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EDITORIAL

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Innovation in supply networks—A research framework and roadmap

Innovation in the products and services offered by a firm does not originate exclusively from activities executed within the boundaries of the firm. Firms are embedded within networks of customers and suppliers (i.e., *supply networks*) with which they exchange products, services, data, and information. All these exchanges are potential vectors of innovation. Supply network actors do not just supplement internal innovation efforts. In fact, the stock of knowledge that a firm can indirectly access through its network is often comparable to or even exceeds internally available resources, because any single firm usually has many suppliers. To illustrate this fact with respect to a firm's suppliers, for example, consider the research and development (R&D) statistics from some of largest publicly traded firms in the US, Japan, and Europe in the Defense, Automotive, Electronics, Consumer and Packaged Goods (CPG), and Industrial Equipment industries (see Table 1, Data source: Factset and Compustat).

As seen in Table 1, in the period spanning fiscal years 2015–2018, the average research and development (R&D) intensity (and cumulative average dollars invested in R&D) of first-tier suppliers is higher than, or at least comparable with, the R&D expenditure of the focal firm, both within and across industries. For example, within Defense sector firms, the ratio of average R&D intensity (cumulative R&D dollars) of first-tier suppliers to that of the focal firm varies from 0.98 to 19.63 (6.90 to 43.00); within the Automotive sector, it varies from 0.60 to 1.40 (3.60 to 18.44). Similar patterns are also observed in the Electronics, Industrial equipment, and CPG sectors. Hewlett Packard, for example, has an average first-tier supplier R&D intensity of 3.27 times its own, and the cumulative R&D of its first-tier suppliers is 54.60 times its own spending. Similarly, General Electric (GE) had first-tier suppliers with an R&D intensity about 62 times its own, while the first-tier suppliers collectively spent 7.30 times the total R&D dollars that GE spent. These examples illustrate that (1) suppliers R&D investment tend to be greater or equal than the investment of their customers, at least for very large publicly traded companies and that (2) the potential to leverage supplier R&D investments varies greatly within a given industry and across industries.

Leading corporations in different industries actively acknowledge and promote supplier-driven innovation. In the CPG industry, for instance, Unilever noted: "Around 70% of our innovations are linked to working with our strategic suppliers." To this end, through its "partners to win" program launched in 2011, Unilever invested in mutually beneficial relationships with key suppliers to "share capabilities and co-innovate" (Trebilcock, 2014). Similarly, as Procter & Gamble (P&G) engaged in innovation activities with its top 15 suppliers—who feature a combined R&D staff of 50,000—the firm saw a 30% increase in the number of innovation projects with joint staffing between P&G and supplier researchers (Larry & Sakkab, 2006). In the case of Toyota's R&D centers for individual platforms, collaboration with suppliers for innovation is institutionalized. Selected suppliers embedded personnel in the R&D center's operations (Wyman, 2015). Technology firms that invest vast resources in innovation have also embraced this practice. For example, Cisco (Gassmann, 2006) and Google (Remneland-Wikhamn, Ljungberg, Bergquist, & Kuschel, 2011) have heavily leveraged supplier partnerships to enhance the pace of their innovations. Overall, these examples emphasize the importance of the supplier network in the current context. Rao (2018) state that as much as 55–65% of innovation is driven by suppliers.

This special issue offers a unique opportunity to take stock of the multiple streams of research that investigate innovation in supply networks and to sketch out new avenues for research. In this introductory article, we first discuss the impetus for investigating innovations in supply networks and offer a brief overview of past research that relates to this topic. Next, we develop a framework that, while integrating past research results, pinpoints numerous opportunities for future research on innovation in supply networks. While doing so, we discuss how the papers that are a part of this special issue fit within the proposed framework.

1 | IMPETUS FOR INVESTIGATING SUPPLY NETWORKS

That supply networks play a role in innovation processes and outcomes is not a novel idea. However, we expect

TABLE 1 Average (2015–2018) R&D intensity and cumulative R&D for select companies across industries (R&D in million dollars)

