	Model 6 Quality	Model 7 Supplier PF	Model 8 Drivers
Supplier relationship length (years, max 5)	0.13*	0.12+	0.12*	0.15**	0.13*	0.13*	0.13*	
	(0.05)	(0.06)	(0.05)	(0.06)	(0.06)	(0.06)	(0.06)	
Supplier relationship length^2	-0.03**	-0.03*	-0.03**	-0.04**	-0.03*	-0.03*	-0.03**	
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	
Engine supplied by competitor	-0.18	-0.18	-0.26*	-0.24*	-0.21+	-0.20	-0.21+	
	(0.14)	(0.12)	(0.13)	(0.12)	(0.13)	(0.13)	(0.12)	
Vertically integrated team (0/1)	0.10	0.01	0.02	-0.01	0.01	-0.06	-0.00	
	(0.14)	(0.19)	(0.14)	(0.15)	(0.19)	(0.20)	(0.20)	
Exclusive third-party supplier	0.02	-0.00	-0.07	-0.04	-0.03	-0.05	-0.03	
	(0.15)	(0.16)	(0.14)	(0.13)	(0.16)	(0.16)	(0.17)	
Status difference	0.04	0.02	0.05	0.04	0.01	0.00	0.01	
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	
Distance to engine maker	0.01	-0.03	0.01	0.01	-0.03	-0.02	-0.03	
	(0.02)	(0.03)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)	
Supplier churn (5 years)	-0.11+	-0.14**	-0.13**	-0.12*	-0.14**	-0.13*	-0.14**	
	(0.06)	(0.05)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	
Number of engine makers	0.02	0.01	0.01	0.01	0.01	0.00	0.01	
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	
Number of constructors using engine	-0.02	-0.02	-0.02+	-0.02	-0.02	-0.02	-0.02	
	(0.01)	(0.03)	(0.01)	(0.01)	(0.03)	(0.03)	(0.03)	
Constructor decision-maker exits	0.03	0.02	0.02	0.04	0.02	0.02	0.02	
	(0.04)	(0.06)	(0.04)	(0.04)	(0.06)	(0.06)	(0.06)	
No data on constructor decision-maker (0/1)	0.03	-0.02	-0.01	0.01	-0.01	-0.04	-0.01	
	(0.09)	(0.07)	(0.07)	(0.07)	(0.07)	(0.08)	(0.08)	
Performance below aspirations	0.86	1.45		2.04*	1.54	1.57+	1.71*	2.74**
	(0.77)	(0.90)		(0.90)	(0.94)	(0.88)	(0.85)	(0.59)
Performance above aspirations	-0.80	-0.51		-0.87+	-0.57	-0.71	-0.93	-2.14**
	(0.64)	(0.66)		(0.51)	(0.91)	(0.90)	(1.38)	(0.27)
Direct feedback (-) (0/1)	0.03	0.04			0.03	0.03	0.03	-0.20*
	(0.09)	(0.06)			(0.07)	(0.07)	(0.07)	(0.08)
Direct (-) * No. of engine users		-0.11*			-0.09	-0.09	-0.10+	
		(0.05)			(0.06)	(0.06)	(0.06)	
Direct (-) * Distance to engine maker		0.11*			0.11*	0.10+	0.10*	
		(0.05)			(0.05)	(0.05)	(0.05)	

