ARTICLES

Orchestration Processes in Network-Centric Innovation:

Evidence From the Field

by Satish Nambisan and Mohanbir Sawhney

Executive Overview

Companies have increasingly shifted from innovation initiatives that are centered on internal resources to those that are centered on external networks (said another way, a shift from *firm-centric innovation* to *network-centric innovation*). In this paper, we combine insights from product development and network theory with evidence from an extensive field study to describe the nature of a hub firm's orchestration processes in network-centric innovation. Our analysis indicates that network orchestration processes reflect the interplay between elements of innovation design and network design. Promising directions for future research related to network-centric innovation are discussed.

As companies try to pursue organic growth strategies, they have increasingly shifted from innovation initiatives that are centered on internal resources to those that are centered on external networks—a shift from *firm-centric innovation* to *network-centric innovation* (Nambisan & Sawhney, 2007). The network-centric innovation model that is prevalent in the technology sector is referred to as the hub-based model, orchestra model, or keystone model (Iansiti & Levien, 2004). While such models have been recognized, the management or *orchestration processes* that a hub firm must perform to coordinate, influence, and/or direct other firms in the innovation network remain poorly understood.

The case of Boeing's development of the Dreamliner 787 airplane has clearly illustrated the challenges of orchestration processes. For the Dreamliner, the promise of network-centric innovation was great, but ineffective network orchestration processes had serious implications for the timely completion of the project. With increasing numbers of companies across industries adopting network-centric innovation approaches, it has thus become imperative that we develop a deeper understanding of the nature of network orchestration processes and the organizational mechanisms involved. This paper addresses this important topic.

A hub firm's orchestration activities occur in a dual context—an innovation context and an interfirm network context. In this paper, we integrate concepts and insights from these two areas to examine three critical orchestration processes in network-centric innovation: managing innovation leverage, managing innovation coherence, and managing innovation appropriability. Our analysis indicates that these three processes reflect the interplay between elements of innovation design (for exam-

***Satish Nambisan** (nambis@rpi.edu) is a Professor of Technology Management and Strategy in the Lally School of Management at Rensselaer Polytechnic Institute.*
***Mohanbir Sawhney** (mohans@kellogg.northwestern.edu) is McCormick Tribune Professor of Technology in the Kellogg Graduate School of Management at Northwestern University.*

ple, modularity) and elements of network design (for example, embeddedness and openness).

Specifically, managing innovation leverage involves the interplay between modularity and network openness; managing innovation coherence involves the interplay between modularity and network embeddedness; and managing innovation appropriability involves openness and embeddedness. The central argument in this article is that by examining the connections or relationships between these two sets of design elements or variables, we can develop a better theoretical understanding of the orchestration processes in network-centric innovation. We further illustrate the above three orchestration processes, their underlying relationships, and associated practices by drawing on evidence from an extensive field study of collaborative innovation initiatives.[1] By doing so, we seek to emphasize the need to adopt a process perspective to understand the challenges related to network-centric innovation (Dhanaraj & Parkhe, 2006; Lichtenthaler, 2011) and indicate the considerable potential for future research to build on existing studies in the areas of product development and interfirm networks. We also develop the foundation for future research on network orchestration by integrating innovation design and network design concepts and identify several important directions for future research in this area, including the need to study the interaction effects among a portfolio of orchestration processes. We start by describing the study context: the hub-based or orchestra model of network-centric innovation.

Toward a Process Perspective of Network-Centric Innovation

The hub-based or orchestra model involves a group of firms coming together to exploit a market opportunity based on an explicit innovation architecture that is defined and shaped by a dominant firm. Based on the role played by the hub firm, two different forms of such an orchestra model can be identified: an *innovation integrator* model and a *platform leader* model (Nambisan & Sawhney, 2007).

Hub Firm as Innovation Integrator and as Platform Leader

As an innovation integrator, a hub firm defines the basic architecture for the core innovation and then invites network members to design and develop the different components that make up this core innovation. The hub firm integrates these different components to build the core innovation and then markets it. A typical example of such an integrator model is Boeing's development of the Dreamliner 787, for which Boeing assembled a set of global partners whom it could trust with the process of creating entire sections of the plane, from concept to production. Boeing made a critical shift from making its partners "build to print" to making them "design and build to performance." The design and development tasks were not just outsourced to these partners; instead, partners made financial investments in those tasks—specifically, partners were required to invest in the project by paying the upfront cost related to design and development (this came to approximately $4 billion of the original $10 billion estimate for the 787 project).

Although each global partner had considerable autonomy with regard to the design of the individual components, Boeing remained the central decision maker in the network. Boeing's role as integrator thus required it to envision and clarify the innovation architecture, facilitate and coordinate the innovation activities of the network partners, and integrate the components and bring the finished product to the market (thereby enabling its partners to appropriate value from their innovative contributions).

As a platform leader, a hub firm defines and offers the basic innovation architecture, which then becomes the platform or the foundation for other network members to build on through their own complementary innovations. These complementary innovations extend and/or enhance the reach and range of the basic architecture or platform. Salesforce.com, the leading "on-demand"

[1] As part of our research on network-centric innovation, we conducted case studies of collaborative innovation projects led by companies such as IBM, Boeing, Microsoft, Henkel, and Salesforce.com. Our effort included conducting multiple interviews in each organization as well as detailed examination of internal reports (such as partner reports and process documentation) and other published materials.

enterprise software solution provider, offers a typical example of this model. The company's core offerings focus primarily on sales force automation, marketing automation, partner relationship management, and customer service/support automation. The unique aspect of the company's core offerings is their availability as "on demand" services that client companies can access through a regular Web browser over the Internet.

Starting in 2003, the company began building a network of partners to harness the innovativeness and capabilities of external developers and transform itself into an all-purpose enterprise computing infrastructure provider. The company defined the AppExchange platform (later renamed Force.com), a foundational on-demand architecture that enables external developers to build applications that complement and extend the scope of the company's core offerings. The company also established the AppExchange forum, which provides a marketplace for partners' complementary solutions and facilitates the sharing of knowledge related to the technology platform. Thus, an *innovation integrator* primarily focuses on envisioning the core innovation and integrating partners' contributions to create the final product or offering, whereas a *platform leader* focuses on defining and developing the core innovation (platform) and facilitating partners' complementary innovations that expand its reach and range.

