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Supply Network Structure and Firm Performance: Evidence From the Electronics Industry

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***Abstract*—Although research in the supply chain area inherently involves the study of supply networks, the majority of existing work is limited to utilizing a dyadic approach in examining relationships between buyer and supplier firms. However, real-world supply networks are characterized by a complex network of interfirm relationships and not just dyads. Thus, it is important to examine how structural relationships among supply chain partners impact the performance of firms using a network analytic lens. This paper examines the influence of structural characteristics of a firm's supply network on its performance. Using a dataset of 114 firms consisting of firm-level variables drawn from multiple sources in the electronics industry, we investigate two important structural characteristics of the supply network—structural prominence, depicting the centrality of a firm's position in the supply network, and density, characterizing the interconnectedness among firms in a supply network. Using a robust regression approach, we find that both the structural prominence of firms and the density of the supply networks, along with the interaction between them, positively influence the performance of firms as measured by the firm's asset utilization, cost performance, and operational efficiency. We discuss both theoretical and practical implications of our findings, and relate the results to managerial significance.**

***Index Terms*—Electronics industry, firm performance, social capital theory, structural characteristics, supply networks.**

I. Introduction

Studies have highlighted that effective execution of supply chains in getting products and services to customers in a timely and economical manner is a primary vehicle for firms to create value for their customers [1], [2]. However, effective execution of the supply chain involves managing the myriad of relationships among the various organizational entities typically involved in a firm's supply chain, including suppliers, customers, manufacturers, distributors, wholesalers, service providers, and business partners. The effectiveness of this execution of interrelated supply chain activities may impact the performance of the focal firm [3]. One of the rather significant paradigm shifts in the contemporary business environment is that the success of firms depends not just on a firm's internal capabilities, but also on the firm's ability to effectively manage its relationships with its supply chain partners [4]. These relationships are becoming particularly important as the competitive marketplace gets more complex, dynamic, and unpredictable [5].

The collective set of connections among all organizations involved in the supply chain of a firm constitutes the supply network of a focal firm. The structure (or structural characteristics) of the supply network describes the topological nature of the network, including types and patterns of interfirm relationships, the strength and nature of these relationships, the different tiers of relationships resulting from the tiered supply and delivery processes, and the power, leadership, and influence in the supply network derived from these relationships [6].

An increasing number of firms across multiple industries design, develop, and deliver products and services through large and complex interfirm networks [7]. Recent studies have shown that interfirm networks can provide a source of competitive advantage, as they allow firms to distribute risks, access new markets, and respond to changes more effectively [8]. More importantly, developing high-quality relationships with a firm's supply chain partners—that come from building alliances, strategic partnerships, and collaborations—are instrumental in fostering interorganizational learning, knowledge creation, and development of collaborative capabilities for effective execution of the supply chain [9]–[13].

Our study examines the following research question: What is the association between supply network structure, i.e., the structural characteristics of the supply network, and performance of firms? We invoke social capital theory as the underlying foundation to study this question. This theory posits that significant organizational and competitive advantage can be achieved by firms from the accrued resources and knowledge assets derived from the relationships with its supply network partners. Specifically, we focus on two structural characteristics of a focal firm in a supply network—structural prominence and supply network density—and their association with performance. Structural prominence reflects the ability of a focal firm to manage, coordinate, and integrate the supply chain activities of its supply network members and, thus, possibly influence their behavior in adopting productive practices in its supply network [14], [15]. Density, on the other hand, is the degree to which a firm's supply network partners are interconnected with each other [16]. To test our hypotheses, we collect data from multiple secondary sources on 114 firms in the electronics industry. The results suggest that these structural characteristics indeed positively influence a focal firm's performance. Drawing from the Com-

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pustat database, we estimate performance using three alternate measures: return on assets (ROA), inventory/sales (I/S), and cost of goods sold (COGS)/Sales. These measures for performance help capture firm efficiency in overall asset utilization and inventory utilization through ROA and I/S, respectively, and cost benefits through COGS/Sales.

This study attempts to advance our understanding of supply networks, in general, and the relationship between structural characteristics of the supply network and firm performance, in particular. Our contributions are multifold. First, using social capital theory as the underlying foundation to study this issue, we affirm that organizational and competitive advantage can be accrued from the relationships with its supply network partners. Second, although supply networks have been examined in the literature, the majority of work is limited to dyadic or even triadic approaches to examine buyer–supplier relationships or supplier–supplier relationships (e.g., focal firm with multiple suppliers) [17]–[19]. However, there is a dearth of empirical studies that have examined a more holistic supply network structure of a focal firm and its association with firm performance [20]. This paucity may be because curation of a comprehensive set of relational data on supply chains is highly resource intensive. There are very few publicly available data sources (which often only contain a subset of relevant information), and many organizations are generally reluctant to divulge potentially sensitive supply network information for obvious competitive reasons. A notable exception is the recent work by Kim *et al.* [21], who examined the structural configuration of supply chains for three automotive companies. However, a large-scale empirical study using secondary data is lacking in the supply chain domain. Third, a network-centric perspective to the study of supply chain structure and performance requires a translation and interpretation of network metrics to appropriate supply chain characteristics, which is often dependent on the context or research question [6]. This paper extends prior attempts by contextualizing two novel graph-theoretic measures in a supply chain context.

From a managerial perspective, our study provides important insights into the effective design and management of supply networks in an increasingly complex global environment. If not appropriately managed, these supply networks can generate significant risks that can cascade and lead to undesirable operational outcomes [22], [23]. In the personal computing industry, for instance, device manufacturers are outsourcing production and in some cases even product development to global multitier networks of contract manufacturers and original design manufacturers [24]. Subtier performance issues can have an operational impact on other firms in the supply network, including quality, inventory, and response to fluctuating market demands. Ericsson suffered losses in excess of $2 billion when a sole lower-tier component supplier experienced significant operational issues that impacted its mobile phone production [25]. On the other hand, properly designed and managed supply networks can be associated with significant improvements in firm performance. In the apparel industry, Benetton leverages its vast network of manufacturers and distributors to lower manufacturing and labor costs and significantly improve its ability to respond to market changes in real time [26].

The remainder of this paper is organized as follows. Section II provides the theoretical development of the research questions and the hypotheses. Section III describes the data collection, variables, and measures and presents statistical methods employed to test the hypotheses. We present results in Section IV, while Section V provides a discussion of the results, theoretical and managerial implications, limitations of the study, as well as future research directions. This paper concludes with Section VI.

II. Theoretical Development and Hypotheses

A. *Social Capital Perspective of Supply Networks*

The conventional view of buyer–supplier relationships has focused primarily on linear or dyadic structures, rather than incorporating a holistic network view [21]. While the dyadic perspective has been useful in capturing the benefits of relationships between two parties, it fails to comprehensively capture a supply chain's dynamic, complex, and increasingly interdependent nature. In contrast, a network approach provides a richer view of the relationships by considering the different relational complexities among the firms in the supply network, rather than the depiction of simple, linear, and unidirectional models often presented for supply chains [6], [13], [27]. Besides the obvious benefit of representing a supply network as exactly that, a network, more importantly, a network representation incorporates the dynamics epitomized in the relationships that exist among the organizations that are members of a firm's supply network.