Table 4. Continued from previous page	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Vicarious performance below historic level * Direct (-)	3.41**	1.47+			2.14+	1.97+	2.19*	-2.59*
	(0.73)	(0.82)			(1.09)	(1.01)	(1.06)	(1.04)
Vicarious performance above historic level * Direct (-)	-0.29	2.07			1.30	1.02	1.00	-1.26
	(0.67)	(2.24)			(2.36)	(2.34)	(2.46)	(1.19)
Vicarious performance below historic level * Direct (+)	-0.54	-3.07			-2.59	-2.77	-2.44	-0.63
	(1.28)	(2.03)			(1.95)	(1.84)	(2.01)	(2.70)
Vicarious performance above historic level * Direct (+)	-1.51	-4.63			-4.81	-5.13	-5.09	1.46
	(1.08)	(3.92)			(4.13)	(4.01)	(4.30)	(1.53)
VPF below historic level * Direct (-) * No. of engine users		3.03			5.97**	5.55**	6.38**	
		(2.31)			(1.71)	(1.61)	(1.58)	
VPF above historic level * Direct (-) * No. of engine users		5.62			3.34	2.87	3.88	
		(5.80)			(6.28)	(6.48)	(5.38)	
VPF below historic level * Direct (+) * No. of engine users		5.91			8.42	8.77	8.67	
		(7.44)			(8.33)	(8.12)	(7.80)	
VPF above historic level * Direct (+) * No. of engine users		-6.34			-7.03	-7.68	-7.15	
		(9.55)			(10.15)	(10.06)	(10.29)	
VPF below historic level * Direct (-) * Distance to engine maker		3.34**			3.35**	3.88**	3.29**	
		(1.05)			(1.02)	(0.82)	(1.05)	