Orchestration Processes

Prior studies (e.g., Gawer & Cusumano, 2002; Iansiti & Levien, 2004; Nambisan & Sawhney, 2007) offer several examples and case studies of hub firms playing the above two roles. However, despite their significance, the management or orchestration processes that comprise these roles remain unexplored, indicating a critical limitation in our understanding of how hub firms should facilitate both value creation and value appropriation in their networks. We know that hub firms perform several orchestration processes, including managing innovation leverage, managing innovation coherence, managing knowledge flows, managing network membership, managing network stability, and managing innovation appropriability. Here, we focus on three of these processes: managing innovation leverage, managing innovation coherence, and managing innovation appropriability (see Table 1).

In an innovation network, members in the network can leverage (reuse or redeploy) the technologies, processes, and other innovation assets of other member firms in the network to facilitate or enable their own innovation (Iansiti & Levien, 2004). Such *innovation leverage* generates additional value in the network (for asset owners as well as for firms that leverage the assets), and the potential for innovation leverage enhances the appeal of the network to existing and future members. Managing or enhancing the opportunities for innovation leverage in a network, thus, forms an important task for a hub firm, and requires it to focus on both the structure of the assets that can be leveraged (innovation design) and the relationships among the members involved in that process (network design).

Managing *innovation coherence* relates to the internal and external coherence of the innovative activities and outputs of the network. Internal innovation coherence relates to the coordination and alignment of processes and outputs of the members within the network (Gerwin, 2004; Welborn & Kasten, 2003), while external innovation coherence relates to the alignment of the goals and outputs of the network vis-à-vis the external technological and market environment (Gawer & Cusumano, 2002). Managing such innovation coherence requires a hub firm to envision and champion changes in the network, in terms of both the innovation goals and architecture (innovation design) and the roles and interactions of the network members (network design).

Managing *innovation appropriability* relates to the mechanisms available for partners to appropriate value from their innovative contributions. Given the potential diversity of partners and their contributions, the hub firm has to play a key role in ensuring equitable distribution of value and in mitigating appropriability concerns the members might have (Dhanaraj & Parkhe, 2006). Bringing clarity to innovation appropriability requires a focus on the nature and packaging of the contributions (innovation design) as well as on the

Table 1
Orchestra Model of Network-Centric Innovation and Network Management Processes

	Hub-Based or Orchestra Model of Network-Centric Innovation	
	Hub Firm as Integrator	Hub Firm as Platform Leader
Key Objective	• Integrate partners' technological assets and capabilities in the development of new product or service	• Support the partners in creating complementary products/services that enhance the reach and range of the platform
Primary Tasks	• Define and explicate the innovation architecture • Assign specific roles/responsibilities to partners • Provide a common technological/process infrastructure	• Define the innovation platform and access points • Provide platform-specific technological expertise • Offer market-based mechanisms for value appropriation
Managing Innovation Leverage	• Offer a common set of technologies, tools, and other assets that partners can deploy across modules with the objective of ensuring consistent quality and enhancing the ease of module integration	• Establish a common repository for partners to share their proprietary tools, technologies, and other assets with one another with the objective of minimizing design/development redundancies and facilitating faster product development
Managing Innovation Coherence	• Make appropriate changes in the innovation architecture to maintain external innovation coherence and ensure that partners adapt their modules accordingly • Coordinate interactions/activities among partners to ensure internal innovation coherence	• Redefine the innovation platform to meet new market requirements and rally partners to adapt their complementary products/services • Redefine the access points and coordinate knowledge sharing among partners to ensure continued interoperability and compatibility
Managing Innovation Appropriability	• Establish policies and guidelines for fair and equitable distribution of rights associated with all intellectual property assets created during the innovation project • Allocate and distribute partners' share of the rewards from product/service commercialization	• Establish and operate open market-based mechanisms for partners to appropriate value from their complementary products/services • Offer additional support for value appropriation including co-marketing arrangements

nature of relationships and transactions among members (network design).

Elements of Innovation Design and Network Design

All of the above three network orchestration processes (managing innovation leverage, managing innovation coherence, and managing innovation appropriability) potentially involve characteristics or elements of both innovation design and network design. Studies in the area of product development (e.g., Baldwin & Clark, 2000; Kim & Wilemon, 2003; Nambisan, 2002; Ulrich & Eppinger, 1999) present several important elements of innovation design, including modularity, choice of technology standards, development process frameworks, technological novelty and risk, and product complexity.

Similarly, drawing on the social network literature (e.g., Coleman, 1990; Dacin, Ventresca, & Bead, 1999; Zaheer, Remzi, & Hana, 2010), we can identify several key network design elements, including embeddedness, openness, cohesion, density, and centralization. The connections or relationships between these two sets of design elements or variables describe the nature of the orchestration processes in network-centric innovation. Given our focus here on the three orchestration processes, we limit our examination to the interplay among three of these design elements: modularity, openness, and embeddedness. The other design elements (mentioned in the last two paragraphs but not examined in this article, for example, choice of technology standards, development process frameworks, centralization, cohesion, etc.) offer additional opportunities for understanding the orchestration processes.

The term *modularity* is used here to imply the degree to which the network's innovation architecture has been decomposed into independent or loosely coupled modules (Baldwin & Clark, 2000) and the interfaces that connect those modules have been specified and standardized (Langlois, 2002; Sanchez, 1995). Modularity can manifest at both the physical level (i.e., in terms of the arrangement of the physical components) and the informational level (i.e., in terms of the arrangement of the knowledge the system comprises) (Richard & Devinney, 2005).

Network *openness* relates to how open or closed an innovation network is. Structural openness reflects the ease with which firms can enter (or exit) the network, that is, the extent to which the boundary of the network is open or permeable (Wasserman & Faust, 1994). Innovation networks can range from closed systems to gated systems (that exercise controlled access) to open systems. Decisional openness reflects the extent to which the innovation decision rights are distributed among the network members, that is, the degree to which the locus of innovation decision-making is diffused in the network. Thus, from the perspective of the "core/periphery" model (Borgatti & Everett, 1999), a network with decision-making rights concentrated in the "core" entities is said to have lower decisional openness than one in which such rights are dispersed among the "peripheral" entities too.