A social network consists of individuals or firms (generally referred to and depicted as "nodes"), which are tied (connected and depicted as "edges") by one or more specific types of interdependence, such as friendship, common interest, membership, association, financial exchange, strategic alliance, collaboration, marketing agreement, or any other type of relationship [28]. In the supply network context, the "social" aspect refers to the interconnected network of suppliers, manufacturers, service providers, and customers that engage in activities related to the procurement, use, and transformation of raw materials in order to produce and deliver goods and services [29], [30]. The two fundamental types of relationships in a supply network can be characterized as supply or alliance based [14]. Supply-based relationships in a supply network are generally transactional in nature and pertain to buyer–supplier contracts, whereby the supplier firms provide some goods and/or services to the buying firms [31]. In contrast, alliance-based relationships in a supply network may or may not involve any material flow between the firms, but the relationships are more collaborative or sharing in nature, resulting in mutual benefits related to joint interfirm activities dealing with collaborative product development, technology sharing, joint promotion, and marketing efforts [29].

Some significant benefits of adopting a social network view of a supply network are rooted in the key tenets of social capital theory. This theory, commonly found in social and organizational research, asserts that organizational advantage can be achieved by the accrued resources and assets derived from a network of relationships by individuals or organizations [32]. In other words, a core principle of this theory is that firms are embedded in a larger network of relationships, comprising other firms that are able to provide access to unique resources, information, and influence [33]. This social capital helps firms facilitate the knowledge creation process by influencing the conditions necessary for exchange and combination of this knowledge to occur and, thus, compete better [32].

Among the fundamental dimensions of social capital are the relational and structural dimensions [34]. The relational dimension asserts that social capital is created and maintained by cultivating, managing, and fostering high-quality relationships among business partners in a network, which beneficially impacts the firm's performance, and thereby its competitiveness [35]. In a supply network, developing high-quality relationships may come from building alliances, partnerships, collaborations, shared values, and/or common goals among firms in the network. On the other hand, the structural dimension of social capital contends that the assets emanating from access to knowledge, resources, and information available from the configuration of the network can help to explain the value embedded in a firm's supply chain [36]–[38]. The structural characteristics of a supply network comprise the overall pattern of ties between partnering firms. The network structure derived from the pattern of ties determines, in part, opportunities and constraints to access valuable resources and information that may not be as accessible to competing firms [39]. Several studies have underlined the benefits of social capital as derived from the characteristics of a firm's position in the network (e.g., [40]–[42]).

There are several underlying tenets that suggest why a network representation of a firm's supply network is particularly critical in explaining a firm's performance advantage and thereby its competitive benefits. Based on [43], four critical theoretical precepts of a network approach are the following.

1) Networks as resource access, whereby networks are considered important sources of resources and capabilities. These resources and capabilities can in fact also originate from the structure of the network itself, i.e., from the characteristics of the interorganizational relationships [42], [44], [45].
2) Networks as a source of power, influence, and control, whereby networks can increase or constrain the locus of power in interorganizational relationships. For example, based on resource dependence, the power of partners over a focal firm increases with a focal firm's increasing dependence on the resources of partners [46], [47].
3) Networks as a source of trust, in which network relationships can also influence the level of trust [48], [49]. For example, the extent to which firms are closely connected to each other in an interorganizational network leads to higher overall trust. Higher trust is often associated with lower transaction costs and, thus, better operational performance.
4) Networks as signaling mechanisms, where networks also function as signals, i.e., the quality and reputation of a firm can be inferred from its interorganizational relationships (relational structure). In this case, their status can be inferred from their relationships with higher status organizations [50].

In the following subsections, we conceptually link the structural supply network characteristics of a focal firm—structural prominence, density, and the interaction between these—with its performance.

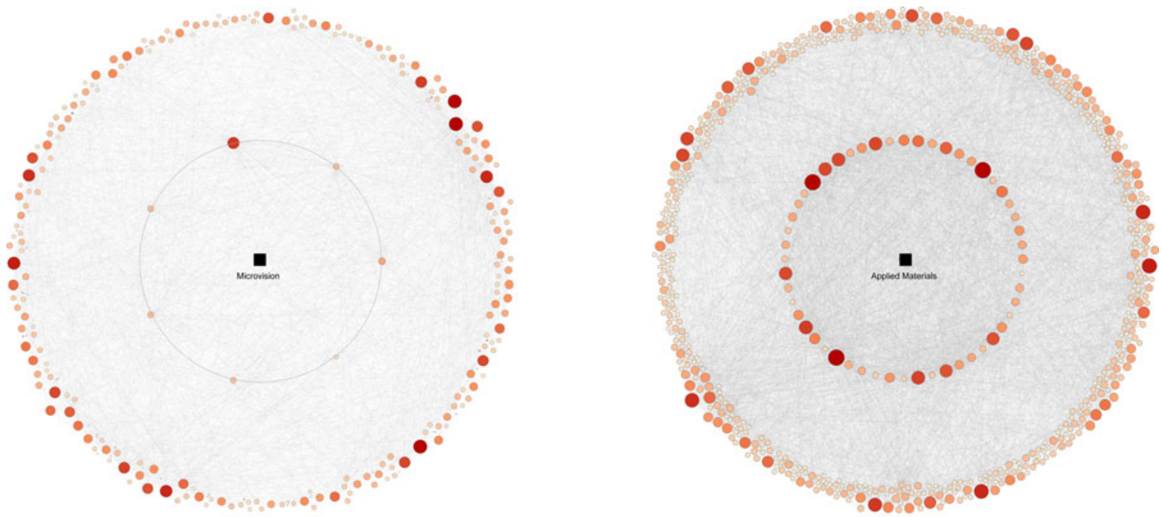
B. *Structural Prominence in Supply Networks*

Since supply networks are considered as systems comprised of a connected set of interfirm relationships [13], [51], [52], one of the structural dimensions of social capital theory arising from a firms supply network is the firm's structural prominence in the network [52], [53]. A firm has higher structural prominence when it occupies a more central position in its supply network, i.e., a focal firm is more central when it is directly connected to firms (i.e., to suppliers and customers), who are in turn also highly connected to other firms in the network. Thus, a structurally prominent firm occupies a distinctive position in the network, which leads to high visibility or importance relative to others, and provides the firm with higher power and influence in the supply network. Thus, a firm's structural prominence in its supply network emphasizes the role that the firm can play in leading or influencing the network by virtue of its relationships and position in its supply network structure. It also provides a firm with the ability to access other prominent firms in the network [15] and, thus, enables it to influence and orchestrate the supply chain practices in the network in order to lower costs and inventory or improve margins [54]. From the social capital perspective, structurally prominent firms drive the social capital that helps facilitate the process by influencing the conditions and practices necessary for the knowledge creation to occur and, thus, be able to drive better operational practices leading to better firm performance.

The higher levels of influence and power derived from a firm's structural prominence enable the firm to impel its supply chain partners to implement processes or practices that may be beneficial for them in terms of reducing costs or enhancing profitability. Some examples of contemporary operational practices that are considered to lower operating cost and inventory levels and thus improve firm performance are, for example, joint business planning, vendor/supplier managed inventory, collaborative planning, forecasting, and replenishment, and cross docking. These practices require developing a relational and partnership-based approach with supply network partners.