Ind.	Firm	R&D Intensity (F) (i)	R&D Intensity (FTS) (ii)	R&D Exp. (F) ($mn) (iii)	Cum. R&D Exp. (FTS) ($mn) (iv)	Ratio of R&D Exp. (FTS/F) (v)	Ratio of R&D Intensity (FTS/F) (vi)	FTS Count (vii)
Defense	Raytheon	0.030	0.077	759.000	10,025.845	13.209	2.534	65.25
	BAE Systems	0.083	0.081	1,998.034	13,797.224	6.905	0.983	64.00
	Boeing	0.037	0.049	3,601.500	42,497.024	11.800	1.310	174.00
	General Dynamics	0.014	0.278	459.000	19,737.572	43.001	19.636	58.50
	Northrop Grumman	0.027	0.058	705.000	8,624.251	12.233	2.109	68.00
	Lockheed Martin	0.022	0.060	1,081.750	32,702.267	30.231	2.762	142.50
Automobiles	Ford Motor	0.049	0.035	7,550.000	87,445.546	11.582	0.719	311.25
	Daimler	0.035	0.040	6,347.326	51,574.841	8.125	1.120	276.00
	Toyota Motor	0.036	0.036	9,244.503	42,816.313	4.632	0.982	244.00
	Volkswagen	0.053	0.038	13,350.095	80,205.345	6.008	0.715	320.00
	Honda Motor	0.049	0.030	6,447.758	23,235.101	3.604	0.605	214.75
	General Motors	0.050	0.031	7,675.000	55,616.255	7.246	0.617	350.75
	BMW AG	0.043	0.038	4,676.652	35,262.702	7.540	0.880	192.75
	Peugeot	0.025	0.036	1,893.090	27,426.980	14.488	1.407	133.75
Electronics	Hewlett Packard	0.026	0.086	1,826.250	99,705.156	54.596	3.269	138.75
	Intel	0.208	0.125	12,877.250	20,794.955	1.615	0.601	98.25
	Apple	0.046	0.071	10,982.250	131,870.399	12.008	1.536	260.00
	Sony	0.056	0.105	4,078.174	23,496.811	5.762	1.852	119.50
Industrial Equipment	ABB	0.044	0.035	1,443.750	3,412.431	2.364	0.795	54.75
	Emerson Electric	0.023	0.045	400.500	2,308.127	5.763	1.943	31.00
	General Electric	0.038	2.347	4,492.000	32,778.877	7.297	62.292	185.75
	Hitachi	0.035	0.095	2,886.388	9,650.477	3.343	2.756	111.75
	Mitsubishi Electric	0.047	0.055	1,818.886	4,342.223	2.387	1.163	38.00
CPG	Nestlé	0.019	0.096	1,742.702	11,445.173	6.567	5.055	87.25
	PepsiCo	0.012	0.188	732.750	2,232.276	3.046	16.304	62.75
	Procter & Gamble	0.028	2.498	1,927.000	3,022.638	1.569	88.436	67.00

Note: Ind. (Industry), Firm (F), First-tier suppliers (FTS); Columns (i), (ii), (iii), (iv), and (vii) are average numbers for the years 2015–2018. Columns (v) and (vi) are ratio of averages. Defense firms List of the firms were accessed from https://people.defensenews.com/top-100/—on April 11th 2020. *Electronics firms*: List of firms were accessed from https://www.statista.com/study/44594/top-100-computer-and-electronics-manufacturers/—on April 11th 2020. *Automobile firms*: List of the firms were accessed from https://www.bizvibe.com/blog/automobiles/top-10-automobile-companies-in-the-world/—on April 11th 2020. *CPG firms*: List of firms were accessed from https://consumergoods.com/top-100-consumer-goods-companies-2018—on April 11th 2020. *Industrial Equipment*: List of firms “cherry-picked” that are considered innovative.

that research efforts in this area will continue to multiply under the combined pressure of economic and societal forces, as well as methodological and data advances.

From an economic and societal perspective, fragmentation and globalization of supply chains is a key factor driving the need for more supply network research (Hummels, Ishii, & Yi, 2001). Vertical disintegration of supply chains is a global phenomenon that is evidenced across industries as different as footwear, machinery, communication equipment, computer and peripherals, electronic instruments, ship and boat manufacturing, and banking, to just name a few (Jacobides, 2005; Lechner, Lorenzoni, & Tundis, 2016). As previously integrated production processes become split among sets of specialized firms, innovation activities that are embedded within organizational hierarchies are divided and recombined across different network actors.

Innovation activities are also increasingly spread across many geographic locations due to the globalization of supply chains (Timmer, Erumban, Los, Stehrer, & De Vries, 2014). Industries such as electronics (Ernst, 2003), and semiconductors (Macher, Mowery, & Simcoe, 2002), are cases in point for the impact of globalization and the consequent innovative capacities within these industries. For example, while Apple Inc.—the firm that controls and orchestrates the iPhone network—is headquartered in the United States, many countries add value, including China ($8.46), Japan ($67.70), United States ($68.69), Taiwan ($47.84), and Korea ($16.40) (estimated values for iPhone 7 based on Dedrick, Linden, and Kraemer (2018)). Similarly, manufacturing locations can also be specialized. For example, the Nokia 1200 phone had a wide dispersion of specialized activities across several locations. While software platform and user interface design were primarily focused in Denmark, product test design, mechanical component manufacturing, and subassemblies were distributed across India and China. Finally, manufacturing was distributed across China, India, Romania, Hungary, Mexico, and South Korea (Larsen, Seppälä, & Ali-Yrkkö, 2018).

Finally, in addition to dispersion of focal products, in several high-tech industries such as semiconductors, complementary investments such as tooling make it easier for suppliers and downstream organizations to copy innovations rapidly (Shih, 2018). These abilities accelerate the dispersion of innovations across geographies, making suppliers of both primary value chain products and complementary tooling for these products important within supply networks. Overall, these trends for disintegration and globalization observed in most industries suggest that the locus of innovation is moving towards supply networks. Given this shift, characteristics of supply networks such as their structure or their coordination and control mechanisms will have a bearing on the way innovation activities are executed, as well as on their outcomes. For instance, actors in different geographic areas that have different cultural traditions, political priorities, or academic institutions can have a subtle yet substantial impact on innovation processes.