Network *embeddedness* relates to the contextualization of member activities and interactions in the social structures of the innovation network (Baum & Dutton, 1996; Dacin et al., 1999); two dimensions of such network embeddedness assume importance here.[2] Structural embeddedness describes how well the network members are linked (directly or indirectly) to one another, that is, it captures the overall connectedness of the network structure (Dacin et al., 1999; Jones, Hesterly, & Borgatti, 1997). Cognitive embeddedness relates to the degree of shared cognition among the network entities (Dacin et al., 1999; Nahapiet & Ghoshal, 1998), that is, the extent to which members are connected to one another through shared vocabulary, common representation and interpretation schemes, and overlapping domains of knowledge.

Next, we examine the connections between these innovation and network design elements and the three orchestration processes. Figure 1 provides an overview of the relationships; Table 2 lists illustrative organizational strategies and practices.

Managing Innovation Leverage

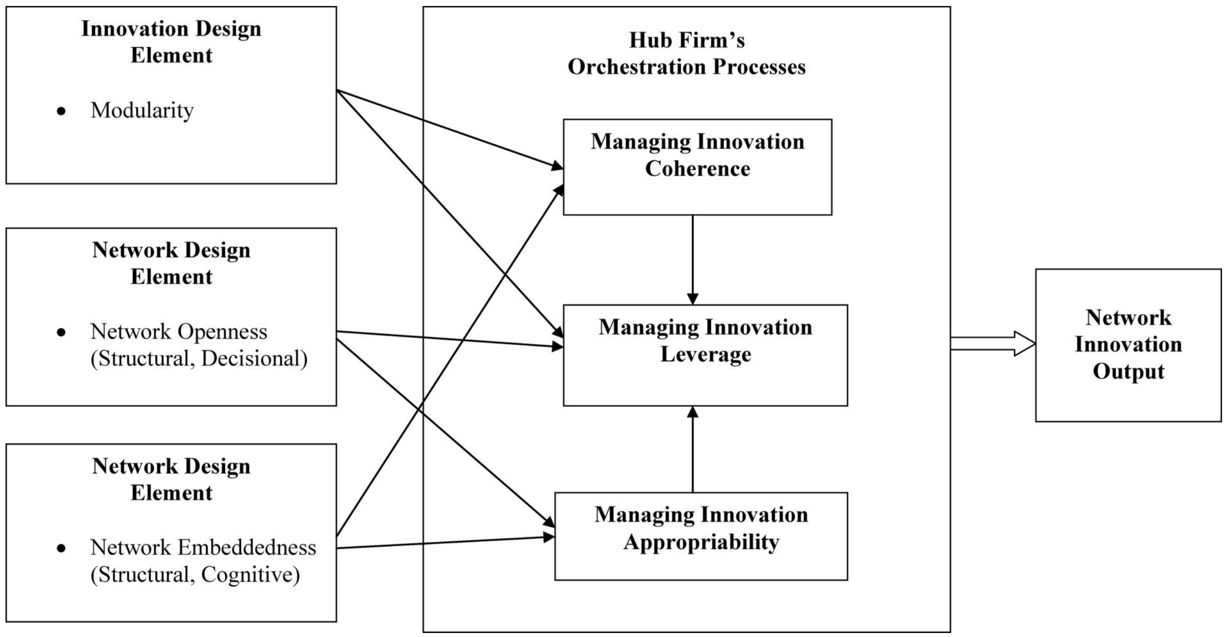
Innovation leverage relates to the sharing or reuse of technologies, processes, intellectual property, and other innovation assets by members of the network. The term "leverage" applies if the value generated by the assets divided by the cost of creating, maintaining, and facilitating their sharing (or reuse) increases rapidly with the number of network members that use or deploy them—that is, if the asset's value curve increases with N (number of users) with an exponent that is larger than one (Iansiti & Levien, 2004). Examples of such leverageable assets include design libraries in the semiconductor industry, sharable utility components (e.g., device drivers, Java beans) and application development tool sets in the software industry, and assaying stations in the pharmaceutical industry. Apart from the initial cost of asset creation, the cost of maintaining and hosting the assets will typically be low compared to the value that can be generated from them through their sharing or multiple deployment by other network members. Therefore, the "surplus value" that is generated through such leveraging of innovation assets by network members could potentially enhance their innovation output.

A hub firm has a central role to play in creating the opportunities for and facilitating such innovation leverage in a network. In its role as integrator, a hub firm typically owns and manages the leverageable assets. For example, Boeing owns many of the design diagnostic and testing tools used by its network partners in the development of the 787. These tools are hosted by and made available through a common IT-based collaborative design environment established and managed by Boeing. By doing so, Boeing has been able to ensure consistent quality levels across partners' modules and enable their faster integration.

In its role as platform leader, often a hub firm's role is to identify assets that may be owned by network partners but may have more common applications, and to facilitate their leveraging in the network. For example, consider the semicon-

[2] The other two aspects of embeddedness identified in the literature, cultural embeddedness and political embeddedness (Zukin & DiMaggio, 1990), have limited relevance in the current context.

Figure 1
Orchestration Processes, Innovation Design, and Network Design



ductor chip fabrication network led by TSMC, an integrated chip manufacturer. Artisan Components, a Silicon Valley firm that is a member of TSMC's network, provides a rich set of design libraries used by the other members of the network. TSMC does not own those assets; however, it hosts the assets and facilitates their leveraging by other members. Utilizing such a common set of design assets has enabled its partners to minimize development redundancies in the network and thereby reduce both development cost and time.

Innovation Leverage, Network Openness, and Modularity

A hub firm can establish varied mechanisms to enhance the extent of innovation leverage in the network; however, the opportunity for such leverage would likely be defined by the inherent characteristics of both the innovation architecture (specifically, modularity) and the network structure (specifically, network openness).

The potential for innovation leverage will be enhanced by the *openness* of the network—both structural and decisional openness. First, structural openness (or more open network boundaries) allows new members to join the network, thereby enhancing the degree to which existing innovation assets can be leveraged (Iansiti & Levien, 2004). New members may also contribute additional assets that existing members may leverage. Second, members are also likely to be more willing to leverage other members' innovation assets if they perceive greater decisional openness (i.e., the potential to influence or shape the decisions related to those assets) (Gawer & Cusumano, 2002). Thus, to enhance innovation leverage, a hub firm will need to maintain both structural and decisional openness.

