DYNAMIC INDUCEMENTS IN R&D INVESTMENT: MARKET SIGNALS AND NETWORK LOCATIONS

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ABSTRACT

This research shows that alliance networks shape how firms respond to uncertainty-reducing information generated outside a network. New product awards provide market signals about the potential commercial success of the award-winning firms, which reduces the uncertainty of new R&D investment. Networks both magnify and diminish a firm’s R&D response to the market signals, depending on its network location, partners’ success, technical proximity to partners, and relative capabilities. The study examines 198 firms in the U.S. computer and telecommunications sector from 1991 to 2000, including hardware, software, and telecommunications firms.
Recent studies suggest that networks reduce firms’ market uncertainty in two ways. First, networks act as pipes for flows of information between firms (Burt, 1992; Uzzi, 1996). Second, networks function as prisms that reflect information cues about the resource quality of particular firms (Podolny, 2001; Stuart, Hoang, & Hybels, 1999). The pipes view assesses mechanisms for resolving a firm’s own uncertainty (Gulati, 1999; Mizruchi & Stearns, 2001), while the prisms view considers mechanisms for resolving exchange partners' uncertainties about the firm (Dahlstrom & Ingram, 2003; Gulati & Higgins, 2003). One question is how the pipes and prisms shape the value of uncertainty-reducing information generated outside a network. We have limited understanding of how different members of a network respond to such new information.

This study focuses on new product awards as market signals that affect a firm’s incentive to undertake new R&D investment. We examine how the constellations of inter-firm relationships in which firms operate shape the value of the signals. We argue that awards provide two signals: a signal that reduces the market uncertainty of the winning firms and a cue about firm’s resource quality. These signals influence the firm’s expected investment payoffs from its R&D investments. The degree and direction of the influences depend on two factors: a firm’s centrality in a network and the number of awards that its partners receive. In turn, a firm’s technical proximity to partners in the network and its capabilities relative to its partners shape how the product awards influence R&D investment. The results contribute to a greater understanding of how networks influence firms’ incentives to respond to new information and have implications concerning firms’ ability to take advantage of uncertainty-reducing information.

BACKGROUND: NETWORKS, R&D INVESTMENT, AND NEW PRODUCT AWARDS

Several recent network studies focus on information benefits accrued to organizations through networks of alliances (e.g. Ahuja, 2000; Gulati, 1999; Stuart, 1998). Information that
diffuses within inter-firm networks of technical and marketing alliances reduces firms’ market uncertainty in delivering products and services. However, different firms within an alliance network have different degree of access to uncertainty-reducing information. Depending on their inter-firm relationships, some firms draw on network information while others rely more on external information such as market signals that are generated outside the network. Network research argues that network relationships influence the accessibility of information generated within the network (Burt, 1992; Podolny, 2001), but we do not know how these relationships shape the value of signals created outside the network.

To enhance our understanding of how different members of the network respond to external information signals, we focus on R&D investment decisions and new product awards. R&D investment is critical to a firm’s success in highly uncertain technically-intensive environments. Firms adjust R&D investment levels based on expected payoffs derived from uncertainty-reducing information. We posit that a change in R&D patterns reflects the extent of market signals that serve as investment incentives. This argument is consistent with the economics of innovation literature, which argues that a firm’s incentives to invest in R&D increase as the market success of its investments becomes more likely (Cohen & Klepper, 1996).

New product awards provide market signals that influence R&D investment incentives in technically-intensive industries. Awards that trade publishers bestow on new products provide signals of impending market acceptance of a firm’s products and indicate the quality of the research activities that underlie the firm’s product family. Awards offer market endorsement of a firm’s new products, raising a firm’s risk tolerance for next-generation product ventures. In turn, this information increases the producer’s expectations concerning returns on R&D investment. Moreover, winning product awards attract potential partners who may be able to act either as
providers of inputs or as outlets for the firm’s innovations. Having access to potential partners will reduce both R&D risk and market commercialization risk (Hagedoorn, 1993). Thus, uncertainty concerning the future value of a firm’s R&D efforts declines when it wins product awards, which creates incentives to increase its R&D investment (Ofek & Sarvary, 2003).