Fig. 1 graphically illustrates the concept of structural prominence with the comparison of a two-tier supply network structure (i.e., inclusion of all firms two steps (connections) removed from the focal firm) of two companies in the electronics industry.[1] The structural prominence of Applied Materials is high as it is connected to a set of supply chain partners, many of whom are highly connected. In contrast, Microvision is

[1]The network visualizations in Figs. 1 and 2 were created using Gephi, an open-source software for visualizing and analyzing large networks. Following [5] and [55], firms were positioned using a concentric layout algorithm. The focal firm is placed at the center, while firms n steps away from the focal firm are placed on the nth circle. Node size and color intensity in Figs. 1 and 2 are proportional to the firm's structural prominence and density, respectively.



(a) Low structural prominence

(b) High structural prominence

Fig. 1. Comparing different structural prominences in the supply network. The figures depict the two-tier supply network structure of (a) Microvision and (b) Applied Materials using a concentric layout algorithm and no node overlap [5]. Microvision and Applied Materials are the focal firms and are placed at the center of the visualization. Tier-1 and Tier-2 supply network partners of the two focal firms are placed on the first and second circles, respectively. The size and color intensity of the nodes correspond to the structural prominence of the firm.

connected to supply chain partners that themselves are sparsely connected.

Both research and practice suggests that the arc of a firm's structural prominence and influence over its suppliers and other trading partners in its supply network can influence its performance (e.g., [14], [56]–[58]). High structural prominence, thus, has the potential of playing a significant role in driving social capital in supply network relationships by allowing firms to influence and shape practices within the supply network in order to improve performance and create better competitive advantage. Thus, we posit as follows.

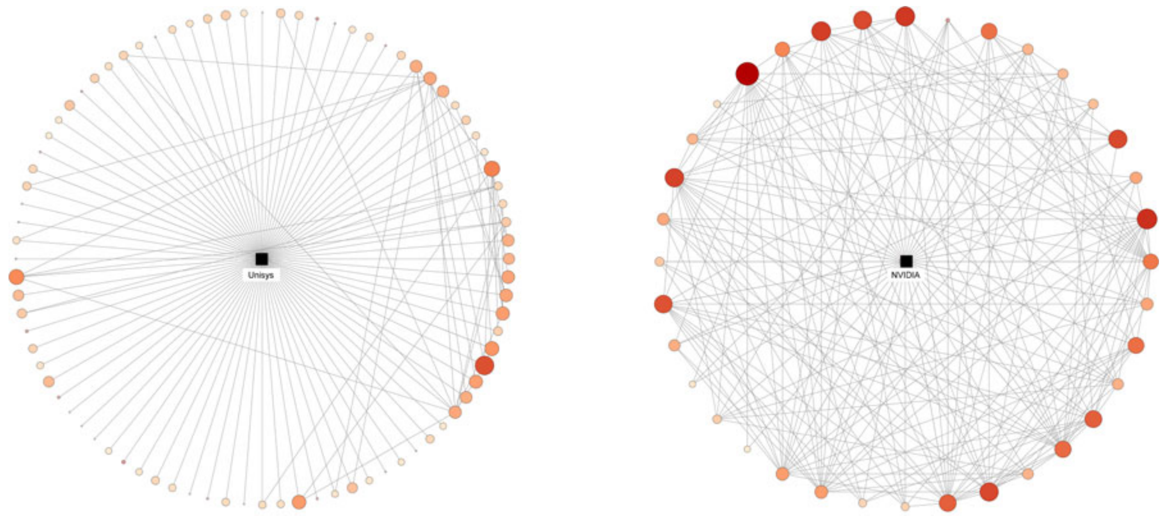
Hypothesis 1: Higher levels of centrality increase a firm's structural prominence in its supply network and beneficially impact its performance.

C. Density in Supply Networks

While structural prominence drives the structural dimension of social capital in a supply network based on its configurational attributes (centrality), the nature of the interconnectedness and relationships among the member firms in the network drives the relational dimension of social capital. Density in a supply network reflects the level of interconnectedness among members of the network and, thus, indicates the potential for collaboration among members in a focal firm's supply network [13]. Thus, density in a supply network emphasizes how social capital is built from the relationships among the member firms in the supply network by enhancing the flow of information and knowledge among the network members. This facilitates the implementation of productive practices within the network and, thus, beneficially influences the performance of the focal firm by reducing cost and inventory levels. Higher density not only enhances sharing, but also enhances network reliability, whereby the failure of a network member may not significantly impact the performance of the focal firm due to the learning and knowledge transfers created from the sharing due to higher interconnectedness among the network members. Thus, while structural prominence provides a firm with the power and influence to drive the appropriate standards and practices to improve performance, density, via higher levels of interconnectedness in the network, further increases the spillover effects by ensuring that these practices and standards are widely adopted by its partners in the supply network. It is important to note that high density also helps to create a common language or platform in the network promoting supply network partners to work with each other toward achieving common/shared business goals, resulting in lowering costs and driving higher firm performance. Therefore, density in a supply network facilitates better strategic alignment among the supply chain partners, which in turn allows the leveraging and creation of higher mutual values, thus leading to better cost position, inventory levels, and margins (firm performance).

As an interesting anecdotal example of this practice, Toyota Motor Corporation drives learning and effective transfer of knowledge within its supply network through the establishment of three organizational processes: supplier associations, consulting groups, and learning teams [59]. Supplier associations drive and promote sharing of information, including Toyota's policies and widely accepted best practices. Its consulting groups provide intensive on-site assistance to suppliers and conduct workshops and seminars. Learning teams facilitate on-site sharing of know-how within small groups of suppliers. Thus, by creating a supply network with high density, Toyota has been able to drive considerable learning, knowledge and information sharing/transfer, and creation of shared business goals that has the potential of benefiting the network partners.

Fig. 2 graphically illustrates the concept of density in the supply network with a comparison of the one-step supply network



(a) Low density (b) High density

Fig. 2. Comparing different densities in the supply network. The figures depict the direct supply network structure of (a) Unisys and (b) NVIDIA using a concentric layout algorithm and no node overlap [5]. Unisys and NVIDIA are the focal firms and are placed at the center of the visualization. Direct supply network partners are placed in a circle around the focal firm. The size and color intensity of the nodes correspond to the level of density of the firm.

structures of two companies in the electronics industry. Clearly, the degree of density within the supply network is much higher for NVIDIA compared to Unisys.

It is expected that the association between density and firm performance will be much more pronounced in high-velocity industries such as the electronics industry [60]. These industries are considered fast "clockspeed" industries and are characterized by high rate of changes in technology and market conditions [61]. Thus, short product life cycles and high-level new product development (NPD) are prevalent in such industries. Another example of high-velocity industry is the semiconductor industry that supplies, among others, to the consumer electronics industry. This enhanced responsiveness enables the focal firm in a high-velocity industry to gain advantages of density in its supply network in order to improve its firm performance. Thus, we posit as follows.

Hypothesis 2: Higher levels of density in a firm's supply network increase network partner interconnectedness and beneficially impact its performance.