In most networks, however, these two factors tend to pull in opposite directions. In general, an increase in structural openness (more open boundaries) is likely to erode network ties or more transient network ties[3] (Lorenzoni & Lipparini, 1999), leading to less cohesiveness in terms of shared goals and ultimately the need to concentrate innovation-related decision rights among a few core members (lower decisional openness) (Coles, Harris, & Dickson, 2003; Grandori, 1997). On the other hand, the static stability of a relatively closed network facilitates wider distribution of such decision rights. Thus, the opposing rela-

[3] In many technology areas, possession of unique assets and other supply-side factors drive network membership (e.g., Venkatraman & Lee, 2004), rather than merely prior alliance history (Gulati & Garguilo, 1999).

Table 2
Network Management Strategies and Practices

Orchestration Process	Sample Strategies and Practices
Managing Innovation Leverage	• Identify opportunities for asset leverage by analyzing common innovation activities among partners • Modularize leverageable assets by redefining innovation architecture • Establish centralized infrastructure to host and to facilitate asset leverage • Group leverageable assets based on their usage context and offer guidance • Establish forums to involve partners in the design and development of leverageable assets • Define multiple levels of partner involvement in asset design based on intensity of asset leverage • Implement systems for monitoring and accounting asset usage by partners
Managing Innovation Coherence	• Utilize ties among partners to disseminate information on the changes in the innovation platform • Utilize common vocabulary/frameworks to shape partners' perspectives on the innovation platform • Offer tools based on common vocabulary and frameworks to facilitate transition to revised platform • Group partners based on innovation architecture to redefine member interactions and task coordination • Organize workshops, etc., to rapidly redefine partner ties based on revised innovation architecture
Managing Innovation Appropriability	• Utilize partner certification and other practices to enhance trust among partners for sharing of assets • Involve partners in devising norms and policies related to IP rights management • Establish IP rights management committees with partner representation to resolve IP-related issues • Implement systems that enhance transparency related to the sharing and usage of IP rights • Provide partners with easy and transparent access to hub firm's commercialization infrastructure

tionship between structural and decisional openness poses a critical challenge for hub firms in deploying mechanisms to enhance innovation leverage in the network.

The *modularity* of the innovation architecture moderates the relationship between structural and decisional openness, and hence forms an important lever for a hub firm to manage innovation leverage. Specifically, modularity enables enhancing the structural openness of a network without increasing the need to limit its decisional openness. Through a carefully crafted modularization strategy, a hub firm can maintain both aspects of network openness, and thereby support innovation leverage.

The first aspect of such a modularization strategy relates to the strategic partitioning of the leverageable assets so as to support the structural openness of the network and enhance the ease of leverage in such an open network. In an innovation network, the common elements of the varied innovation problems being addressed by the network members indicate the potential areas for innovation leverage (Iansiti & Levien, 2004). By identifying the solutions pertaining to such problems and devising an architecture that isolates those components into loosely coupled modules, a hub firm can enhance the ease with which members can leverage the innovation assets. It lowers the cost of augmenting/excluding the assets (Baldwin & Clark, 2000) and reduces the probability of ripple effects in the innovation system (Sanchez, 1995). Such an approach also lowers the cost and effort for new members to customize their leverageable assets to fit the network's innovation architecture. Further, given the performance implications of the partitioning decisions in modular systems (Ethiraj & Levinthal, 2004), decisions on the appropriate decomposition for leverageable assets can be guided by the pattern of asset usage (that in turn reflects the underlying problem structure) rather than merely asset ownership.

Both Boeing and Salesforce.com (as integrator and as platform leader, respectively) offer good, albeit slightly different, examples of this approach. In the 787 project, Boeing was primarily concerned about final module integration, and much of its effort focused on offering its partners a common set of design and testing tools to enhance module interoperability. The company early on realized the potential for leveraging common assets to enhance product quality, and as such was able to incorporate this aspect in making key decisions about the basic configuration (or architecture) of the new plane. Boeing also assumed the responsibility for building design and testing tools that would help its partners overcome challenges related to module interoperability. These common assets were then partitioned into different packages based on their likely use during joint development and hosted on Boeing's proprietary IT-based global virtual collaboration environment.

In the case of Salesforce.com, however, the development tools and libraries were not predefined; rather, they evolved as the solution space and the technology platform (i.e., AppExchange) evolved. Further, while some of these common assets were developed by Salesforce.com, many were contributed by its partners, who in a role similar to lead users had developed them primarily for internal use. Importantly, the company mapped these various tools and libraries into different "use packages" based on their underlying domain or technology-related knowledge and the inherent informational modularity of the AppExchange platform. By defining and establishing such a well-defined structure for offering the varied assets, the company positioned itself to leverage assets owned by its partners (rather than assuming the responsibility for developing all the assets). The company combines this with tailored guidelines for the usage of each package of tools. As a result, partners (including new partners) have used these tools to a great degree and have developed subsequent complementary innovations at lower cost.

Prior research has shown that such a strategic partitioning of modules can allow partners to share components without negative effects on performance, such as an inability to evolve or higher integration costs (Nambisan, 2002; Schaefer, 1999). Thus, careful consideration of modularity—typically physical modularity in the case of integrator and informational modularity in the case of platform leader— helps to maintain the structural openness of a network and enhance the ease of innovation leverage by new and existing members in the network.

Modularization strategy also enables a hub firm to enhance the decisional openness in an open network through appropriate partitioning and allocation of decision rights (i.e., involving firms that leverage the assets). Given its close collaboration with partners, an "integrator" hub firm can directly involve its partners in the development and specification of the access points to the leverageable assets. Access points relate to the standardized modular interfaces and the specialized interpretation tools that facilitate the use of the assets in different contexts (Baldwin & Clark, 2000).

For example, all 14 of Boeing's main global partners were involved in the specification of the basic configuration of the 787 and the related common design and testing tools (although the actual development of these tools was undertaken by Boeing). Their involvement during the joint development phase enabled the partners to better understand the benefits of leveraging these common assets, and in turn led to their more effective use. Note that a modular structure enables a wider set of firms (including peripheral members) to rapidly acquire and share a worldview of the innovation system (Parnas, Clements, & Weiss, 1985) and the role of the leverageable assets in it, thus empowering them to effectively participate in such decision making. Indeed, in the case of Boeing, many of the suggestions to further improve some of these tools originated not from its global partners but from the second-tier suppliers (peripheral members) that had employed some of these tools in their work with global partners.