This argument contrasts with the premise that award-winning firms might shift R&D investment to partners. For such shifts to occur, partners would need to take on R&D activities in lieu of the focal firm. Yet, it is the focal firm’s skill that attracts partners to it, so that the partners do not have incentives to replace the focal firm’s R&D. Instead, both the firm and its partners will commit more resources in complementary areas when the market reward is large (Amaldoss, Meyer, Raju, & Rapoport, 2000) and when opportunism is self-defeating to the extent that the benefits outweigh the risks of under-commitment (Nooteboom, Berger, & Noorderhaven, 1997).

**HYPOTHESES: NETWORKS SHAPE HOW AWARDS INFLUENCE R&D**

Several studies show that networks of inter-firm relationships can function as conduits of information about resource and partnership opportunities. A central issue in this research is what kind of network position is most useful for acquiring information. Burt (1992) demonstrated that non-redundant contacts in structural holes give rise to distinct information sources. Other scholars show that direct ties or central network locations lead to information exchange that is beneficial to learning and innovation (Ahuja, 2000; Gulati, 1999; Lane & Lubatkin, 1998).

In technically-intensive industries, the alliance networks consist of direct and indirect linkages with competitors and complementary firms. Knowing the competency of other firms and the technical concepts embodied in their products provides design advantages for a focal firm’s product development processes, either by creating values to enhance the complementary products or by improving the rate of product innovation relative to that of competitors. Similarly,
knowing what resource opportunities potential partners possess helps firms select partnerships. Therefore, networks serve as information-gathering devices because firm can obtain information via many direct and indirect partners.

However, two constraints hinder information accessibility in alliance networks. First, information transmitted through indirect ties is filtered by the ability of these ties to act as information processing units (Ahuja, 2000). Every firm can process externally received information differently, based on its own level of absorptive capacity, while information benefits can be realized only when a firm has the motivation and ability to mobilize resources (Adler & Kwon, 2002). Second, information distortion may occur through excessive intermediaries in the networks (Powell, Koput, & Smith-Doerr, 1996). Untimely and inaccurate information will have no value to any network members receiving the information.

Existing studies show that more central firms in a network can better overcome the information constraints (Powell et al., 1996). Central firms can mediate the flows of information between all other pairs of members in the network (Brass & Burkhardt, 1993). Furthermore, the amount of information increases with the centrality of partners with which firms have formed direct contacts (Sorenson & Stuart, 2001). Thus, central firms can capitalize on opportunities more effectively than others.

The first prediction considers how network position will affect the value of new product awards. We suggest that centrality will temper the value of such external signals. Because central firms already possess superior information, new product awards provide less new information that will reduce their market uncertainty. Similarly, information about new partnership opportunities generates less value for central firms because their extensive existing relationships increase the probability of commercialization success of new products. Moreover, for firms that
already have many partnerships, adding new partnerships may lead to diminishing returns when the coordination with diverse partners becomes difficult (Singh & Mitchell, 1996).

By contrast, peripheral firms gain more from new product awards. Peripheral firms have less access to diverse information within their networks. In addition, other firms are less sure about a peripheral firm's resource quality because the information status of the firm requires longer chains of referrers to disseminate in the network. As a result, the chances of market success and opportunities to gain new commercialization partners increase when a peripheral firm receives a product award, inducing higher expected payoffs and greater incentives for R&D investments. Thus, market signals offer substantial value for peripheral firms, while central firms gain fewer marginal benefits from awards because they already have access to information and partners.

Hypothesis 1. The lower a firm’s centrality in an inter-firm alliance network, the more that the firm’s R&D investment will increase after it receives new product awards.