D. Structural Embeddedness in Supply Networks

Structural prominence is important for a firm to be able to drive the structural dimension of social capital in the supply network due to a focal firm's ability to influence its supply chain partners to adopt the required practices, and density drives the relational dimension of social capital by providing the firm with the ability to promote the required knowledge and information exchange that may be necessary to influence adoption of the practices among the network partners. While both structural prominence and density are individually important to drive the adoption of appropriate supply chain practices that beneficially impact firm performance and thus help to drive social capital, the interaction between them can further influence performance. We argue that the interaction effect of structural prominence and density provides a focal firm with the opportunity to drive higher firm performance. We characterize this interaction effect between the two as structural embeddedness. We posit that structural embeddedness provides an effective combinative influence of the structural and relational dimensions of social capital via the interactive effect of structural prominence of a firm and the density of its supply network, and thus captures a more synergistic and comprehensive characterization of the impact of social capital of the firm on its performance. While structural prominence provides a firm with the power and influence to drive the appropriate standards and practices to improve performance, density further increases the spillover effects and ensures that these practices and standards are widely adopted by its partners in the supply network. This helps to create embedded social capital in the network.

Despite the extant literature in this area, there is no commonly accepted definition of embeddedness—it is a discipline-specific terminology related to relational, structural, temporal, and institutional contexts within a network [62]. Generally, researchers have proposed four broad categories of embeddedness: cultural, political, cognitive, and structural [63]. Citing [63], Grewal *et al.* [64] define structural embeddedness as the "contextualization of economic exchange in the pattern of ongoing interpersonal relations." Structural embeddedness thus captures the configurational/structural as well as the relational characteristics of the architecture of the underlying interfirm supply network. Thus, we posit as follows.

Hypothesis 3: Higher interaction effects between a firm's structural prominence and density of its supply network beneficially impact its performance.

III. Methodology

A. Data Sources

As shown in Fig. 3, we created an integrated dataset using both public and proprietary data sources. In particular, for

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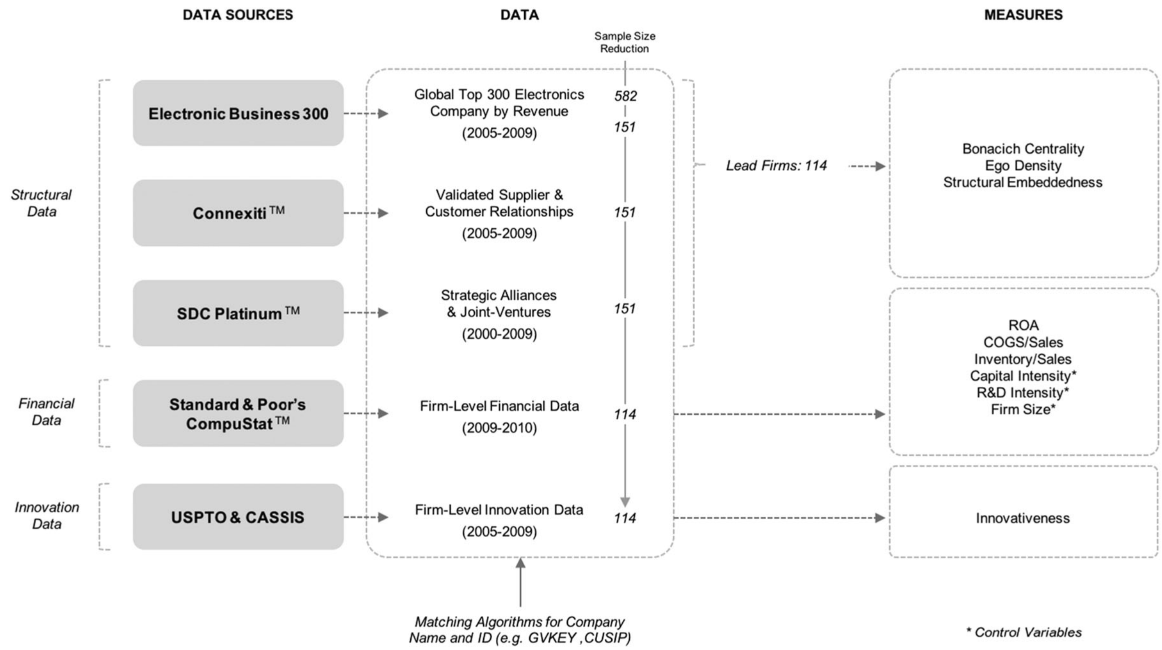

Fig. 3. Data sources and measures.

the creation of the supply network, we drew on three well-established sources: Electronics Business (EB) 300, Connexiti, and Thomson-Reuters SDC Platinum Database. Our initial dataset was seeded using all unique firms listed in the EB300 from 2005 to 2009. The EB300 is an annual global ranking of the top 300 electronics firms ranked by their respective revenues provided by Electronics Design, Strategy, and News. Revenue information is derived from market segmentation information, and Reed Research estimates and includes revenue from the sale, service, license, or rental of electronics/computer equipment, software, or components. The EB300 is a well-established data source and has been used in previous studies (e.g., [65]). Our initial dataset resulted in 582 unique firms spanning 2005–2009. However, since the focus of our study is on lead companies, contract and original design manufacturers, and component suppliers in the electronic industry, we limited company inclusion to these business avenues. This focus reduced the EB300 dataset to 151 core electronics industry companies.

Next, we employed a comprehensive commercial business relationships database called Connexiti to obtain data on the supplier and customer relationship for these 151 firms. Connexiti contains over 150 000+ verified supplier and customer relationships of over 10 000 global companies (public, private, domestic, and foreign).[2] Data are retrieved from SEC filings, company press releases, website updates, analyst reports, and earning transcripts. It is extracted and mined using both computer and human intelligence, thus ensuring relevancy, accuracy, and comprehensiveness. The Connexiti database captures information on suppliers, customers, competitors, and partners. The database has been extensively used by risk management companies, consultancy companies, and as well as in several previous studies (e.g., [16], [66], [67]). Since our initial data from EB300 identified firms from 2005 to 2009, we limited our inclusion to all active supplier and customer relationships for the same period. We identified 449 Tier-1 and Tier-2 suppliers for the 151 firms. We also examined if these 600 firms had any alliances among themselves by extracting information from the Thomson-Reuters Financial SDC Platinum alliances and joint-venture database. This database contains comprehensive information on various types of strategic alliance agreements, including manufacturing, research and development, supply, marketing, and licensing relationships. The database has been shown to be a comprehensive and appropriate data source for the study of interfirm relationships [68] and is commonly used in strategic management (e.g., [69]), finance (e.g., [70]), and entrepreneurship (e.g., [71]). We included all completed alliances and excluded terminated or pending ones between the 600 firms. For creating measures for the 151 firms on performance and pertinent control variables, we used information from Standard & Poor's Compustat. We also controlled for firm innovativeness for which data were drawn from U.S. Patent and Trademark Office and CASSIS Patents Database. Since some firms were either privately held or had missing information our sample reduced to 114 firms that spanned relevant three-digit North American Industry Classification System (NAICS).

B. Data Management

One of the challenges we faced during the data collection process was the proper matching of companies across multiple databases. Each database utilizes a different unique company identifier (e.g., CUSIP, GVKEY, stock ticker symbols, etc.). To overcome this challenge, we developed custom matching algorithms to ensure that we mapped the right company names to the appropriate corresponding identifiers in the other databases. All company and interfirm relationship information was captured and organized in a relational database for easy management and retrieval. Custom scripts were developed to

[2]Since our last data extraction Connexiti was acquired by Bloomberg L.P. and incorporated into their SPLC function.

autogenerate the source code for use in the UCINET network analysis program.