Thus, our research suggests that hub firms should implement a tiered decision-making structure whereby members that play more important roles in innovation leverage gain more say in such decisions. Such an approach would also facilitate more dynamic levels of participation by network partners (i.e., over time partners that are active participants may become less so and vice versa). For example, Salesforce.com employs its AppExchange forum to involve a subset of the complementary product developers—primarily those developers with multiple active products—in defining/enhancing the design libraries and setting the parameters for their usage. The strategic partitioning of leverageable assets, as described earlier, also enables partners to offer critical insights based on their asset usage experience (which also takes into consideration other related leverageable assets), and thereby provides additional incentives for asset owners to involve such members in decisions related to the modification of the assets themselves. Such decisional openness further enhances members' willingness to leverage the assets. For example, IBM in its role as the platform leader of the Power Architecture network has set up advisory groups for maintaining the interface specifications and interpretation tools. These advisory groups, which include a wide range of network partners (representing the application of the Power Architecture in different industries/markets), enable the partners to offer feedback on asset usage in different contexts and to influence their evolution.

Thus, on one hand, careful definition of the modular structure supports structural openness by enhancing the ease of asset leverage by new/existing members in the network and the ease of expanding the portfolio of leverageable assets. On the other hand, careful definition of the modular structure also supports decisional openness by facilitating the establishment of more open decision-making processes related to those assets. The moderating effect of modularity on the relationship between structural openness and decisional openness is central for a hub firm's ability to manage innovation leverage in a network. In short, a hub firm—an integrator or a platform leader—can orchestrate innovation leverage in the network by devising and deploying a modularization strategy that maintains structural openness without sacrificing decision openness. Table 2 lists a sample set of actions and practices that typify such a modularization approach.

Managing Innovation Coherence

Firms operating within an innovation network risk becoming entrenched in a static vision of how the industry/market and the associated products and technologies should evolve (Bullinger, Auernhammer, & Gomeringer, 2004; Welborn & Kasten, 2003). Thus, lack of *external innovation coherence*—that is, coherence between a network's innovation goals and architecture and the external technological and market context—could diminish the value of the network output. For example, in the early 2000s, the emergence of new wireless technologies and smartphones posed a critical threat to Palm Inc.'s innovation network in the handheld computing area, forcing the company to redefine the network's innovation architecture to maintain the external relevance of the network outputs (PDA-related products/services) (Gawer & Cusumano, 2002). Early identification of such external threats and rapid evolution of the network's innovation architecture are important to ensure the external innovation coherence of the network.

Internal innovation coherence—alignment of the innovation tasks, components, and interactions of the members within the network—is also critical to ensure network innovation output. The need to reestablish such internal coherence may arise when there is significant flux in network membership (e.g., addition of new members) or in innovation architecture (e.g., incorporation of new technologies or standards). Lack of such coherence is typically evidenced in terms of process delays, design redundancies, technological incompatibilities, higher innovation costs, and inferior performance (Bullinger et al., 2004; Gerwin, 2004). As the number of members and the diversity of their activities in the network increase, managing internal coherence becomes more critical.

In an innovation network, a hub firm has an important role to play in managing innovation coherence, both internal and external. Its success in orchestrating external innovation coherence by correctly interpreting the waves of external technological/market changes and rallying other members around those changes decides the continued relevance and market value of the network's innovation output. Similarly, its ability to coordinate and align the varied processes and outcomes in the network determines the overall innovation efficiency and effectiveness of the network. In sum, a hub firm—in its role as integrator or platform leader—can enhance innovation output by orchestrating external and internal innovation coherence. Despite the significance of this, such a focus is missing in both research and practice.

Innovation Coherence, Modularity, and Network Embeddedness

Both modularity and network embeddedness can play critical roles in shaping a hub firm's strategy for managing innovation coherence in a network. Specifically, while embeddedness becomes important in managing external innovation coherence, modularity assumes prominence in managing internal innovation coherence. Next, we discuss how embeddedness-based mechanisms enable managing external innovation coherence whereas modularity-based mechanisms enable managing internal innovation coherence. We then consider the implications of the duality between these two sets of mechanisms (i.e., embeddedness-based and modularity-based) for managing innovation coherence.

External Innovation Coherence and Embeddedness-Based Mechanisms. To address external technological/market dynamics, a hub firm needs to envision and champion changes in the innovation architecture (modules and their interrelationships). In more dynamic environments, responding to such external factors may even call for remodularization—that is, redefining the encapsulation boundaries of the innovation system (Langlois, 2002). Microsoft's .NET initiative, launched in 2002, is a good example of this. The .NET initiative arose out of the need to address the threats posed by Internet and related technologies to Windows-based products and services offered by Microsoft and its network partners. The company decided to transition to a service-oriented architecture (SOA), which in turn had the potential to significantly redefine the roles and contributions of the network partners. In such situations, while some partners may opt to leave the network, to succeed in its agenda-setting role, a hub firm needs to hold onto the other partners and rally them around those changes—that is, persuade them to adapt to the revised architecture. A hub firm's success in reestablishing external innovation coherence will be shaped by its ability to deploy mechanisms that draw on the embeddedness that preexists in the network.

Embeddedness-based mechanisms facilitate two micro-processes that constitute a hub firm's orchestration of external innovation coherence: (a) information dissemination and (b) information interpretation and persuasion. Faster and more efficient information and knowledge dissemination (Davis, 1991; Inkpen & Dinur, 1998) and the greater extent of trust (Coleman, 1990) associated with structural embeddedness form the backdrop for the mechanisms a hub firm may employ to communicate and build confidence in its new vision. For example, in addition to communicating directly with application developers, Microsoft also co-opted key industry players such as IBM[4] and HP to disseminate information about .NET to other second-tier and third-tier network members. Further, it used its alliances with firms such as Avanade and Thetis Technologies (which develop applications for select markets) to disseminate industry-specific information about .NET to other developers. Similarly, in the early 2000s, Palm Inc. employed its close ties with major companies such as Nokia, Motorola, Qualcomm, and Sony to advance its new vision for the handheld devices market. Palm also held a developers' conference, which helped the company strengthen its ties with hundreds of complementary developers and shape their views of the redefined technology platform it was promoting.

The limitations of such a "conduit" model with regard to information interpretation (Nahapiet & Ghoshal, 1998) indicate the critical need to consider cognitive embeddedness too. The collective meanings, frameworks, and systems of thought that underlie cognitive embeddedness can be leveraged by a hub firm to guide or steer members' interpretations of the changes in the innovation system. For example, Microsoft leveraged the common vocabulary and frameworks provided by protocols such as XML and SOAP to aid and to shape network partners' interpretations and understanding of the .NET agenda. More recently, it has started offering tools that are based on such frameworks to facilitate the interpretation of and the transition to .NET in specific application domains (e.g., its Portal Development Kit for the ERP application area).