The issue of information quality arises here, because the concept of centrality says little about the quality of information a firm receives through its partners. Although greater access to partners through direct and indirect ties increases the accuracy of information, some contacts provide redundant information. To the extent that ties facilitate information flows, two direct contacts are redundant if an indirect tie exists between them (Hansen, 1999). If many existing ties contain redundant information, awards have greater chance of providing novel information, even for central firms. We will assess redundant ties in the focal actor’s network by measuring the ratio of actual ties between partners over the number of potential ties between partners.

The second prediction addresses product awards to partners, which also provide useful information in a network. Recent research suggests that inter-firm relationships help others make inferences about the relative resource quality of particular firms (Podolny, 2001; Stuart et al.,
Similarly, new product awards to partners offer information about partners’ capabilities that will have both positive and negative effects on a firm’s investment incentives.

Substitution and complementarity among partners’ products each create non-monotonic influences on a firm’s investment incentives. First, consider the incentives when products of the focal firm and its partners are substitutes. If the firms’ products are substitutes, then partners that pull ahead may dominate the market. This idea parallels winner take all assumption of many R&D racing models, in which the odds that any particular firm will reach its desired objective falls with successful investment outcome by others (e.g., Gilbert & Newbery, 1982). The greater the partners’ lead, the more a firm will fear that its own efforts will not pay off. These concerns will be particularly strong in technically-intensive industries, in which winners often gain large market positions owing to network externalities and dynamic increasing returns to scale (Cohen & Klepper, 1996), while losers become marginalized or exit. Initially, a firm has incentives to increase its R&D investments in an effort to catch up to its partners. At some point, however, partners with substitute products will gain such a wide lead that the firm has little chance of catching up. When partners receive many awards, the firm ultimately will downgrade its chances of success and reduce its investments unless it receives awards itself.

Second, consider the investment incentives that arise from complementarities between the firm and its partners. Complementarities create incentives for a firm to increase its R&D investment when a partner wins awards. To the extent that the products of a firm and its partners are complements, awards to partners also signal greater market potential for the firm’s own products. This creates incentives for the firm to increase its investment in order to internalize the spillovers from the partners’ complementary activities (Uzzi, 1999).
At some point, however, a firm faces disincentives to invest if partners with complementary products pull ahead, because the firm becomes less attractive to the partner. The firm must compete with others – both within and outside the existing network – for access to its partners’ complementary resources. When partners win awards, the partners’ options regarding alliance relationships expand, which means that the firm may become less competitive vis-à-vis other firms with whom the partners can form alliances. The loss of attractiveness leads to a decline in firm’s access to its partners’ resources. Even in industries in which standards are important, so that all players tend to develop complementary products, firms can provide selective lead time and inter-operability advantages to preferred partners that reduce the chances of success of other producers of complementary product. As in the case of substitution, therefore, complementarity creates both incentives and disincentives to invest.

Thus, we expect that the number of awards to partners will have a non-monotonic effect on a firm’s change in R&D. Initially, as partners’ awards increase, the potential for product complementarities, the desire to remain an attractive partner, and the need to maintain pace with substitute products increases the firm’s R&D investment incentives. If partners win too many awards, however, the increasing likelihood of losing access to partners’ resources and losing customers to partners’ products reduces the firm’s investment incentives. From the standpoint of the focal firm, if the marginal benefits from partners’ awards decrease and the marginal costs increase with the level of partners’ awards, the initial positive effect of partners’ award on a focal firm’s change in R&D eventually becomes negative.

Hypothesis 2: The number of product awards a firm’s alliance partners receive in a given period will have an inverted-U impact on the subsequent change in a firm’s R&D investment.
We will consider two scenarios in which either the positive or negative effects are likely to
dominate in order to unpack the non-monotonic relationship in hypothesis 2. First, the technical
proximity of the firm and its partners will influence investment incentives. Greater technical
proximity implies greater likelihood that the firms are investing in related products, whether
substitutes or complements, which increases the need to respond to partners’ awards in order to
avoid falling behind in the market for substitute products and to benefit from spillovers from
complements. Second, if partners’ awards indicate a firm’s loss of attractiveness, the threat of
losing a partnership will be greater when partners have stronger capabilities. When partners are
much stronger, continued partner success may cause a firm to reduce its efforts because it
recognizes that its chance of retaining partnerships is declining. By contrast, when there is little
difference in capabilities, or when the firm has been stronger historically, its partners' success
may spur the firm to invest heavily in current product lines.