Managing the environmental impact of global supply networks is another factor creating an impetus for innovation. These impacts can differ by the nature of suppliers (Villena & Gioia, 2018). Large firms in many industries (3M, BASF, Ford Motor Company, Ikea, Lenovo, PepsiCo, Quanta Shanghai Manufacturing, etc.) are testing measures to comply with the Scope 3 Greenhouse Gas Protocol Corporate Value Chain Standard (Knight & Jackson, 2011). This standard aims to reduce all indirect emissions that occur in the value chain of the reporting company, including both upstream and downstream emissions. A McKinsey report indicates that CPG companies will need to reduce their emissions by more than 90% before 2050 to comply with the Paris Accord while maintaining their yearly growth of 5.3% per year (Bové & Swartz, 2016). Working with suppliers to achieve this is critical. Despite being the primary producer of the iPhone, Apple Inc. facilities account for only 2% of CO_2 emissions associated with its manufacture and distribution (Apple Inc, 2016). To reduce its carbon footprint, Apple must engage in product and process innovation efforts with its supply network partners with respect to sustainability. Similarly, LEGO attributed 75% of its greenhouse gas emissions to its suppliers (Lego Group, 2014), and Wal-Mart attributed over 90% (Rosen, 2016). Given these dependencies, buying firms may need to design appropriate incentives to induce suppliers to engage in innovation activities geared towards reducing carbon emissions (Villena & Dhanorkar, 2020).

Finally, the recent coronavirus pandemic has demonstrated that modern societies need to find new ways to balance the resilience and efficiency of global supply networks during health crises. In line with predictions of high-reliability theory (Weick, Stutcliffe, & Obstfeld, 1999), a centralized response to such crises is suboptimal, as shown by the failed attempts of central governments to secure a sufficient supply of essential medical materials. These events have also shed light on how supply network actors can engage in innovative efforts to increase their overall resilience to such global shocks. This is also a topic of a recently called-for special issue in this Journal.

Besides the economic and societal forces, there are opportunities for research in innovation in supply networks arising as new data become available. For many years, data and analytical approaches used by empirical operations management scholars to investigate supply networks have been quite limited. As it often happens in empirical research, data and methodological limitations shape the type of questions that scholars can answer, thereby curtailing the development of theory along specific directions. Many of these limitations are rapidly disappearing. The ability of researchers to gather fine-grained information about supply networks will enable them to characterize the inner workings of these networks and their impacts on innovation. For example, in the automotive industry, numerous databases have been compiled and are publicly accessible about different aspects of supply network structure and other significant covariates. These include databases such as Marklines and the IHS "Who supplies whom" databases. Other databases make indepth research into industry-wide supply networks more feasible: Bloomberg SPLC database, Factset Supply Chain Relationships data, and Compustat segments files, among others. Other worldwide databases such as Carbon Disclosure Project, Asset 4 ESG, and Bloomberg ESG increase access to data related to sustainability. These databases complement databases such as the SDC Platinum Mergers and Alliances database.

Companies themselves are becoming a formidable source of supply-network data, thanks to the Industrial Internet and Industry 4.0 initiatives. Individual firms will be able to provide unique, micro-level data about their supply networks due to the considerable investments they have made in their supply networks' visibility that characterize corporate Industry 4.0 initiatives. A single firm such as Schneider Electric processes 150,000 order lines per day on average, relative to 260,000 SKUs that are routed through 95 distribution centers, 204 factories, 44 countries, and that involve 22,000 suppliers. Capturing this information opens exciting, novel possibilities for advancing supply network theory and practice. In parallel, with the accessibility of new data sources that were unimaginable only a decade ago, the supply chain community also has more effective tools for data manipulation (e.g., Python), data visualization (e.g., Gephi), and data analysis, in addition to increased computing power. These advances will propel a flourishing of research into innovation in supply networks.

2 | WHAT DO WE KNOW ABOUT SUPPLY NETWORKS? A VIEW FROM 30,000 FEET

Research on the role of supply networks in innovation processes has roots that stretch back to multiple consolidated research streams. We briefly detail these research streams covering their essence, in line with the purpose of this editorial. A natural point of departure in understanding how innovation transcends the boundaries of the firm is the research on innovation in the context of buyer–supplier dyads. Starting from the premise that suppliers retain knowledge that is often not available to buyers (Cassiman & Veugelers, 2006), these studies found that buyers can leverage supplier knowledge to create innovative products (Henke & Zhang, 2010; Jean, Kim, & Sinkovics, 2012; Narasimhan & Narayanan, 2013; Wagner & Bode, 2014) and ultimately improve their performance (Azadegan & Dooley, 2010). The benefits of buyer–supplier collaboration are not restricted to buyers; suppliers can also garner buyer knowledge and incorporate it into their innovation processes (Alcacer & Oxley, 2014). Mechanisms through which buyers can leverage suppliers for innovation purposes can be relational or contractual. A meta-analytic study by Leuschner, Rogers, and Charvet (2013) found that relational integration mechanisms (based on trust, commitment, and long-term collaboration) among buyers and suppliers had the highest correlation with a composite of performance indicators that included product innovation. However, other studies found that higher levels of collaboration and social capital between suppliers and buyers may not always be effective (Narayanan, Narasimhan, & Schoenherr, 2015; Villena, Revilla, & Choi, 2010). Investigation of the mechanisms underlying successful buyer–supplier innovation efforts thus remains a priority in this research stream.

Beyond buyer–supplier dyads, suppliers also collaborate among themselves to benefit one another and the buyers, as seen in examples of firms in the Toyota network (Dyer & Nobeoka, 2000; Wilhelm & Kohlbacher, 2011) and as theorized by the research on supplier triads (Wu & Choi, 2005; Wynstra, Spring, & Schoenherr, 2015). The central tenets of supplier triads research are that dependencies between the buyer and supplier are manifold (financial, material, and technological) and that one supplier's performance can be affected by other suppliers in the network (Choi & Kim, 2008). While empirical studies investigating triads do not explicitly focus on innovation performance, ideas from this literature suggest that the deep, multifarious relationships among suppliers can have implications for both buyer and supplier innovation.