C. Variables and Measures

The dependent, independent, and control variables used in this study are explained as follows.

1) Independent Variables: The concept of structural prominence and density are measured and operationalized as follows.

a) Structural prominence: A firm has a more central structural prominence if, through its relationships with other firms, it is prominent or visible to others in the network [72]. There are various network centrality measures, each appropriate under different circumstances [28], [73]. We measure the structural prominence of a focal firm in the supply network using Bonacich centrality, an extension of eigenvector centrality [74]. The use of the Bonacich centrality measure for structural prominence is consistent with prior studies, which have used it to determine the position of a firm (node) in a network [62], [75]–[77]. Bonacich centrality asserts that the power of any node in a network is recursively defined by the power of its direct as well as indirect connected nodes. The nature of the recursion involved is controlled by an attenuation factor, commonly known as the beta coefficient β_{BC}, where the subscript BC denotes Bonacich centrality. It should be noted that we utilize the notation β_{BC} to differentiate this parameter from the regression betas used in our subsequent analyses. β_{BC} can take on positive and negative values to indicate positive and negative ties, respectively. Positive β_{BC} values imply that firms become more powerful as the centrality of their neighbors, neighbors' neighbors, and so on increases, while negative β_{BC} values imply that firms become more powerful only as the centrality of their neighbors, neighbors' neighbors, and so on decreases [74]. In a supply network context, positive β_{BC} values, thus, suggest that a focal firm gets more powerful, the more central its suppliers and customers are. Similarly, negative β_{BC} values suggest that a firm becomes more powerful, the less central its connected firms are [6], [74]. In instances when β_{BC} is zero, a firm's centrality increases with the number and magnitude of direct relations. The absolute magnitude of β_{BC} indicates the tendency of the effect of power and influence decay, with higher magnitudes of β_{BC} implying slower decay [74]. In the supply chain context, a small β_{BC} value infers that power decays quickly and thus emphasizes local or close connections to low-tier suppliers. Large β_{BC} values suggest that power decays slower and thus emphasizes global or connections to lower tier suppliers. The Bonacich centrality measure $\mathrm{BC}_i(\alpha, \beta_{\mathrm{BC}})$ is computed as

$$\mathrm{BC}_i(\alpha, \beta_{\mathrm{BC}}) = \sum_j (\alpha + \beta_{\mathrm{BC}}\mathrm{BC}_j) R_{ij}$$

where α is a scaling vector set to normalize the score, R is an adjacency matrix of supply network firm relations, i is the focal firm, j is the focal firm's directly connected supplier, and β_{BC} is the radius of structural prominence. Consistent with prior studies, we compute β_{BC} at fractional levels of the inverse of the absolute value of the largest eigenvalue [76].

b) Density: We measure supply network density by a focal firm's ego (network) density. According to social network theory, an ego network consists of a focal node (ego), the nodes to which ego is directly connected (alters), and connections, if any, among alters [28]. In this study, a firm's supply base network thus represents its ego network. Ego network density thus captures the extent of ties within a focal firm's supply base network and is measured as the number of actual ties divided by the total number of potential ties among partners. This measure is well established and has been used in several previous studies [42], [43], [78]–[80].

More formally, consider a supply network SN that consists of a set of firms F and a set of relationships (e.g., connections) R between them (e.g., $\mathrm{SN} = (F, R)$). A relationship r_{ij} connects firm i with firm j. Relationships represent connections between firms and can include supplier/customer relation, strategic alliances (e.g., research and development (R&D), manufacturing, marketing) or licensing relationships. The neighborhood N_i for a focal firm f_i is defined as its immediately connected neighbors as follows: $N_i = \{f_i : r_{ij} \in R \wedge r_{ij} \in R\}$. The neighborhood in the supply network context can be considered the supply (and customer) base of a focal firm. We further define k_i as the number of firms $|N_i|$ in the supply base of a focal firm. The ego network density ED_i for a focal firm f_i is then given by the proportion of connections within its supply base divided by the total number of potential connections among them.

Since supply network relationships are bidirectional connections, where information, knowledge, and other resources may flow from a supplier to a customer and vice versa, we assume supply networks to be undirected networks. In an undirected network, r_{ij} and r_{ji} are considered identical. Therefore, if a focal firm f_i has k_i neighbors, $k_i(k_i - 1)/2$ connections could exist among the firms within the neighborhood. Thus, the ego network density for our supply network can be defined as $\mathrm{ED}_i = \frac{2|\{r_{jk}\||}{k_i(k_i-1)} : f_j, f_k \in N_i, r_{jk} \in R$. The ego network density is 1 if every firm in the supply base is interconnected. When none of the firms in the supply-based network are interconnected, ego network density is simply the ratio of direct connections of focal firm f_i (i.e., $\deg(f_i)$) over all possible connections. As $\{r_{jk}\}$ approaches $k_i(k_i - 1)/2$, the more collaborative the supply base; as $\{r_{jk}\}$ approaches $\deg(f_i)$, the less collaborative the supply base. In a supply context, the latter case implies that the focal firm handles all the interactions and information flows. The former case suggests that suppliers interact greatly and exchange information freely, which can possibly lead to faster reaction and execution times to changes in design requirements. Ego network density can consequently be interpreted (or defined) as the level of interconnectedness in the supply base. We specified the interaction effect of a firm's structural prominence and its supply network density as follows:

$$\mathrm{EMB}_i = \mathrm{BC}_i \times \mathrm{ED}_i.$$

2) Dependent Variables: We collected data from the Compustat database to employ three alternate measures to estimate the dependent-variable firm performance: ROA, I/S, and COGS/Sales. ROA captures firm's efficiency as a measure of asset utilization and is estimated as the net income before extraordinary items divided by average total assets. In other words,

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ROA depicts the earnings of a firm in relation to its overall resource utilization [81]. Hence, we expect that a firm exhibiting a more central structural prominence and higher supply network density should generate a higher ROA.

We employed I/S as a second measure of firm performance, which depicts a firm's operational efficiency. As hypothesized, we expect a focal firm with a more central structural prominence and higher supply network density to portray higher efficiency in its inventory utilization. Thus, for the same level of sales, a firm with high structural network properties should have a lower I/S. The third measure COGS/Sales indicates whether firms with high structural network properties accrue a cost advantage. Lower COGS/Sales will depict higher gross margin and thus higher manufacturing productivity [82]. To assess the association of the independent variables with future performance, these measures for firm performance are estimated for the year 2010. In other words, the independent variables measuring structural characteristics are lagged one year.

3) Control Variables: We employed several control variables to isolate the association between structural characteristics of the supply network and firm performance. Specifically, we controlled for firm innovativeness, capital intensity, R&D intensity, firm size, and industry affiliation. High levels of innovativeness may enhance firm performance [16]. Patents granted have been used to reflect a firm's innovativeness [83]. We measured firm innovativeness as a four-year average of granted patents. We also controlled for capital intensity, which has been shown to be associated with firm performance [84]. We measured capital intensity as a four-year average of annual plant, property, and equipment expenses divided by annual sales. This ratio denotes the physical assets required per unit of sales. Past research suggests that R&D intensity is not only prevalent in innovative industries such as the electronics industry, but it can also influence performance [85], [86]. R&D intensity is measured as annual R&D expenses divided by annual sales. We also controlled for firm size measured as log of annual sales. The measures for firm innovativeness, capital intensity, R&D intensity, and firm size were also lagged one year. Finally, we also controlled for industry effects by incorporating the three-digit NAICS code for each firm.