METHODS

Data and Sample

We began by identifying 1,354 firms in the U.S. computer and telecommunications sector
that were listed by eight widely-cited trade publications (Communications Week, Data
Communications, Internetwork, LAN Magazine, LAN Times, Network Computing, Network
VAR, and PC Magazine). Owing to our need for financial information, we focused on the 241
publicly-listed companies among the 1,354 firms. We used the publications to collect
information about new product awards: 393 firms received a total of 1,078 awards from 1991 to
2000; among the 241 public companies, 167 firms received 573 awards.

Alliance activity is common in the sector. User demand for internet activities has driven
product innovation in the industry, leading to the convergence of computer and
telecommunications industries. Competing firms responded to this demand with alliances that helped develop open system standards, broadened product lines, and reduced product development cycles. Using the alliance announcements published through Dow Jones News, we collected bilateral agreements for the 241 public firms from 1991-2000. The agreements include two common types of alliances in the industries: business alliances involving marketing, distribution, product bundling, OEM, and value-added reselling activities; and technical alliances involving the exchange of design knowledge and joint product development. We excluded standards-setting alliances since they do not encompass clear bilateral relations among member firms. Among the 241 public firms, 177 established at least one alliance during the 10-year period, with a total of 746 alliances formed among themselves. We tested the hypotheses using 198 public firms for which we could collect complete data.

Measures

We collected data on R&D investments for each firm-year observation, using the Compustat database. The dependent variable is the one-period Change in $R&D_{t,t+1}$. As a robustness check, we also used percentage change in R&D as the dependent variable.\(^2\)

The initial independent variable is the count of new product Awards for each firm-year observation. The award data raise two measurement issues. First, the publications did not select all possible products or firms for evaluation each year. Editorial and advertising decisions might determine the magazines’ award processes. However, product analysts stated that they screened as many new products shipped within the year as possible and disqualified only those that had low performance specifications or little difference relative to previous generations of products. Second, testing standards and quality might vary across publishers, resulting in uneven market signals from the awards. However, the publications report similar performance criteria for each
product category. For example, common benchmarking tests for communications products include rate of data transfer by packets per second, features of algorithms for load distributions across the network, price per port, and network management capability.

We addressed award reliability in several ways. We selected credible publications that provide wide coverage of award data across multiple product categories as well as a relevant list of firms. We were concerned that awards might result from advertising choices, rather than objective assessment, but we found no significant correlation between awards and advertising expenses. We used dummy variables to control the magazines from which the firm obtained awards, finding no significant influence. We also found consistent results when we eliminated firms that acquired others with awards. We believe that the awards provide valid market signals.

The hypotheses require measures for centrality and partners’ awards. As our measure of centrality we used *Eigenvector Centrality*, which computes the eigenvector of the largest positive eigenvalue of the relationship matrix (Bonacich, 1972). To measure *Partner Awards*, we counted the number of awards that a firm’s partners received in a given year. We lagged the impact of the centrality and partners’ awards variables on R&D expenditure by one year (year \( t \)).

Sensitivity analyses also assessed network locations by three other common measures (Brass & Burkhardt, 1993; Wasserman & Faust, 1994): degree, betweenness, and closeness centrality. Degree centrality counts the number of partners with which the focal firm is allied, but does not consider relational activities beyond direct ties. Betweenness centrality calculates the probability that a firm lies between two other firms on their shortest path and indicates potential indirect access to information or control that the firm enjoys. Closeness centrality measures the shortest path between a firm and all others. Betweenness and closeness centrality are conceptually less appropriate than eigenvector centrality because they treat all ties equally,
whereas eigenvector centrality weighs partners by their own centrality. We used UCINET IV, a software program for social network analysis, to generate the normalized values for each network measure for each firm based on yearly alliances (Borgatti, Everett, & Freeman, 1992). The normalized values mean that the measures are not sensitive to changes in network sizes.