Shared cognition may play a role in channeling member firms' perceptions and definitions of strategic issues and in shaping their related actions (Dacin

[4] This was before IBM devised its own SOA agenda based on Rational Software, which it acquired in 2002.

et al., 1999; Porac, Thomas, Wilson, Paton, & Kanfer, 1995; Walsh, 1995). For example, in the case of Palm, the company encouraged an informal Web-based forum (run by an e-commerce company called PalmGear H.Q.) for its "community of users" (i.e., partners) to exchange information and to develop a shared understanding of the new technology platform. Such shared cognition may constitute a "zone of familiarity" and common starting point for member firms to transition to the revised architecture, and can be leveraged by the hub firm to "sell" or to advance its agenda.

Internal Innovation Coherence and Modularity-Based Mechanisms. Adoption of changes in the innovation architecture or incorporation of new members indicates potential changes in the nature of interactions among members and among innovation components, and calls for reestablishing internal coherence. Modularity-based mechanisms assume significance in such contexts. A critical function of modularity, one that has found limited focus in the product development literature, is communication and coordination. Much of the product development literature has emphasized flexibility as the primary functionality of a modular structure (Baldwin & Clark, 2000; Ulrich & Eppinger, 1999).

In software development, however, the communication aspect of modularity has often been deemed more critical than its flexibility-related function (Meyer, 1988). A modular structure not only communicates to the key design stakeholders the underlying assumptions and expectations related to the functions and roles of the different parts, but also provides the information structure that serves as the foundation for coordinating and synchronizing activities and interactions during the innovation process (Richard & Devinney, 2005; Sanchez & Mahoney, 1996).[5] Thus, by employing mechanisms that leverage the inherent modular structure, a hub firm could potentially redefine member- and task-level innovation interactions in the network and reestablish internal coherence.

For an innovation integrator, this would imply forming groups of partner firms (working groups) that reflect the modular groupings in the innovation architecture to enforce and maintain interfirm task coordination. For example, Boeing divided its overall 787 development effort into six integrated assemblies, or "work packages." The network partners associated with each work package were brought together and their interactions and activities coordinated separately. Such an approach enabled Boeing to sustain the overall internal coherence of the development activities. It also enabled Boeing to effectively manage the added complexity that generally arises when new partners (e.g., second-tier suppliers) join the development effort.

As a platform leader, a hub firm can deploy mechanisms that provide the context for or host interfirm interactions and coordination activities. For example, Intel organizes compliance workshops (Gawer & Cusumano, 2002) at which related member firms come physically to one place to coordinate and test the interoperability of their innovation components. Such workshops also enable members to rapidly reinterpret and reestablish the interfirm innovation linkages based on the revised innovation architecture or standards. Salesforce.com organizes "developer meetups" at locales around the world that enable developers to demonstrate their latest products to peer companies and to identify potential alliances and ties based on product interactions.

Duality Between Embeddedness-Based and Modularity-Based Mechanisms. So far we have discussed the significance of modularity-based and embeddedness-based mechanisms to manage internal and external innovation coherence, respectively. The notion that organization design may reflect product design (Sanchez & Mahoney, 1996) when extended to the interfirm network context (Langlois, 2002) indicates the potential duality between modularity and embeddedness. The orchestration process of managing innovation coherence can then be viewed as capturing or reflecting such a duality between these two concepts and their associated mechanisms.

[5] Richard and Devinney (2005) offer an excellent discussion of the implications of the modularity-based information structure on supply chain operations in a network.

In the external coherence phase, a hub firm may rely on embeddedness-based mechanisms to transition a network to a new or revised architecture—as Microsoft did with the .NET architecture—and in the process reconfigure innovation design-based connectivity. In the internal coherence phase, a hub firm may depend on modularity-based mechanisms to coordinate or redefine interfirm interactions and linkages—as Boeing did in the 787 project—and in the process reconfigure network design-based connectivity. In other words, modularity-based mechanisms help redefine embeddedness and embeddedness-based mechanisms help redefine modularity. The duality between modularity and embeddedness connects these two types of mechanisms and serves to bring congruence to the hub firm's efforts at managing both internal and external innovation coherence in the network. In Table 2 we list several practices that illustrate this.

Managing Innovation Appropriability

A hub firm has a central role to play in ensuring the establishment of the right set of mechanisms for network members to appropriate value from their innovative contributions. The significance of appropriability mechanisms in mitigating network members' concerns related to free-riding and other types of opportunistic behavior in innovation networks has been emphasized in earlier studies (Dhanaraj & Parkhe, 2006; Teece, 2000). Network members may also be concerned about their innovations being leaked to their competitors or to companies associated with competing networks (Mowery et al., 1996). Lack of clarity in innovation appropriability could also lead to concerns regarding undue dependencies and potential legal complications from building on or leveraging other members' assets (Kline, 2003). Such fears and concerns are amplified when there is disparity in power and size of the firms involved. For example, in most platform-based networks, firms that desire to build complementary products are smaller and less dominant than firms that own the innovation platform (such as Microsoft and Intel). Similarly, companies that play the integrator role (for example, Boeing) often dwarf their network partners in both size and scope of operations.

When the appropriability regime lacks clarity, firms with the most valuable assets or the most potential to contribute are less likely to participate in the network. And even if they do participate, they are likely to be conservative and minimize the scope of their partnership with other members. On the other hand, when a hub firm is able to orchestrate innovation appropriability, members are likely to adopt a more open approach and seek out opportunities to contribute to the innovation goals (Dhanaraj & Parkhe, 2006).

In the integrator model, more effective orchestration of innovation appropriability would likely motivate partners to be more transparent in their innovation activities, thereby enhancing innovation efficiency. It may also lead them to make more innovative contributions (given the asset protection assured by the hub firm), thereby enhancing the innovation quality or effectiveness. In the platform leader model, better orchestration of innovation appropriability would likely lead partners to be more willing to share their technological knowledge and assets (as well as leverage others' assets), thereby facilitating faster and more cost-effective development of complementary products/services. In general, effective orchestration of innovation appropriability by a hub firm will lead to greater network innovation output.