A recent stream of research moved beyond triads to investigate how broader structural characteristics of supply networks impact the innovation and performance of the companies that operate within these networks. These studies are inspired by early strategic management research that focused on the implications of changes in network structure and its influence on the innovation performance of the firm (Ahuja, 2000). This literature has suggested that the reach and clustering of collaborative, inter-firm networks (Schilling & Phelps, 2007), cluster membership (Ozer & Zhang, 2015), and partner-breadth portfolio (Lahiri & Narayanan, 2013) are all critical for driving a buyer's innovation performance. More recently, Bellamy, Ghosh, and Hora (2014) found that supply chain accessibility and interconnectedness can positively affect the innovation performance of a firm. Similarly, Carnovale and Yeniyurt (2015) examined the impact of network structure, focusing on the various dimensions of betweenness, density, brokerage, and weakness on the innovation performance of the supply network. Besides the structural characteristics of the network, other factors such as partner technological diversity also impact the innovative efforts of firms (Gao, Xie, & Zhou, 2015).

Several studies focus on supply chain contracts and the importance of their legal enforcement for successful inter-firm innovation efforts (Li, Poppo, & Zhou, 2010; Zhou, Zhang, Sheng, Xie, & Bao, 2014). Contracts may be considered a deterrent for opportunism. Yet their effectiveness within product innovation settings is subject to the strength of intellectual property rights (IPRs) of a specific country or geographic region. For example, Zhao (2006) noted that returns to innovation are lower when firms operate in countries with weak protection of IPRs. Similarly, Skowronski and Benton (2018) found that poaching of buyers' intellectual property is higher when suppliers are in weak IPR settings, mainly when they invest in highly specific assets. The role of contracts has received less attention at the network level. A notable exception is a study by Ravindran, Susarla, Mani, and Gurbaxani (2015) that used unique data from a network of IT outsourcing contracts. This study found that structural, relational, and contractual embeddedness within a buyer–supplier network plays a key role in determining contract duration. It is likely that such contractual embeddedness influences innovation outcomes as well.

Finally, research on innovation in supply networks is also informed by a stream of literature that investigates the link between product innovation and supply network structure, both at the firm and the industry level. In this case, the supply network is restricted to firms involved in the design and manufacture of a specific product family. Several scholars noticed the existence of an association among supply network, product structure, and firm performance (Fixson & Park, 2008; Forza, Salvador, & Rungtusanatham, 2005; Gokpinar, Hopp, & Iravani, 2010). The rationale underlying this idea—also known as the mirroring hypothesis (Colfer & Baldwin, 2016)—is that product architectural innovation changes dependencies among the actors involved in designing the product (Henderson & Clark, 1990). Thus, product architectural innovation may push firms to alter the structure of their supply networks (Cabigiosu & Camuffo, 2012), or even of industry-wide networks (Baldwin, 2018; Fixson & Park, 2008; MacCormack, Baldwin, & Rusnak, 2012). By the same token, a certain structure of the supply network can enable or hinder architectural innovation. Moreover, a mismatch between product architecture and supply network structure tends to negatively affect firm performance (Eppinger & Browning, 2012; Hofman, Halman, & Looy, 2016; Salvador, Forza, & Rungtusanatham, 2002). The broader implication of this stream of research is that, as product innovation becomes an increasingly multi-firm endeavor, an understanding of the interplay between architectural innovation decisions and supply network dependencies will become more and more critical to properly manage innovation processes.

3 | A FRAMEWORK FOR RESEARCH INTO SUPPLY NETWORK INNOVATION

Herein, we propose a general framework that subsumes previous research and pinpoints a broad range of future research opportunities. The starting point in sketching this framework (see Figure 1) is that empirical research so far has mostly focused on investigating the association between network characteristics (left construct in Figure 1) and innovation outcomes (right construct in Figure 1). Mechanisms explaining the existence of such associations (center construct in Figure 1) have been theorized but so far remain largely unexplored by empirical research. The model depicted in Figure 1 suggests several avenues to expand research on innovation in supply networks. We identify future research opportunities by providing an overview of the three main elements in our framework and their connections.

3.1 | Novel and richer conceptualizations of supply network characteristics

One of the prevailing views in the conceptualization of supply networks depicts a network as a set of firms connected by buyer–supplier relations captured by commercial contracts. In this view, a network is conceived as a "system of flows" among nodes (Borgatti & Lopez-Kidwell, 2014) where flows refer to products, information, and finances. While certainly valid, this conceptualization of a network has significant limitations. Considering a firm as a single node hugely simplifies how interactions among firms happen, detracting from the explanatory power of theory. Many large firms are themselves networks of research, production, and logistic facilities. Evidently, the mutual location of these units may favor or hinder the interchange of information and hence innovation. For instance, if the R&D facilities of two nodes with a direct tie are on different continents, collaborative innovation may be more challenging than if they were in the same country or city.