Several variables address alternative explanations. *Egodensity* controls for the impact of network tie redundancy, by taking the proportion of the number of ties in the ego network (excluding the ties to ego firm) to the number of potential ties between alters. *Prior Award Share* records a firm’s share of awards in the last three years; we found similar results using share during the last year and last two years. Firms that have received many earlier awards may already have incorporated most of the available information and have reached near equilibrium in R&D spending, so that they would have little year to year increase in R&D. Three variables address the firms’ financial position. *Initial R&D* controls for mean reversion (Bergh & Fairbanks, 2002). *Change in Sales* records change in sales from $t$ to $t+1$. If innovation relies on internal financing (Himmelberg & Petersen, 1994), only firms with high liquidity can support sizable R&D efforts; a firm’s increase in sales will correlate with its ability to raise finances. *Relative Stock Performance* measures the difference between the firm’s average stock price and the industry’s average stock price in a given year, indicating the financial incentives available in the capital market. Sensitivity analyses used three alternative measures for liquidity – cash flow, operating income, and debt-equity ratio – finding results that were equivalent to those we report here. We collected annual financial data from the Compustat database.

The covariates have only limited correlation, as Table 1 reports. *Partner Awards* correlates moderately with *Awards* and *Centrality*, while *Initial R&D* correlates moderately with *Change in Sales*, but the results were robust to adding the variables incrementally.
Thoughtful readers might suggest caution in assigning causality in any relationship between awards and R&D. While awards can affect R&D, R&D might also lead to awards. Moreover, unobserved firm-specific effects, such as entrepreneurial ability, might correlate with the Awards and Change in R&D variables. In part, we deal with the causality issue by lagging the independent variables. We address the concern about unobserved heterogeneity by using fixed effects analyses. In addition, we identify the mechanisms by which awards would affect R&D – technical proximity and capability relative to network partners – and then document how R&D activity changes in the face of variation in the mechanisms (Rajan & Zingales, 1998).

RESULTS

Table 2 reports regression results using fixed effects models, which control unobserved firm-specific differences that might influence the results. Model 1 reports the baseline model. Firms that receive awards increase their subsequent R&D, while firms with a high share of prior awards have less increase in R&D. Firms that already have a high level of R&D also have less increase. Model 2 adds the main effects of the network variables. Central firms tend to increase their R&D, likely because the firms needed to invest in order to maintain their central positions in a highly dynamic sector. Egodensity, which assesses network tie redundancy, has no significant impact. The awards, prior award share, and initial R&D effects remain stable.

Model 3 tests the hypotheses by interacting the network position and award variables and adding the partner awards variables. Centrality, awards, prior award share, and initial R&D retain their signs and significance relative to the earlier models. The negative eigenvector Centrality x Awards interaction supports Hypothesis 1. As expected, awards have less influence
on new R&D investment by more central firms. Model 3 also supports Hypothesis 2, because Partner Awards has an inverted-U impact on the firms' change in R&D (a positive main effect and a negative quadratic effect). Firms respond to moderate levels of partner awards by increasing their R&D, but reduce R&D if partners receive many awards. We later report analyses that untangle the non-monotonic influences.

Sensitivity analyses found robust results. We examined alternative measures of centrality: degree, closeness, and betweenness centrality. We also used percentage change in R&D as an alternative measure of change in R&D investment. We found similar results to those that we report, although the effects of Closeness Centrality x Awards (Hypothesis 1) were somewhat less significant than with the eigenvector centrality measure. Adding industry-specific variables with dummies for computer software (67 firms) and telecommunications (45 firms), which we compared to computer hardware (86 firms), created no material differences.