D. Methods

Table I shows the means, standard deviations, and correlations for the variables. The mean ROA of the sample firms is 7%, COGS/Sales is 58%, and I/S is 12%. Furthermore, the means of capital intensity and R&D intensity are at 6% and 10%, respectively. The mean value of the independent variables Bonacich centrality and ego network density is 24.49 and 26.60, respectively.

We used robust regression to test the hypotheses. The general specification is

$$\text{Performance}_i = \beta_0 + \beta_1 \times \text{BC}_i + \beta_2 \times \text{ED}_i + \beta_3 \times \text{EMB}_i + \beta_4 \times \text{FirmInnovativeness}_i + \beta_5 \times \text{CapitalIntensity}_i + \beta_6 \times \text{R\&D Intensity}_i + \beta_7 \times \text{Size}_i + \beta_8 \times \text{Industry}_i + \varepsilon_i.$$

Performance_i is the dependent variable measured by ROA, COGS/Sales, and I/S for firm i; BC_i measures the structural prominence of a firm as measured by Bonacich centrality for firm i; ED_i measures the density as measured by the ego network density for firm i; EMB_i is measured as the interaction between Bonacich centrality and ego network density for firm i; $\text{CapitalIntensity}_i$, $\text{R\&D Intensity}_i$, and Size_i are the control variables for firm i, respectively; Industry_i is the categorical variable that captured the three-digit NAICS code for firm i; and ε_i is the residual error. Since we are testing interaction effects among continuous variables, we mean centered the measures for Bonacich centrality and ego network density, as suggested by Aiken *et al.* [87] to reduce any possible multicollinearity issues. To test for multicollinearity among independent variables, we checked the bivariate correlations in Table I and found that the variables did not demonstrate high correlations among them. Finally, we also estimated variance inflation factors (VIF). The maximum VIF value obtained was 1.55, which is well below the rule-of-thumb threshold value of 10 indicative of collinearity problems [88].

To ensure that error terms in the models are normally distributed, we ran the Kolmogorov–Smirnov test. We could not reject the null hypothesis that there is no difference between the cumulative distribution of the error terms against the theoretical normal distribution ($p < 0.38$), confirming the normality of the data. Finally, the presence of heteroscedasticity in residual errors violates a critical assumption of homoscedasticity. To confirm that the variance of residual error is constant for all values of an independent variable, we ran both the Whites and Breusch–Pagan tests. Based on both tests, we could not reject the null hypothesis of no heteroscedasticity for all the three measures of firm performance.

IV. Results

Table II reports the results from the robust regression. Models 1.1–1.3 show the results employing ROA as the dependent variable. Models 2.1–2.3 and 3.1–3.3 depict the results employing COGS/Sales and I/S as the dependent variables, respectively. Models 1.1, 2.1, and 3.1 included only the control variables.

Models 1.2, 2.2, and 3.2 include Bonacich centrality and ego network density as independent variables. Using ROA as the dependent variable, we found support for Hypothesis 1 in model 1.2 with the coefficient of Bonacich centrality being positive and significant ($\beta = 0.001; p < 0.001$). In other words, higher levels of centrality positively influences ROA. We also found support for Hypothesis 1 using COGS/Sales and I/S as dependent variables. In model 2.2, the main effect of Bonacich centrality on COGS/Sales is negative and significant. In other words, as the focal firms display higher levels of centrality, they can expect to reduce their COGS/Sales. Similarly, in model 3.2, consistent with Hypothesis 1, we found a significant and negative association between Bonacich centrality and I/S ($\beta = -0.81$, $p < 0.01$).

Hypothesis 2 posited that firms with a high ego network density would have higher performance that is higher ROA and lower COGS/Sales and I/S. Employing ROA as the dependent variable, we found support for this hypothesis in model 1.2 ($\beta = 0.010$, $p < 0.01$). Model 2.2 confirms that the association

TABLE I
DESCRIPTIVE STATISTICS AND CORRELATIONS[a,b]

	Variable	Mean	SD	1	2	3	4	5	6	7	8	9
1	ROA[c]	0.07	0.09	1.00								
2	COGS/Sales[c]	0.58	0.34	−0.29	1.00							
3	Inv/Sales[c]	0.12	0.11	−0.13	0.16	1.00						
4	Firm Innovativeness[c]	39.36	144.36	0.24	−0.14	−0.08	1.00					
5	Sales (Ln)[d]	8.71	1.97	0.28	0.06	−0.33	0.48	1.00				
6	Capital Intensity[c]	0.06	0.12	−0.11	−0.10	0.09	0.24	0.07	1.00			
7	R&D Intensity[c]	0.10	0.11	−0.13	0.24	0.14	0.05	0.18	0.09	1.00		
8	Bonacich Centrality	24.49	21.45	0.10	−0.08	−0.07	−0.04	0.22	0.02	0.09	1.00	
9	Ego Network Density	26.60	15.16	0.10	−0.16	−0.12	−0.18	0.13	−0.05	0.09	0.10	1.00

[a] $n = 114$ observations
[b] All correlations with an absolute value greater than 0.07 are significant at the 0.05 level.
[c] Variables are estimated as average of four years.
[d] Sales is log transformed.

TABLE II
RESULTS FROM ROBUST REGRESSION PROCEDURE FOR PERFORMANCE[a]

	ROA			COGS/Sales			Inv/Sales		
	(1.1)	(1.2)	(1.3)	(2.1)	(2.2)	(2.3)	(3.1)	(3.2)	(3.3)
Firm Innovativeness	0.000	0.000	0.000	0.000	0.000	0.000	−0.008	−0.008	-0.007
Sales (Ln)	0.018***	0.019***	0.019***	0.032**	0.030*	0.029*	−0.214**	−0.198**	-0.186***
Capital Intensity	0.066	0.065	0.065	−0.052	−0.052	−0.051	−0.687	−0.679	-0.667
R&D Intensity	−0.113	−0.110*	−0.121*	1.57***	1.55***	1.49***	0.947	0.934	0.921
Bonacich Centrality[b]		0.001***	0.001***		−0.004*	−0.003*		−0.81**	-0.79**
Ego Density[b]		0.010**	0.010**		−0.024**	−0.024**		−0.16***	-0.16**
Bonacich Centrality×Ego Density[b]			0.009***			−0.103*			-0.17**
Constant	−0.09**	−0.11**	−0.11**	0.084*	0.084*	0.083*	−3.016	−3.154	-3.632
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prob	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
R^2	0.221	0.278	0.315	0.494	0.533	0.591	0.247	0.262	0.306

$*p < 0.05$,$**p < 0.01$,$***p < 0.001$.
[a] $n = 114$ observations.
[b] Variables are centered.

between ego network density and COGS/Sales is negative and significant ($\beta = -0.024$, $p < 0.01$). Hypothesis 2 is also verified in model 3.2 with a negative and significant association between ego network density and I/S ($\beta = -0.16$, $p < 0.001$).

We included the interaction term in models 1.3, 2.3, and 3.3. As hypothesized in H3, the coefficient of the interaction term is positive and significant in model 1.3 ($\beta = 0.009, p < 0.001$) and negative and significant in models 2.3 ($\beta = -0.103$, $p < 0.05$) and 3.3 ($\beta = -0.17$, $p < 0.01$). Fig. 4 shows the interaction graph using ROA as the dependent variable.