VPF above historic level * Direct (-) * Distance to engine maker		-4.30			-3.98	-3.93	-3.96	
		(4.15)			(4.31)	(4.26)	(4.21)	
VPF below historic level * Direct (+) * Distance to engine maker		-2.66			-3.02	-2.75	-3.03	
		(3.87)			(3.94)	(3.80)	(4.07)	
VPF above historic level * Direct (+) * Distance to engine maker		-1.04			-1.53	-0.84	-1.61	
		(6.11)			(6.05)	(5.79)	(5.91)	
Count of other component users that terminate supplier relationship		0.05						
		(0.03)						
Engine maker: best customer performance (points share)			-0.81*	-0.39	-0.03	0.16		
			(0.40)	(0.35)	(0.42)	(0.43)		
Engine failures (this supplier as % of year's total)						0.56+		
						(0.31)		
Engine maker: best average speed in year						-0.03		
						(0.03)		
Engine maker performance below aspirations							-0.35	
							(0.88)	
Engine maker performance above aspirations							0.38	
							(1.19)	
Observations	432	432	432	432	432	432	432	432
Number of constructors	57	57	57	57	57	57	57	57
Adjusted R-squared (within constructor)	0.113	0.205	0.097	0.128	0.199	0.207	0.205	0.052
Constructor fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses, clustered by constructor and engine supplier. ** p<0.01, * p<0.05, + p<0.1

Figure 1. Configurations of joint component usage

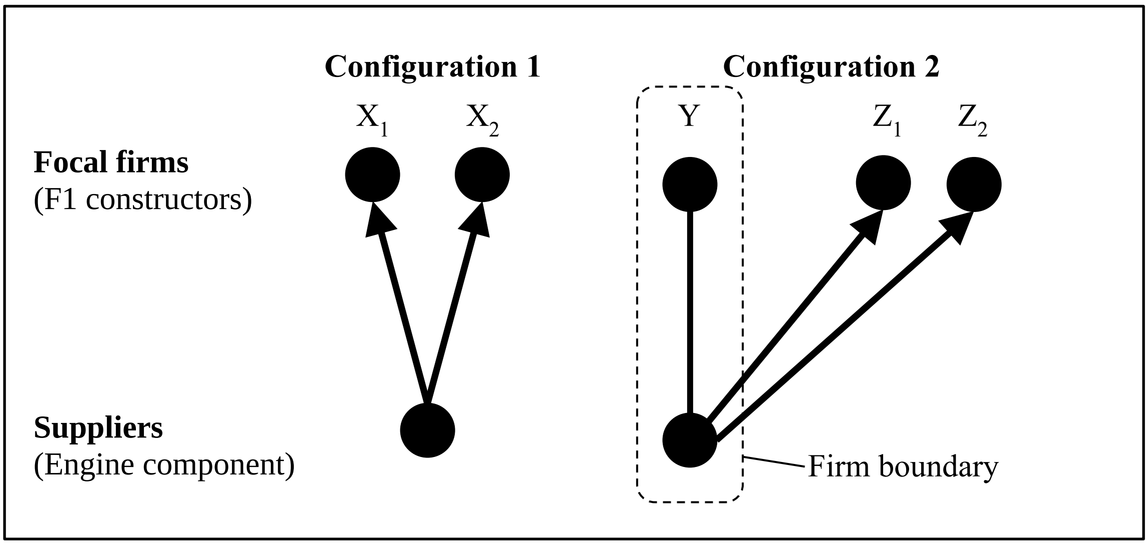
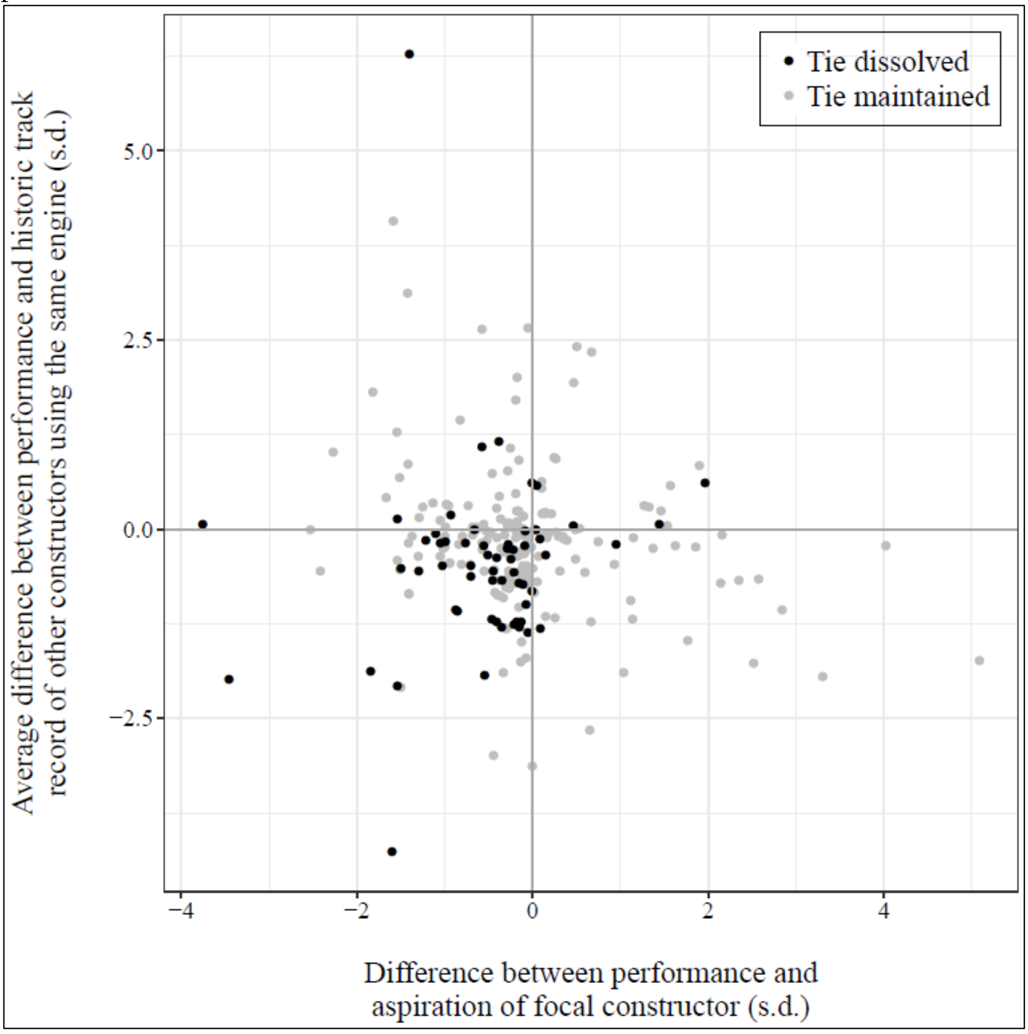