We were concerned that variation in diversification might influence the results. The R&D incentive from product awards will be stronger for moderately focused firms that can leverage complementarities across product lines, because improvements of award-winning products create opportunities to advance related products (Bresnahan, Stern, & Trajtenberg, 1997). By contrast, diversified firms with multiple products, such as IBM, can benefit from such complementarities, but variations in R&D strategies across product lines will dampen the link between product-level awards and overall R&D expenditures. At the other extreme, highly focused firms with expertise in a single product line will be less able to internalize technical complementarities from a single success. Therefore, we defined the firms as highly-focused, medium-focused, or diversified, using product line information from the Thomas Register. Consistent with our expectations, product awards had greater effect on firm-level R&D by firms with a moderate number of
products than by firms at the extremes of diversification. Nonetheless, awards influenced R&D investment by firms throughout the range of diversification, while adding diversification as a control variable in the analysis did not materially change the results.

Finally, we used nonparametric multivariate kernel regression (Hardle, 1990) to examine the underlying mechanisms by which partners’ awards lead focal firms to initially increase and then eventually reduce their own R&D investment as partners’ award becomes too large (Hypothesis 2). Non-parametric estimation techniques allow the data to determine the shape of the functional form without *a priori* constraints. These techniques are useful for checking parametric models, as well as for data description. A 3-dimensional graph provides a closer view on how two explanatory variables interact with each other at different levels.

We created two measures to assess the incentive mechanisms. First, we assessed technical proximity of the focal firm and its partners. We constructed an n x n matrix on yearly patent citation for all listed firms. Each cell indicates the number of times firm i’s patents have cited firm j’s patents in the last 10 years. We used a moving window of 10 years for each patent citation matrix. We defined technical proximity by the number of cross citations between firm i and firm j divided by total citations made by all firms in the industry (excluding self-citations). The greater the cross citation ratio, the higher the technical proximity of firm i and firm j.

Second, to assess a firm’s capabilities relative to its partners, we took the ratio of partners’ awards to focal firm’s awards, cumulated over the last three years. The higher the ratio of partners’ awards, the greater is the focal firm’s loss of attractiveness relative to other firms with which the firm’s partners might form alliances.

Figures 1A and 1B illustrate how Technical Proximity (1A) and Relative Capabilities (1B) moderate a firm’s change in R&D investment. Figure 1A shows that partners’ awards have the
greatest positive impact on a firm’s R&D investment when technical proximity is high (from the lower left to the upper rear of Figure 1A). Partners’ awards have little impact on a firm's investment when the firms are far apart technically (from the lower front to the lower right of the figure), where there are few opportunities for complementarity and few fears of substitution. Figure 1B shows that when a firm is stronger or close to its partners, as measured by the low ratio of partners’ awards to the firm’s awards, the firm responds to partners’ awards by increasing R&D (from the mid rear to the upper right of the figure). By contrast, when partners have been much more successful with past products (the Ratio is high), the firm responds to partners’ awards by reducing R&D (from the upper left to the lower front of the figure).

DISCUSSION AND CONCLUSION

This study demonstrates that inter-firm alliance networks shape how uncertainty-reducing information affects firms’ incentives to undertake new R&D investment. We focus on new product awards in technically-intensive industries, which provide market signals that both reduce a focal firm’s uncertainty surrounding R&D projects and increase its attractiveness to potential partners. We first show that low-centrality firms that have less access to network information and lack the visibility to potential partners tend to increase their R&D investment after they receive awards. Awards provide opportunities for peripheral firms to improve their competitive standing in two ways: by allowing them to advance into next-generation product development, and by increasing their access to potential partners that may act either as providers of inputs or as outlets for the firm’s innovations. We next show that firms may react to partners’ awards by increasing or reducing their own R&D investment. The potential for product complementarities, the need to remain attractive as a partner, and the need to maintain pace with substitute products imply that
partners’ awards initially spur the focal firm to enhance its R&D investment. If partners win too many awards, however, the threat of losing access to partners’ resources and losing customers to partners’ products curtails the focal firm’s investment incentives. A decreasing gap in partners’ capability and close technical proximity both amplify the positive value of partners’ awards.