To plot this interaction, we took the values of one standard deviation below the mean (low level) and one standard deviation above the mean (high level). Using predicted values of ROA on the vertical axis, the dotted line portrays that at low Bonacich centrality, ROA is higher for firms with higher ego network density. However, this relationship between ROA and density is stronger at higher levels of Bonacich centrality.

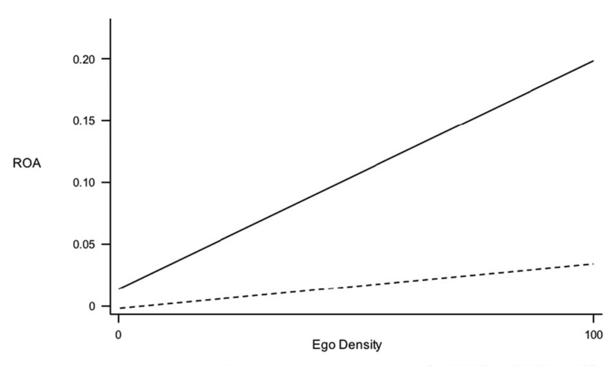

Fig. 4. Interaction effect of Bonacich centrality and ego density on firm performance (ROA).

A. Robustness Checks

We conducted additional checks to ensure robustness of our findings. First, to smooth out yearly fluctuations in the data, we averaged the three alternative measures of the dependent variable from 2010 to 2012. The regression results were consistent to the main analysis. Second, in examining the association between supply network structure and performance, it is possible that the independent variables (Bonacich centrality and ego network density) are choice variables and are themselves influenced by other variables that have been omitted in our study. Omitted variables that are not accounted for in the analysis of

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TABLE III
RESULTS FROM INSTRUMENTAL REGRESSION PROCEDURE FOR FIRM PERFORMANCE[a]

	First Stage (Bonacich Centrality)	Second Stage (ROA)
Degree Centrality	1.210*	
Eigenvector	3.420**	
Firm Innovativeness	0.000	0.000
Sales (Ln)	0.023*	0.019***
Capital Intensity	0.007	0.059
R&D Intensity	−0.675	−0.111*
Bonacich Centrality[b]		0.000***
Ego Density[b]		0.009**
Bonacich Centrality* Ego Density		0.007**
Constant	−1.480**	−0.049**
Industry Dummies	Yes	Yes
Prob	0.000**	0.000**
R^2	0.765	0.379

*$p < 0.05$,**$p < 0.01$,***$p < 0.001$.
[a] $n = 114$ observations.
[b] Variables are centered.

network structure may introduce the issue of endogeneity [89]. To address this potential issue, methodological approaches suggest running a two-stage least-squares regression with instrumental variables and employing the Hausman test [90]. We went through the literature to find appropriate instruments for structural prominence (measured as Bonacich Centrality). Among those, five recent studies were helpful to address endogeneity [43], [91]–[94]. We drew from these the list of potential instrumental variables (IVs) such as other network measures and other variables such as firm age and firm diversification. We then tested if the relevance assumption is satisfied. Two variables satisfy the assumption: past degree centrality and past eigenvector centrality. Degree centrality is defined as the number of connections or edges a focal firm has [73], [95]. The degree centrality of a focal firm i is computed by $\deg_i = \sum_j FR_{ij}$, where j represents all other firms, F is the total number of firms, and R is the adjacency matrix, in which the cell is defined as 1 if firm i is connected to firm j, and 0 otherwise. Eigenvector centrality is defined as the centrality of a node that is proportional to the sum of the centralities of the nodes it is connected to [74]. It measures how well a node is connected to well-connected nodes. The eigenvector centrality of a focal firm i is computed by $\mathrm{EC}_i = \frac{1}{\lambda} \sum_j a_{ij} \mathrm{EC}_j$, where j represents all other firms and λ is the largest eigenvalue of the adjacency matrix A.

Similar to [92], we tested to establish the appropriateness of the instruments used. Following Zaheer and Soda [94], we then tested the IVs for overidentification and underidentification that indicate instrument relevance. Using the Sargan statistic, we cannot reject the null for overidentification and underidentification ($p = 0.44$, n.s. and $p = 0.31$, n.s.). Table III shows the results of the two-stage least squares using the instrumental regression procedure. The results are structurally similar to ones that were obtained with the robust regression procedure.

We also employed quadratic assignment procedure (QAP) regression techniques to test Hypothesis 1 through 3. QAP is a nonparametric technique that is commonly used in social network analysis [96]. The steps involved in this technique are as follows. First, a standard multivariate regression is conducted across the matrices of the dependent and independent variables. Second, the rows and columns are randomly permuted, and the corresponding regression results are stored. This step can be repeated several number of times to estimate the standard error and also compare the regression coefficients of these randomly generated matrices with those from the actual regression. Specifically, in executing these two steps, we employ the well-established multiple regression quadratic assignment procedure (MRQAP) suggested by Krackhardt [97] and use the MRQAP procedure in UCINET 6.0 [98]. This regression procedure, the double Dekker semipartialling method, is robust against the issues of multicollinearity [99]. It is repeated 10 000 times for our analyses to estimate the standard errors and correspondingly the significance levels of the coefficient estimates of our independent and control variables in relations to the firm performance measures. The results are consistent to what we find from the robust regression analysis.

V. DISCUSSION

In this study, we invoke the well-established social capital theory as the underlying foundation to study the significant organizational and competitive advantage that can be achieved by firms from the accrued resources and knowledge assets derived from the relationships with their supply network partners. Specifically, we focus on two structural characteristics of a focal firm in a supply network—structural prominence and density—and their association with firm operating performance, as reflected by ROA, COGS/Sales, and I/S.

Supply networks serve as important sources of resource access, power, and trust and can also act as signaling mechanisms. These sources serve as catalysts for the development and dissemination of new ideas, applications, and supply chain practices. This organizational phenomenon is espoused by social capital theory, which asserts that performance advantage can be accrued by knowledge and information assets derived from the interrelationships among firms in a network. However, little empirical evidence exists that validates that structural characteristic of supply networks influence firm performance. The primary function of a firm's supply chain is to respond to market demand signals consistent with the strategic positioning (i.e., cost-based or differentiation-based focus) of the firm [4]. Therefore, firm performance is dependent, in part, on how the firm responds to the market relative to its competitors. However, a firm's capability to respond is significantly impacted by how the firm designs, manages, and operates its supply chain [100].

Structural prominence in a supply network, as measured by Bonacich centrality in this study, indicates the role that a focal firm can play in leading or influencing its supply network partners in driving better operating performance. Our results confirm a beneficial relationship between structural prominence and all three measures of firm operating performance, thus providing strong support for Hypothesis 1. The importance of this finding is evidenced by the fact that when firms have a higher structural position in its supply network, the entire network, i.e., all firms in the network, potentially benefits from achiev-

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ing better performance. This is the very essence of structural prominence—structurally prominent firms have the ability and power to undertake and drive beneficial practices that can benefit the entire supply network. In contrast, in a dyadic or triadic approach, only a few firms that are in the dyad or triad have the potential to be beneficially impacted, but no transferability can be guaranteed to all the firms in the supply network. However, decisions made from a network perspective, for example, structural prominence, can benefit the entire network.