Figure 2. Scatterplot of tie dissolution versus retention at varying levels of own and vicarious performance feedback.



Notes: Each point represents one constructor-supplier-year observation for a constructor that has at least one joint component user.

Figure 3. Estimated effects of vicarious performance feedback with own performance above and below aspirations

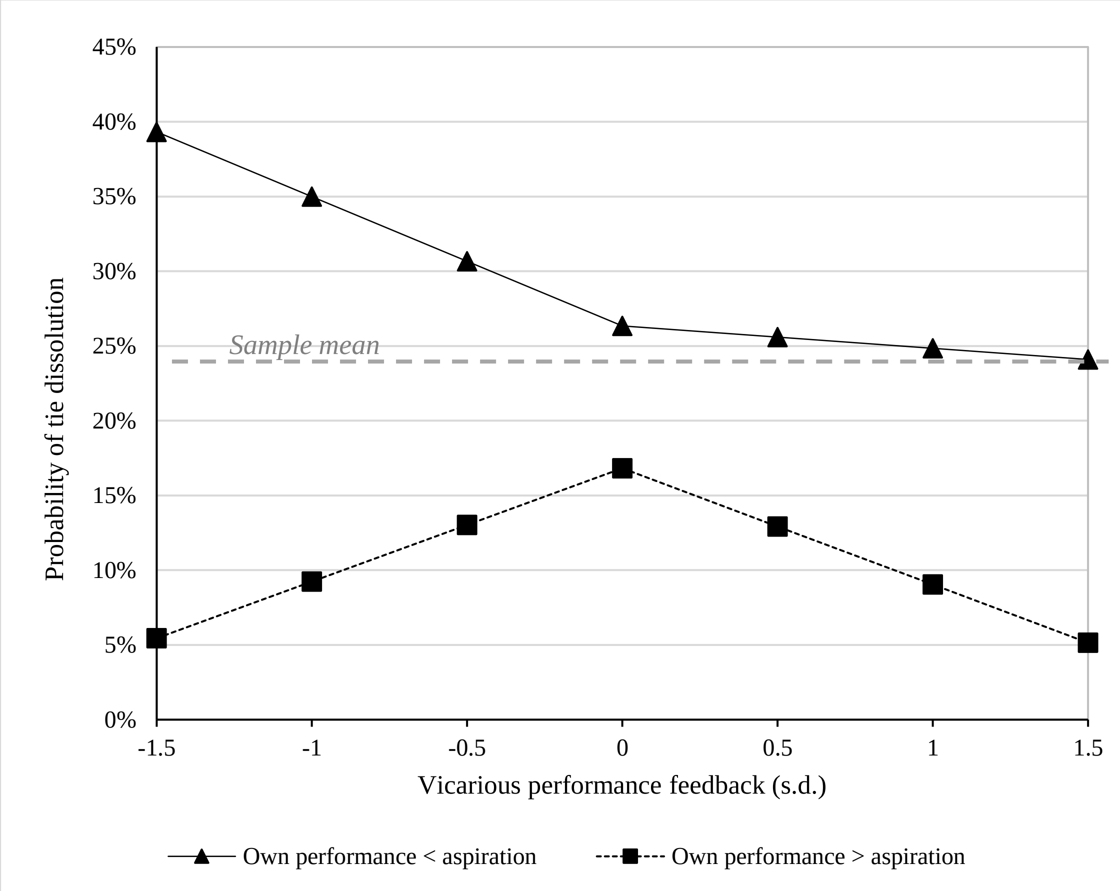


Figure 4a. Estimated effects of vicarious performance feedback at varying numbers of other component users and own performance below aspiration

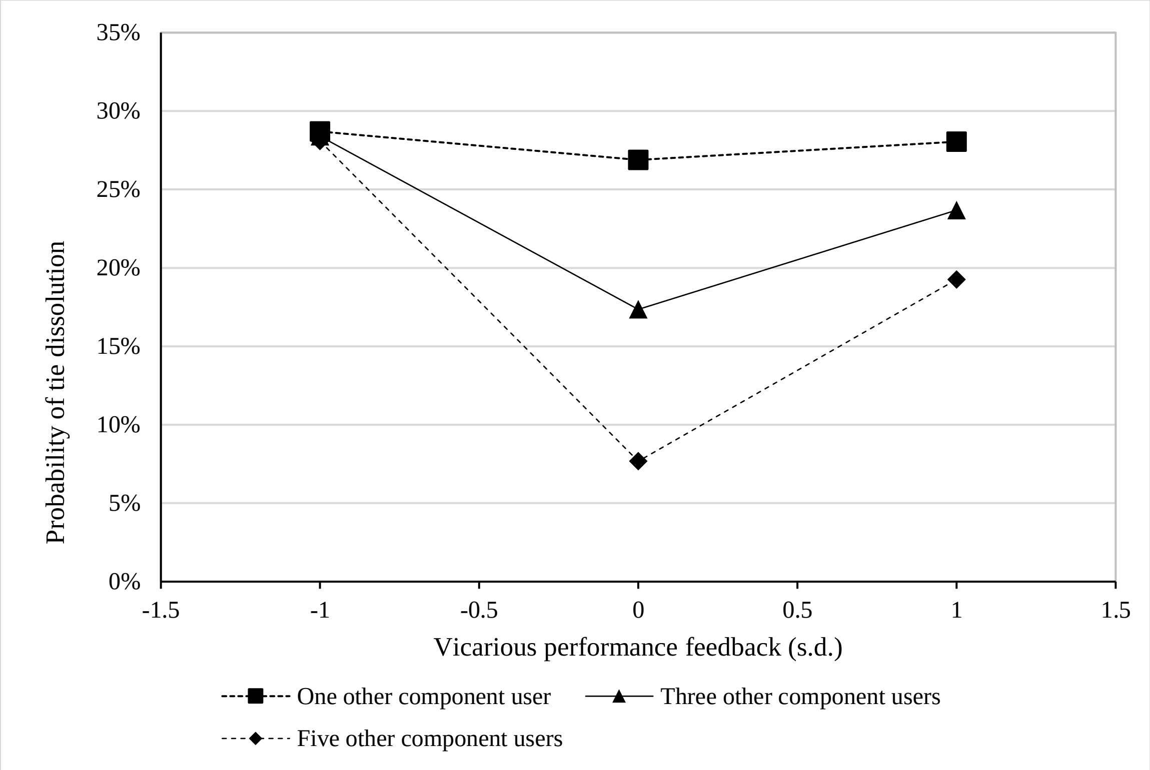


Figure 4b. Estimated effects of vicarious performance feedback at varying distances between constructor and supplier and own performance below aspiration