The results extend both the pipes and prisms views of networks. Consistent with the pipes view, peripheral firms benefit from winning awards while similar awards have less significance for firms with greater network accessibility. However, awards not only reduce winning firms’ own uncertainty and increase their access to network resources, they also signal a change in the relative attractiveness of firms within a network. When partners win awards, it signals to the focal firm that its relative competitiveness within the network has declined. The basic idea is that partners within a network differ from each other in terms of relative attractiveness, inducing the focal firm to either increase or decrease its R&D investments. This aspect of the study emphasizes the prisms effect of networks in resolving market uncertainty.

Overall, new product awards offer market signals to firms that are situated in constellations of collaborators and competitors. Peripheral firms can respond to awards by increasing their investments and attempting to move into more central positions. Firms can also attempt to grow with successful partners, especially those that share technical proximity, so long as the partners do not gain too much of a lead in the market. By contrast, less successful firms, especially those whose partners are gaining extensive success with their new products, gain less value from new investment and may have to scale back rather than waste resources. Thus, networks can accelerate both success and failure, leading to rapid growth for some firms and rapid decline for others. The paper offers insight into research that suggests that embeddedness insulates firms from some information and that ongoing ties can both facilitate and constrain a firm’s economic
actions (Uzzi, 1999). A firm that is more central may be more embedded in existing ties and so may be less responsive to a changing environment. The results contribute to a nuanced understanding of the benefits and risks of alliance networks, identifying mechanisms that shape network dynamics (Adler & Kwon, 2002).

The work suggests several extensions. One question is to understand the contingency of market signals in different network structures. Peripheral and central firms might have similar information access in closed networks, where long-term relationships involving trustworthiness and shared vision facilitate information diffusion even among peripheral firms (Coleman, 1990; Portes, 1998; Tsai & Ghoshal, 1998). By contrast, location could influence information value more strongly in more open networks, such as those in this study. Second, it would be useful to examine tie strength. Weak ties might facilitate the transfer of only general knowledge whereas transfer of specific knowledge may require strong ties (Hansen, 1999). The issue is most likely to arise for partners’ awards, in a way that is consistent with our prediction. The complementary and competitive effects that lead firms to respond aggressively to partners’ awards unless partners gain too much of a lead will arise from both strong and weak ties, but it is possible that the benefits of complementarities will be greater for strong ties. If so, this might lead to a longer period on the upward slope of the inverted-U. Nonetheless, concerns about losing attractiveness and losing product races would still arise and the inverted-U relationship would apply.

A final concern is whether new product awards have actionable meaning in managerial practice, or whether they are simply peripheral events that only correlate with firms' development activities. As a reality check, therefore, we discussed the results with executives of two leading firms. We asked whether product awards influenced their investment decisions. Both people noted that awards were noisy indicators, but that they paid attention to them. They used awards
in marketing campaigns and used award success as part of the internal business case for related product development. For both firms, awards had greater impact on allocating resources among projects than in increasing the firms’ total investments, which is consistent with our finding that centrality reduces the impact of current awards because both firms were central players in the industry. The discussions lend credence, though, to the argument that awards provide meaningful information, even for market leaders.

**ENDNOTES**

1 Competing views hold that network centrality might increase or decrease a firm’s equilibrium level of R&D investment, but our argument does not depend on equilibrium investment.