In this special issue, Potter and Wilhelm (2020) begin to go beyond the view of "node-as-a-firm" when investigating how structural characteristics of the Toyota supply network foster supplier–supplier innovation. In line with this view, they investigate how a supplier's closeness centrality, betweenness centrality, and small world clusters in 2015 are associated with co-patents registered by the supplier with other Toyota suppliers in the period 2015–2018. However, in their last hypotheses, they move beyond this conceptualization of the network to investigate how the number of manufacturing plants owned by each firm (e.g., by each "node" in the network) and located in Japan affects supplier–supplier innovation. They indeed find this variable to have both direct and interactive (together with supplier indegree centrality) effects on supplier–supplier innovation.

In general, it is fair to observe that social network metrics are only a small subset of what can and should be considered as supply network characteristics. For example, in light of a network tying different firms together in a product development project, elements complexity (number of components, activities, people, tools, and goals), relationship complexity (complexity of interaction among the elements) and complicatedness (the subjective assessment of complexity) impact the ability of the project actors to deal with unk-unks (unknown-unknowns), thereby impacting innovation success (Browning & Ramasesh, 2015; Ramasesh & Browning, 2014). Likewise, supply networks can be characterized through typical dimensions of complexity, such as their breadth, heterogeneity, and interconnectedness (Choi & Krause, 2006).

Networks can be also characterized in terms of their modularity (Baldwin & Clark, 2000)—that is, how innovation processes are affected when the network is split; suppliers are dropped, swapped, or "ported" from one network to another; or connections among suppliers are augmented via new product, process, and information flows. It should also be possible to develop these modular characteristics to improve network performance. More generally, valuable, and novel insights into supply networks can be gleaned by applying known product-development-related tools. For example, Eppinger and Browning (2012, p. 312) demonstrated the application of design-structure methodology to a stakeholder-value network identifying the multiplexity of flows of political influence, information, goods/services, and finances across a diverse stakeholder group of organizations including firm, customer, and suppliers in a project environment. Lastly, we see opportunities in empirical studies of supply networks examined through the lens of complex adaptive systems (Choi, Dooley, & Rungtusanatham, 2001; Nair & Reed-Tsochas, 2019) that move beyond simulation (Hwarng & Xie, 2008) to investigate how network characteristics or periodic behaviors affect innovation processes and outcomes.

Three papers in this special issue provide conceptualizations of supply networks that go beyond social network theory and metrics. Chae, Yan, and Yang (2020) examine how three types of social capital (structural, relational, and cognitive) influence a supplier's innovation value to the original equipment manufacturer (OEM). They argue that endowments across all suppliers are not the same for automotive OEMs. Specifically, they demonstrate that suppliers whose networks overlap with the OEM's network (structural equivalence) are more likely to provide valuable innovations to the OEM, and that the effect is stronger for culturally distant suppliers. As firms find themselves collaborating with foreign suppliers, the lack of familiarity can make working on joint innovations challenging. Their study offers important insights into how the structural design of a supplier network might somewhat compensate for cultural distance.

Venkataraman, Dong, Skowronski, Song, and Zou (2020) use data from Bloomberg and Compustat to investigate how the R&D intensity of first-tier suppliers affects the buying firm's financial performance. Following in the footsteps of Choi and Krause (2006), they further conceptualize the characteristics of a firm's first-tier suppliers in terms of breadth, heterogeneity, and interconnectedness. Their analysis indicates that these supply network features negatively moderate the positive effect of suppliers' R&D intensity on financial performance. That is, firms should be careful in promoting connections among first-tier suppliers, because the resulting network complexity can hinder the benefits from suppliers' R&D investments.

Sharma, Pathak, Borah, and Adhikary (2020) use data from a large-scale network of 201 firms across six industries and 20 countries to explore how a supply network's horizontal, vertical, and spatial complexity affect a firm's innovation performance. They find positive (marginally decreasing) effects of horizontal and vertical complexity and a negative impact of spatial complexity. Specifically, this study shows that, beyond a certain point, horizontal and vertical complexity of a supply network results in diminishing innovation performance. Additionally, a firm's strategic emphasis and its network influence