Density, measured by ego network density in this study, indicates the interconnectedness among a firm's supply network partners. Similar to the impact of structural prominence, our results provide robust support for higher density positively influencing firm performance. This result also provides very important implications regarding how knowledge transfer and spillovers due to the relationships created through higher interconnectedness among the supply network partners can create a significant value by benefiting all firms in the network. In contrast, an approach that only involves a few firms, such as a dyadic or triadic arrangement, can only benefit those firms, as opposed to the entire supply network. Thus, the significance of these results has deep implications for how a firm chooses to manage its relationship with its supply network partners.

The combinative effect of structural prominence and density provides further opportunities to a firm for creating embedded social capital for itself. For example, using raw data on Bonacich centrality, ego network density, and RoA to represent structural prominence, density, and performance, respectively, we find that firms such as Plantronics Inc. and QLogic Corp. that are high on both structural prominence and density also anecdotally show high ROA. Our results for Hypothesis 3 empirically validates this relationship, which suggests that possessing high levels of both these structural characteristics positively influences firm performance. Thus, while structural prominence provides a firm with the power and influence to drive the appropriate standards and practices to improve performance, density further increases the knowledge transfer and spillover effects and thus ensures that these practices and standards are widely adopted by its partners in the supply network. In other words, firms that have high structural prominence in their supply networks can leverage this power even further if these firms can also ensure high density in their supply networks. The interaction plot shown in Fig. 4 demonstrates that when a firm's structural prominence is high, compared to when its structural prominence is low, the impact on performance (captured by ROA) is higher as the density increases.

A. Scholarly Contributions and Managerial Implications

This study contributes to the growing yet nascent literature adopting a network analytic view of supply networks. The results of this study show that the benefit of structural prominence in a supply network yields a firm high power and influence, irrespective of firm size. Moreover, smaller firms that often cannot influence their structural prominence in a network have the option of driving firm performance benefits by seeking high density in their supply network. The findings also suggest that a focal firm can enhance performance if they simultaneously have structural prominence and also are part of a dense supply network.

In such supply network configurations, firms tend to transact more efficiently through recurring interactions and connections that engender familiarity and trust, promote richer knowledge and information sharing, increase spillover effects, and thus promote and foster collaborative relationships that drive contemporary supply chain practices needed for effective response to a dynamic market and competitive environment.

Previous studies in the literature on supply network relationships examine the focal firm and its structural relationships either as dyads or triads [6], [101]. While the dyadic view has been useful in capturing the relationship details between two parties, it does not comprehensively capture a supply chains dynamic, complex, and increasingly interdependent nature, i.e., while the dyadic approach is better in capturing several levels of details in the relationship between two parties, which the network approach cannot, the network approach provides a more holistic view of the supply network. In this study, using a network-centric approach linking supply network structure and firm performance, we examined a more holistic supply network structure for a focal firm, thus adding to the small but growing literature on whole network analysis of supply networks [21].

However, at another level, despite these benefits, there is also a potential where performance of a focal firm could be hurt or compromised in a supply network. Consider the example of Wintel, a supply alliance between Microsoft and Intel, where the structural prominence of both Microsoft and its major supplier Intel appears be equally high. In such scenarios where the power of both firms is purportedly high, Casadeus-Masanell and Yoffie [102] analytically show that performance of both firms can be compromised. Future studies can investigate the conditions where a few firms simultaneously have high structural prominence in the supply network and the influence of this concurrent high position on performance of these firms.

The broader managerial implications of this study are as follows.

1) Architect High-Performance Supply Networks Using the Network Perspective: Decision makers have the choice and opportunity to design or engineer high-performing supply networks by ensuring that relationships with supply network partners are chosen and managed "wisely," that suppliers are selected appropriately such that it provides the opportunity for greater collaboration intensity, and that the "right" relationships are built, maintained, and cultivated. For example, it may be more judicious to have a few good relationships, i.e., establish relationships with the right suppliers or other supply network partners, who are also well connected on their own, i.e., engage in the right strategic relationships with supply chain partners, rather than have a lot of direct relationships that does not reflect high structural prominence for the firm. Current practices related to the need for reducing or consolidating the supply base in order to implement effective supplier relationship management practice are based on this paradigm of strategically selecting the few "right" suppliers who provide the opportunities for establishing meaningful collaborative partnerships and high level of trust, cooperation, and knowledge sharing. Our findings also suggest that if firms have limited resources to invest in building relationships with their suppliers, then it is appropriate to first invest in building strong relationships with their direct suppliers, compared to their lower tier suppliers.

2) Leverage the Power of the Supply Network: Implementing effective supply chain practices that can significantly benefit the firm performance entails going beyond the boundaries of the focal firm, by seeking how the capabilities of the firm's supply chain partners can be exploited to create much higher levels of shared value. This involves creating high-value collaborative relationships with the appropriate external partners such that the firm can use its power from the ensuing structural prominence to influence and drive the creation of shared values needed to positively influence performance.

Toyota is a very good example of how a firm's structural network attributes drives effective knowledge/information sharing and learning within its supply network in order to create better firm performance. As illustrated in [59], Toyota created knowledge-sharing collaborative networks with its suppliers to drive higher operational productivity in its supply network. In the early stages of the knowledge-sharing network, Toyota established bilateral relationships with its suppliers. This hub-spoke supply network structure had the potential of giving Toyota limited structural prominence as well as low network interconnectedness, that is, low structural embeddedness. Later, it influenced its suppliers to form ties with each other as nested subnetworks, i.e., drive higher network interconnectedness. Creating these multilateral relationships facilitated the flow of knowledge so that its partners were able to learn much faster than rival nonparticipating suppliers. This provides a good example of how a focal firm can be proactive in managing the structural attributes of its supply network to drive better performance.

B. Limitations and Future Research

Our study is not without limitations. First, our research setting is limited to the supply networks of firms in the electronic industry. While we believe that the findings have bearing in other high-velocity industries, we recognize that the generalizability to stable industries can only be emphasized with future studies. With extensive supply networks, the automotive industry is a potentially ripe research setting. We also suggest future studies to conduct interindustry comparisons. For example, comparing the structural characteristics in two distinct industries can explain if these characteristics influence performance in distinct or similar ways. Second, we focus our analysis between structural characteristics in a supply network and firm performance in an undirected supply network context. Future research can examine this relationship in directed supply networks, which would enable a differentiation between customers and suppliers and an understanding of paths of value flow. Third, we use cross-sectional data to compute structural characteristics of supply networks in the electronics industry. On one hand, we believe that having access to raw data and merging it with other data sources has facilitated a study to empirically view a holistic supply network for a large sample of focal firms. On the other hand, we also recognize that the findings are limited because of nonavailability of longitudinal data across these firms.

VI. Conclusion

This study examined the association between supply network structure and firm performance. Specifically, we focused on two structural characteristics: structural prominence and density. We also estimate the combinative effect of these two structural characteristics. Using a multisource dataset of firms in the electronics industry, the results suggest that high structural prominence and density significantly influence firm performance, as measured by the firm's asset utilization, cost performance, and operational efficiency. In doing so, we advance our theoretical understanding of supply networks and the relationship between network structure and firm performance. Our study also provides important managerial insights into the effective design and management of high-performing supply networks in an increasingly complex and global environment.

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