2 Change in the level of R&D is an appropriate measure of R&D investment dynamics in firm-level studies, compared to alternative measures such as change in R&D/Sales. Although firms sometimes report R&D expenditures as percentages of sales, firms typically plan their R&D budgets in terms of financial levels. Even more importantly, the R&D/Sales ratio includes two effects that product awards and centrality might influence: R&D and Sales. Just as we expect R&D to increase with awards, so one would expect sales to increase with awards. In addition, both centrality and partners’ awards might affect sales change. Moreover, while R&D is a decision variable for a firm, the firm’s sales are determined by the market. Given that the denominator and the numerator arise from different decision processes, using change in R&D/Sales as a dependent variable would mix two sets of processes. It is more appropriate to use change in R&D (or percentage change in R&D), while controlling for change in sales.
REFERENCES


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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Change in Sales</td>
<td>513.10</td>
<td>2048.66</td>
<td>0.11</td>
<td>0.15</td>
<td>0.20</td>
<td>-0.07</td>
<td>0.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Partner Awards</td>
<td>9.48</td>
<td>21.56</td>
<td>0.04</td>
<td>0.34</td>
<td>0.49</td>
<td>-0.29</td>
<td>0.29</td>
<td>0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Egodensity</td>
<td>0.01</td>
<td>0.08</td>
<td>0.06</td>
<td>0.06</td>
<td>0.15</td>
<td>-0.08</td>
<td>0.13</td>
<td>0.08</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>9. Initial R&amp;D</td>
<td>398.06</td>
<td>970.15</td>
<td>0.11</td>
<td>0.18</td>
<td>0.25</td>
<td>-0.15</td>
<td>0.28</td>
<td>0.46</td>
<td>0.29</td>
<td>0.16</td>
</tr>
</tbody>
</table>
### TABLE 2. FIXED EFFECTS REGRESSION ESTIMATES OF NETWORK AND PRODUCT AWARD INFLUENCES ON ANNUAL CHANGE IN R&D

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Networks x Awards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H1 (-): Centrality x Awards</td>
<td>-0.45 *** (0.18)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2 (+): Partner Awards</td>
<td>3.43 ***</td>
<td>-1.14</td>
<td></td>
</tr>
<tr>
<td>H2 (-): Partner Awards$^2$</td>
<td>-0.05 *** (0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network effects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrality</td>
<td>1.35 ** (0.76)</td>
<td>2.46 *** (0.87)</td>
<td></td>
</tr>
<tr>
<td>Egodensity</td>
<td>44.48</td>
<td>14.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(76.69)</td>
<td>(78.58)</td>
<td></td>
</tr>
<tr>
<td>Award effects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Awards</td>
<td>30.29 *** (9.44)</td>
<td>29.39 *** (9.42)</td>
<td>43.58 *** (9.73)</td>
</tr>
<tr>
<td>Prior Award Share</td>
<td>-178.4 ** (105.6)</td>
<td>-149.9 * (106.4)</td>
<td>-201.9 ** (106.3)</td>
</tr>
<tr>
<td>Other effects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial R&amp;D</td>
<td>-0.17 *** (0.03)</td>
<td>-0.18 *** (0.03)</td>
<td>-0.19 *** (0.03)</td>
</tr>
<tr>
<td>Relative Stock Performance</td>
<td>0.31 (0.25)</td>
<td>0.27 (0.25)</td>
<td>0.18 (0.25)</td>
</tr>
<tr>
<td>Change in Sales</td>
<td>0.004 (.006)</td>
<td>0.004 (.005)</td>
<td>0.0006 (.004)</td>
</tr>
<tr>
<td>Constant</td>
<td>89.38 *** (17.32)</td>
<td>92.39 *** (17.39)</td>
<td>89.36 *** (17.52)</td>
</tr>
<tr>
<td>R-square</td>
<td>0.06</td>
<td>0.09</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Positive coefficient = greater increase in R&D; s.e. in parentheses; 900 cases

* $p < .10$
** $p < .05$
*** $p < .01$ (one-tailed tests)
FIGURE 1A
Moderating Effects of Technical Proximity between Focal Firm and Partners
(Multivariate Kernel Regression Using Nadaraya-Watson estimator)

FIGURE 1B
Moderating Effects of Relative Capabilities
(Multivariate Kernel Regression Using Nadaraya-Watson estimator)
About Authors

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