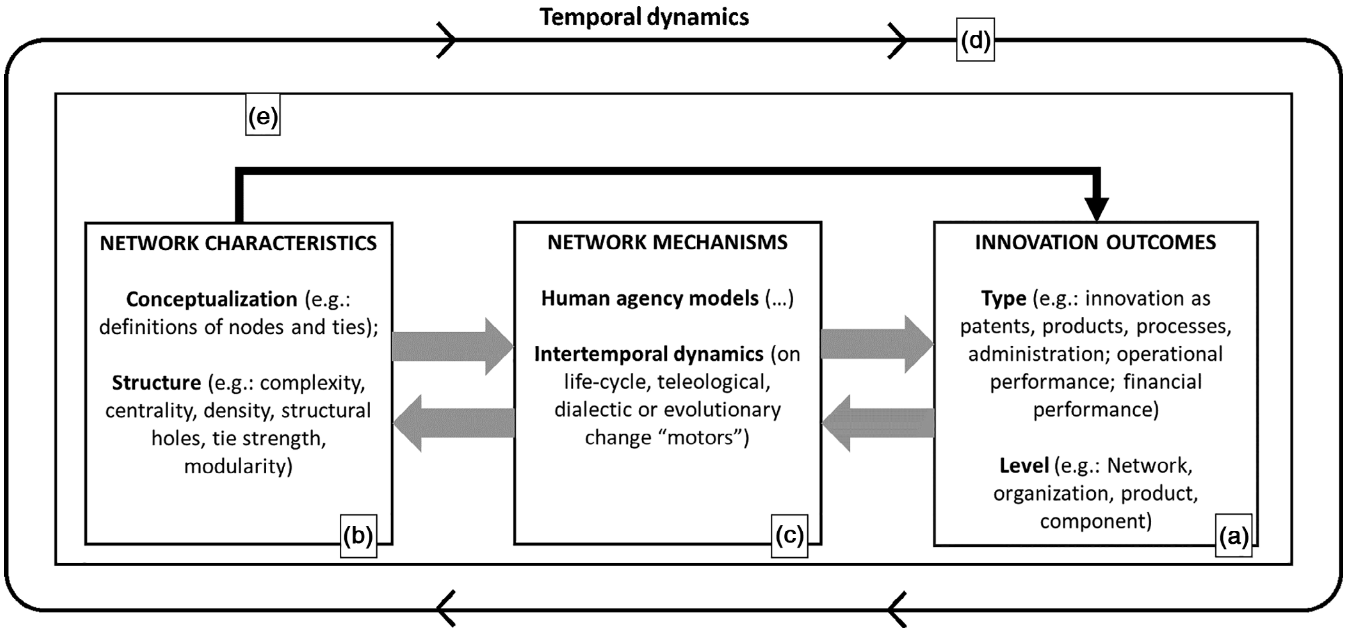

FIGURE 1 Supply network research model

positively moderate the link between the complexity dimensions and innovation performance, attesting to the importance of a firm's control over its network and its strategic emphasis on innovation in leveraging the supply network. This study also emphasizes the importance of lower-tier suppliers in contributing to the innovation performance of the focal firm.

Finally, novel network characteristics can also emerge from broader conceptualizations of supply networks that include actors who are not tied by buyer–supplier relationships. Restricting the unit of analysis to entities that have formal buyer–supplier relationships may not be sufficient to understand how these entities interact. In this regard, the social network literature makes an essential distinction between network flow models (as discussed before) and network architecture models (Borgatti & Lopez-Kidwell, 2014). In the former, the focus of the analysis is on how information, relationships, and products flow among nodes. In the latter, the focus is on how links among nodes create structures and dependencies. For instance, Cheung, Haw, Hu, Swink, and Zhang (2020) show that institutional investors (e.g., retirement funds) can improve the financial performance of a firm they invested in when they also hold stakes in a buyer of such a firm. That is, besides buyer–supplier relationships, other relevant links (i.e., investment by financial institutions) explain the operating and market performance of focal firms. Furthermore, financial institutions are connected among themselves through trading networks, which can expose them to failure (Elliott, Golub, & Jackson, 2014) with possibly serious consequences for the supply network actors in which they invest. The interplay between supply networks and the trade networks of financial institutions thus opens potentially novel research perspectives and insights.

3.2 | Novel and richer conceptualizations of innovation outcomes

The conceptualization of innovation outcomes is another area ripe with opportunities for new and exciting research. Research on innovation in supply networks, both in strategy and operations, has relied extensively on patents to measure innovation activities (e.g., Bellamy et al., 2014). Patents are an important measure (Katila, 2000), but the literature has also noted that not all innovations are patentable (Acs & Audretsch, 1989). Understandably, the predominant use of patents as an innovation measure originates from the scarcity of data on the innovation activities and outcomes of firms. However, patents remain, at best, a partial proxy for innovation outcomes (Ketchen, Ireland, & Baker, 2012) since they capture only the front end of innovation activity (Basulto, 2015).

Research on innovation management has shown that there are many other possible metrics to capture innovation (Chan, Musso, & Shankar, 2008; Von Hippel, Thomke, & Sonnack, 1999; Wadhwa, Bodas Freitas, & Sarkar, 2017), both at the firm level (e.g., sales from new products, number of radically improved new products) and the product level (e.g., time-to-market, product performance, product conformance), among others. Likewise, patents do not necessarily capture innovation efforts, which can be more precisely tapped with firm-level (e.g., R&D staff, R&D expenditure, project mix) or component-level (e.g., project budget, team size, innovativeness) metrics (Kim, Narayanan, & Narasimhan, 2019). Outcomes of innovations can also be focused on failures, not just successes (Bonabeau, Bodick, & Armstrong, 2008). At the product level, these failures can be leakage of intellectual property, product-related challenges such as product quality, and project failure. At the firm level, these could be conflicts or risks of different forms, including bankruptcies.

In this special issue, Lan, Gray, Chandrasekaran, and Massimino (2020) use a novel, network-level dataset of video games to examine how increasing network centrality increases product performance while reducing confidentiality performance. Furthermore, they find that the firms that span more structural holes experience superior product and confidentiality performance. This study also highlights the need to consider multiple performance measures within the context of a larger network.

A further opportunity to expand research on innovation outcomes is the study of process and administrative innovation which has largely been ignored by supply network research. Innovation in supply networks should be understood not only as firm-level or product/service innovation but also as process innovation (Pisano, 1997) or administrative innovation, such as the adoption of total quality management (TQM) among a set of network actors (Westphal, Gulati, & Shortell, 1997; Young, Charns, & Shortell, 2001). Studying how network characteristics may drive process innovation, rather than just product innovation, is essential because in many settings the two types of innovations are largely independent—e.g., the automotive, electronics, or defense industries (Pisano, 1996). Process innovation involving buyer and supplier has been studied in the past, for example, in the cases of electronic data interchange systems (Narayanan, Marucheck, & Handfield, 2009) and inter-firm product configuration systems (Forza & Salvador, 2002). Little is known, however, about how network structure could promote or hinder the speed of diffusion and reach of process innovation among network players.