Innovation Appropriability, Structural Embeddedness, and Decisional Openness

In a network, innovation activities are enhanced by the effective sharing of knowledge—typically, the greater the extent of knowledge that is shared among the members, the greater the opportunities for individual members to build on that knowledge and create value. Key to such rich information sharing, however, is a trust-based environment that encourages member interactions and strengthens the appropriability regime (Uzzi, 1997). As such, a hub firm's orchestration of innovation appropriability should be focused on building trust and providing a broader framework for the knowledge interactions among the members. As we discuss below, this in turn indicates the need to focus on the interplay between two key design elements: structural embeddedness and decisional openness.

Interfirm ties that define the structural embeddedness of the network provide the backdrop for the hub firm to establish a secure and trust-based environment for knowledge sharing (Coleman, 1990; Davis, 1991). Hub firms can deploy mechanisms that leverage the structural embeddedness in the network to minimize undue appropriation of value without sacrificing the intensity of knowledge sharing. Formal contracts best illustrate this approach.[6] Prior studies have shown that contracts do serve to reduce appropriability fears when the outcomes are more explicit (observable) and when the partners understand that exploiting their individual technological capabilities requires collaboration (Mayer & Salomon, 2006). For example, in the case of Boeing, the company spent considerable time and effort at the beginning of the project in establishing formal written contracts with all of its global partners. These contracts largely mirrored the formal ties established by Boeing with (and among) its global partners for joint development of the various sections of the 787.

However, such mechanisms work primarily when the level of uncertainty associated with the innovation activities (and the associated outputs) is relatively low. When such uncertainty is on the higher side—as was the case with the 787 project, given its use of a new carbon composite material for building the fuselage—it is incumbent on the host firm to offer a fair and transparent process for deciding the distribution of the intellectual property rights associated with the outputs. For example, Boeing's global partners conducted considerable R&D (jointly as well as independently) as part of their development efforts in order to better understand the full implications of the new carbon composite material on the design, manufacturability, and functioning of the different components.

Procedural justice (the fairness of the decision process) (Kim & Mauborgne, 1998) assumes considerable importance and implies the need to focus on mechanisms that also enhance decisional openness. A wide range of mechanisms can be deployed by the host firm, including committees to set guidelines for asset ownership decisions and multitiered decision refutation processes. When partners are given a seat at the decision-making table, it enhances the overall trust in the allocation process and minimizes unnecessary legal measures related to the various decisions (Wellborn & Kasten, 2003).

In the case of Boeing, the company complemented the formal contracts with some of these mechanisms. As noted previously, the company had formed different partner groups based on the work packages they contributed to. The strong direct ties (and the intense interactions) among the partners within each group enabled Boeing to develop a sense of trust and openness that encouraged partners to share information on proprietary technologies with limited fear of intellectual property (IP) leakage and misuse. Boeing also involved the partners in developing a set of norms and policies on the management of IP assets created during the development of the 787. Such a participatory approach enabled the global partners to bring forth and resolve their specific IP-related concerns on an ongoing basis—issues that were peculiar to specific work package groups—and subscribe to a shared understanding on the distribution of intellectual property rights.

Salesforce.com also has deployed similar mechanisms that rely on both structural embeddedness and decisional openness to facilitate innovation appropriability for its partner firms. The company established the AppExchange forum to serve as an open, transparent marketplace for complementary products, enabling network partners to appropriate value from their contributions. The forum registration and the certification process instituted by the company helped establish direct formal and informal ties with (and among) its network partners and created a trust-based environment for partners to share as well as market their enterprise software components and modules. At the same time, the forum also serves

[6] Another approach is to use modularity as a mechanism to reduce the need for information sharing among partners and thereby alleviate appropriability concerns. For more details on this approach, see Tiwana (2008).

as a venue for Salesforce.com to jointly set the rules and policies with its network partners regarding knowledge sharing and the use of other partners' IP. While Salesforce.com retains the right to make final decisions on IP issues, the transparent process and the connections among partners serve to reduce potential misunderstandings regarding IP management and enhance partners' overall innovation appropriability in the network.

Hub firms can create a more open and fair appropriability environment within the network by instituting mechanisms that leverage both structural embeddedness and decisional openness. While the former provides the basis for building trust among the partners, the latter enables bringing greater transparency into the development and the administration of the IP rules and policies. These two design elements together form the foundation for hub firms to manage innovation appropriability in the network (see Table 2 for related practices).

Interactions Among Orchestration Processes

We now discuss the interactions among the different orchestration processes—specifically, the relationship between managing innovation coherence and managing innovation leverage and that between managing innovation appropriability and managing innovation leverage. We do not see a direct relationship between the processes of managing innovation coherence and that of managing innovation appropriability.[7]

Managing Innovation Coherence and Managing Innovation Leverage

Managing innovation coherence creates the context for managing innovation leverage. First, higher levels of innovation coherence may enhance the clarity of member firms with regard to how their innovation assets relate to other relevant components and processes in the network. This in turn enhances their ability to evaluate the potential and value of leveraging other assets. For example, Salesforce.com makes visible the potential connections between partners' contributions (components) and its core customer relationship management (CRM) solution and the broader technology platform. The company also uses the testing process (instituted as part of the AppExchange forum) to ensure the internal innovation coherence among the different components, thereby bringing more clarity and facilitating easier evaluation of the components by other partners.

Second, the mutual understanding and coordination among members that ensue from higher internal innovation coherence may enable a hub firm to manage the expectations of the member firms with regard to the leverageable assets. Undue or incorrect expectations regarding the availability, performance, or delivery of the leverageable assets that may arise from a lack of innovation coherence can potentially discourage or retard innovation leverage in the network (Iansiti & Levien, 2004). For example, TSMC, the integrated chip manufacturer, spends considerable time and effort ensuring the optimization of the design tools, components, and libraries (contributed by its partners such as Artisan Components) vis-à-vis its manufacturing platform. As such, when other partners search for components during their design, they understand how these components will perform as well as their potential yield in TSMC's fabrication plant, and are thus able to leverage them in their design work more effectively. Thus, a hub firm's efforts at managing innovation coherence can actually enhance or contribute to its concurrent efforts at managing innovation leverage.

Managing Innovation Appropriability and Managing Innovation Leverage

The appropriability regime of an innovation network will influence the extent of innovation leverage achieved. The role of appropriability mechanisms in mitigating the concerns of member firms providing the leverageable innovation assets (i.e., the asset owners)—concerns related to "free riding" and other opportunistic behavior—is

[7] Appropriating value from an incoherent innovation may be difficult. However, our focus here is on the orchestration processes, and the relevant question is whether the process of managing innovation coherence would contribute to managing innovation appropriability (or vice versa). We think there is limited rationale to conclude so.

evident (Teece, 2000). A hub firm's efforts to orchestrate innovation appropriability encourages members to allow more of their assets to be leveraged by other firms in the network. For example, in TSMC's network, members who contribute to the design libraries do not get any fee up front. Instead they receive royalties when TSMC manufactures chips (designed by other partners) that have leveraged these common assets. Such clarity with regard to value appropriation helps manage members' expectations and in turn encourages them to make more contributions to the common design libraries.

Further, in innovation networks, the concerns of the firms that desire to leverage such assets are also important. Lack of clarity in innovation appropriability could lead to concerns regarding undue dependencies and potential legal complications from leveraging other members' assets (Kline, 2003). Such fears and concerns are amplified when there is disparity in power and size of the firms involved (i.e., when firms that desire to leverage are smaller and less dominant than firms that own the assets). For example, Boeing made it explicit that the design and testing tools developed by the company are available free of charge to its partners (including second-tier suppliers) for use in the 787 development project. At the same time, it created detailed formal contracts for leveraging IP that its partners created (during their own internal R&D on the new carbon composite material). This has enabled partners to understand the legal and financial obligations before utilizing other partners' IP during the project.

IBM offers another such example. The company allows members of its Power Architecture network to leverage many of the core technology components by customizing them to suit specific markets that IBM does not cater to directly. Many of IBM's partners in this network are small companies that have specialized knowledge in specific niche markets, and as such, have the technological capabilities to customize and integrate IBM's core technologies with their own complementary technologies to devise innovative solutions for those markets. However, given their smaller size and resources, often they are wary of leveraging the assets if they are not comfortable with the policies governing value appropriation. To overcome this, IBM clearly spelled out how the partners can appropriate value from these components and how such value will be shared with IBM. Bringing such transparency has allowed smaller partners such as India-based HCL Technologies to actively seek out opportunities to leverage IBM's technology components in different markets.

The above examples indicate that when the appropriability regime lacks clarity, firms are likely to be conservative and minimize innovation leverage, whereas when a hub firm is able to orchestrate innovation appropriability, members are likely to adopt a more open approach and seek out opportunities to leverage one another's assets. Thus, a hub firm's efforts at managing innovation appropriability would likely contribute to its efforts at managing innovation leverage.

Discussion and Directions for Future Research

As hub-based network-centric innovation initiatives become more prevalent, the critical challenge will be to develop a deeper understanding of hub firms' management strategies in such innovation networks. We now discuss some of the important and valuable new directions for future research in this regard.

An important research implication relates to the identification of additional orchestration processes. We limited our focus here to a few key constructs from the product development and network theory areas. A more extensive mapping of constructs from these two areas to the innovation network context and their joint consideration would enable the identification and analysis of additional network orchestration processes. For example, studies in product development have developed multidimensional perspectives of innovation complexity (e.g., Kim & Wilemon, 2003). Extending those study findings and relating them to relevant network theory constructs could lead to insights on the processes a hub firm may employ to manage different types of complexity and risk in innovation networks.

Similarly, technology standards form an important decision point for hub firms in most network-centric innovation initiatives. The selection and implementation of such innovation/technology standards along with the network design elements could describe the management processes a hub firm may deploy to manage technological change and evolution of the innovation. Future studies may focus on identifying such additional orchestration processes and analyzing their underpinning innovation design and network design elements.

A related avenue for future studies is the potential relationships or interactions among the network orchestration processes and the ensuing focus on orchestration process portfolios. Building on the work done here, studies may investigate the interaction effects among a broader set of network orchestration processes (for example, managing network stability and managing knowledge flows). Such potential interaction effects would imply the need for hub firms to adopt a portfolio approach to evaluating the appropriateness of different combinations of network management strategies vis-à-vis the context.

Another research implication relates to the characteristics of the hub firm and their impact on network orchestration. Our focus here has been on innovation networks wherein a dominant firm sets the innovation agenda and orchestrates the network activities, but other forms of network-centric innovation exist. While a single large firm serving as the hub entity (e.g., Boeing's network) is common, networks where a group of firms serve as the hub entity and those with more than one hub (multi-hub networks) are also evident. Similarly, the extent of power enjoyed by hub firms may also vary. In some networks, the hub firm may exercise considerable power, while in other networks the hub firm may be less dominant. Although the basic goals of the network management processes remain the same—for example, enhancing innovation coherence and network asset leverage—the nature of the processes and their implementation likely vary with the structure and power of the hub entity, indicating another promising line of future inquiry.

The need for more rigorous empirical research forms another implication. Given the number of case studies that exist on innovation networks (e.g., Iansiti & Levien, 2004; Nambisan & Sawhney, 2007), meta-research work that treats the orchestration processes as points of departure and collates insights from the various studies could describe the contextual nature of such processes. Another feasible empirical path involves building on these insights to relate the extent of implementation of these management processes by a hub firm to innovation outcomes. Interactions among the processes constitute yet another promising area for empirical work. A hub firm may need to deploy not just one but a portfolio of network orchestration processes. Future studies may empirically examine the implications of the interactions in such a process portfolio on the hub firm's strategies and capabilities on innovation outcomes.

Finally, our analysis also holds implications for research in organizational design. The central message of our paper is that successful management of the orchestration processes will require carefully crafted, deliberate actions on the part of the hub firm—actions that take into consideration both innovation design and network design factors. In turn, this indicates the need for a hub firm to integrate the decision-making processes related to innovation architecture and network or alliance management, two areas that in most firms tend to be situated in different parts of the organization.

For example, our discussion indicates that decisions around modularity optimization (Ethiraj & Levinthal, 2004) should be informed by the hub firm's goals and strategies related to network openness. Future research should examine the elements and forms of organizational design (or the specific structural arrangements) that would facilitate such cross-functional decision-making processes to support network orchestration. Beyond such structural arrangements, future research should also examine the specific skills and capabilities that individual managers will need to appropriately interpret and align decisions being made related to innovation and network design.

In conclusion, this paper has extended the ongoing discussion of network-centric innovation by adopting a process perspective and examining the innovation and network design elements that underlie a hub firm's network management processes. We believe such an approach opens up numerous issues for future research in this area and holds considerable potential to bring clarity to the hub firm's management strategies in network-centric innovation.

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