More generally, the process innovation that occurs in supply networks is not restricted to manufacturing and logistics processes. It embraces administrative activities such as environmental management (Doherty & Hoyle, 2009) and environmental protection (Hoffman, 2001). In this special issue, Bellamy, Dhanorkar, and Subramanian (2020) focus on administrative environmental innovations such as establishing policies for managing a firm's own environmental impact (e.g., ISO 14001) and that of its suppliers (involvement in supplier development activities related to the environment, such as waste and emission reduction). They find that a firm's implementation of environmental innovations—internally within the firm, externally with suppliers, or both—positively influences environmental disclosures by the firm, highlighting the synergistic importance of not only internal but also external administrative innovations to the quality of environmental disclosure. They also investigate how this relation is moderated by network accessibility (closeness centrality), network flow control (betweenness centrality), and network interconnectedness (network density). Based on this analysis they discover that the implementation of internal and external environmental innovations results in more pronounced environmental disclosure when firms have a favorable network position or play a gatekeeping role for information.

3.3 | Mechanisms underlying theories of innovation in supply network innovation

The mechanisms underlying the effects of network characteristics on organizational outcomes remain mostly untested and, in many cases, not explicitly discussed by theory. How might network centrality affect the decisions made by purchasing or design managers? How might a structural hole hinder or alter their choices and actions? To address these questions, supply network theory needs to evolve to incorporate a sort of micro-foundational logic where human agency is explicitly modeled and measured (Felin, Foss, & Ployhart, 2015). Such human decision making may also be driven by differences in location of the supplier(s), supplier priorities, and how the buyer managers may perceive the supplier's priorities vis-à-vis their own. Recognizing these nuances is essential to increase the explanatory power of supply network theory. This is also one of the foundational ideas of social network research, which attempts to explain information flows across ties as a consequence of similarities, social proximity, and interactions among network actors which are also known as network "backcloth" (Atkin, 1975; Atkin, 2013). Empirical researchers willing to unveil the micro-foundations of supply networks' effects on innovation outcomes will be entering an almost empty theoretical space. To this end, qualitative, vibrant, and detailed studies that reconstruct how network characteristics shape individual and collective decision processes are a priority. Experimental approaches can also tease out behavioral facets of network innovation dynamics.

In this context, Yan, Yang, Dooley, and Chae (2020) show how procurement managers select suppliers to work on innovation activities. In leveraging suppliers, procurement managers can view suppliers' connections within and outside the industry as a source of novel information or as a threat of information leakage. Deploying signaling theory, the authors find that purchasing managers value other-industry customer ties and external innovation ties—other suppliers, customers, or non-supply-chain partners such as government organizations and universities—as positive signals, and competitor ties as negative signals, when innovation novelty is the goal of supplier engagement. Furthermore, when the procurement managers' goal is to protect the leakage of information in an innovation project, all ties (other industry ties, competitor ties, and external innovation ties) are perceived negatively. The results of this study highlight the need to consider the behavioral traits of managers such as risk aversion in the process of selecting suppliers for sourcing innovation.

Understanding how and why network characteristics affect innovation outputs may also require future studies to distinguish between contractual and relational mechanisms and the interdependent risks across the network. Contractual mechanisms refer to reward and incentive systems that are directly tied to cooperation of supply partners and explicitly contracted (Choi & Kim, 2008). On the other hand, relational mechanisms refer to initiatives a buyer takes to encourage suppliers to pursue certain practices (Huang, Narayanan, & Swaminathan, 2020; Johnsen, Wynstra, Zheng, Harland, & Lamming, 2000). Both mechanisms may have an impact on how managers design policies across the supply network. Similarly, when existing contractual and relational mechanisms fail and relationships end up in conflict, challenges experienced in one part of the network may also propagate to other parts of the network (cf., Marle, Vidal, & Bocquet, 2013). This is especially true for innovation projects that may have a high level of noise, given uncertainties in innovation efforts. More generally, recognizing the multiplexity of supply network connection attributes is essential to move theory away from the current, descriptive approach to a more prescriptive approach and increase the explanatory power of mechanisms by which supply networks influence innovation performance.

3.4 | Temporality in networks

Another important, related opportunity is the explicit modeling of temporality within networks. Networks change over time because of emerging and/or controlled factors (Choi et al., 2001). However, empirical research on supply networks has not explicitly modeled time and chains of events, essentially sticking to the formalization of "variance theory" (Langley, Smallman, Tsoukas, & Van de Ven, 2013; Mohr, 1982). This fact calls for developing supply network "process theories" meant to shed light on the change motors triggered by specific network characteristics, be they based on life-cycle, teleological, dialectic, or evolutionary logics (Poole, Van de Ven, Dooley, & Holmes, 2000; Van De Ven & Poole, 1995). For instance, do networks change across a set of stages and is this process reflected in innovation outcomes? Or do certain network characteristics trigger the creation of thesis-antithesis clashes that subsequently initiate the synthesis of innovative solutions? How do the changes in supply network structure and supply network consolidation usurp value from buyers and influence future learning efforts? These are open questions.

For example, Seppälä (2013) studied the evolution of Nokia's cell phone supply network between 2000 and 2010 identifying how its structure evolved under the effect of five major disruptions related to global, emerging-market suppliers (e.g., Flextronics' acquisition of Nokia's Finnish suppliers, the introduction of Asian suppliers, and the merger between the Motorola and Nokia Siemens networks). Similarly, Larsen et al. (2018, p. 683) documented how Nokia's supply network changed from a set of individual suppliers (pre-2004) to multi-technology commodity clusters (where some suppliers were responsible for modules and technologies) and from a number of individual suppliers within Nokia's direct supply network (between 2004 to 2007) to four different, large, vertically-integrated, multi-technology suppliers like Foxconn, Jabil, BYD, and Lite-on. The evolution of Nokia's supply network impacted innovation dynamics because these large, vertically integrated suppliers gained a substantial role in the platform design, software design, and other development-related aspects of Nokia's products. It remains an open question whether this evolution of the network was good for Nokia or not. Similar questions arise when observing network evolution patterns in the relationship of Microsoft with IBM, or of certain aircraft part suppliers with their customer, for example, Boeing. In general, there is a need for research (probably longitudinal) to distinguish between short-term and long-term causes and effects, benefits, and costs.

Supply networks may also have differential levels of tie strengths and collaboration patterns depending on the entities firms in the networks interact with and the strategies pursued by a firm in creating its network, resulting in the evolution of different network archetypes. For example, Pathak, Wu, and Johnston (2014) introduced different network archetypes of community, hierarchy, federation, and consortium. Specifically, they also explain the evolution of a network from one archetype to another in terms of the strategy of tertius gaudens (keeping supply partners separate for a third party to benefit) and tertius iungens (keeping supply partners together for a third party to benefit), and the resultant cooperation or competition that the network generates.

3.5 | Direction of causality: Supply network characteristics as driver versus outcome

As previously discussed, most research on innovation in supply networks investigates how network characteristics affect innovation outcomes. That is, these models take supply network characteristics as exogenous. However, supply networks are shaped by a multiplicity of actors and forces. Hence, there is a need for theory that explains the characteristics and evolution of supply networks. How do networks change across different industries? Why do they evolve towards or away from a certain type of structure within the same industry? Why do structural holes emerge or disappear? What are the mechanisms that determine these changes? To what extent do firms in the network design, control, prompt, or ride out these changes? Investigating these questions may require researchers to undertake more longitudinal and quasi-experimental studies.

At the end of the day, supply networks are shaped by the decisions of managers and other economic actors; hence, it is fundamental to develop theory that predicts the impacts of *network mechanisms* on *network characteristics* (see Figure 1). It may also be that these decisions are partially driven by innovation goals, past innovation successes or failures, the need to reduce innovation risks, or technological gaps with competitors. A further path to be investigated is therefore the impact of *innovation outcomes* on *network mechanisms* and consequent *network characteristics*. Thus, it would be theoretically useful to model simultaneity in the link between *network mechanisms* and *innovation outcomes*.

3.6 | Understanding supply networks by looking beyond them

Lastly, while the unit of analysis for this burgeoning stream of research is a network of firms linked by buyer–supplier relationships, it is vital to consider more explicitly the role of the ecosystem of stakeholders and institutions that can influence the structure, workings, and performance of the supply network. The Alliance for Automotive Innovation, an organization newly formed in 2020, fosters collaboration among automotive firms to face the innovation challenges caused by electrification (Anonymous, 2020). Governmental agencies promote the collaboration of firms with clusters of academic institutions by creating biotechnology parks (Bstieler, Hemmert, & Barczak, 2015) — a special type of cluster that differs from those normally identified as industrial districts in supply networks. Further collaboration can also be incentivized through explicit innovation policy making by governments. Spring, Hughes, Mason, and McCaffrey (2017) argued that industrial and innovation policies are deeply intertwined in making manufacturing viable in high-cost economies through the systems-of-innovation approach in which emphasis is placed on specific technologies or specific industrial sectors. Two papers in this special issue attest to the importance of the environment.

Li, Li, Choi, and Sethi (2020) analyze the relationship among green supply chain management pressures, practices (an administrative innovation), and performance under the moderating effect of quick response technology. This study finds that export pressures and market pressures play a positive role in the implementation of green supply chain management practices, and consequently, environmental performance. This study also suggests that implementation of green supply chain management practices may be different across countries (Japan and China) that experience different levels of natural resource endowments.

Taking a geo-economic approach, Benton, Skowronski, and Hill (2020) show how the economic environment in which the supplier operates (developing vs. advanced economy) drives the buyer's perception of supplier opportunistic behavior (namely, poaching and shirking)—which has arguably deep implications on the success of the buyer–supplier relation. Their study also reveals that the relation between supplier's economic environment and buyer's perceptions of poaching and shirking are moderated by the supplier's strategic priorities (low cost vs innovation). Their study suggests that buyers' perceptions of perceived poaching and shirking are less dependent on the suppliers' economic environment, to the extent that the supplier pursues low cost. Conversely, this differential perception becomes stronger when the supplier pursues innovation as a strategic priority.

4 | CONCLUSION

In this editorial, we presented a conceptual framework that focused on different attributes of network characteristics, network mechanisms, and network outcomes. We used this framework to examine the common themes in literature around these attributes and considered how the papers in this special issue tied to these themes. Finally, based on our framework, we suggested novel, future research avenues that could extend the past studies as well as the papers published in this special issue.

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