Unbundling dynamic capabilities for inter-organizational collaboration

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Unbundling dynamic capabilities for inter-organizational collaboration

The case of nanotechnology

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Abstract

Purpose – The purpose of this paper is to explore two distinct subsets of dynamic capabilities that need to be deployed when pursuing innovation through inter-organizational activities, respectively, in the contexts of broad networks and specific alliances. The authors draw distinctions and explore potential interdependencies between these two dynamic capability reservoirs, by integrating concepts from the theoretical perspectives they are derived from, but which have until now largely ignored each other – the social network perspective and the dynamic capabilities view.
Design/methodology/approach – The authors investigate nanotechnology-driven R&D activities in the 1995–2005 period for 76 publicly traded firms in the electronics and electrical equipment industry and in the chemicals and pharmaceuticals industry, that applied for 580 nanotechnology-related patents and engaged in 2,459 alliances during the observation period. The authors used zero-truncated Poisson regression as the estimation method.
Findings – The findings support conceptualizing dynamic capabilities as four distinct subsets, deployed for sensing or seizing purposes, and across the two different inter-organizational contexts. The findings also suggest potential synergies between these subsets of dynamic capabilities, with two subsets being more macro-oriented (i.e. sensing and seizing opportunities within networks) and the two other ones more micro-oriented (i.e. sensing and seizing opportunities within specific alliances).
Practical implications – The authors show that firms differ in their subsets of dynamic capabilities for pursuing different types of inter-organizational, boundary-spanning relationships (such as alliances vs broader network relationships), which ultimately affects their innovation performance.
Originality/value – The authors contribute to the growing body of work on dynamic capabilities and firm-specific advantages by unbundling the dynamic capability subsets, and investigating their complex interdependencies for managing different types of inter-organizational linkages. The main new insight is that the "linear model" of generating more innovations through higher inter-firm collaboration in an emerging field paints an erroneous picture of how high innovation performance is actually achieved.

Keywords Dynamic capabilities, Strategic alliances, External networks, FSAs, Nanotechnology, Sensing and seizing

Paper type Research paper

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Introduction

There is hardly any sector of economic activity that has not embraced innovation through inter-organizational collaboration, whether through specific alliances or broader networks. Firm-level responses to a faster pace of competitive dynamics and the heightened importance of knowledge creation via technological change have fueled research on the role of and the value of strategic alliances (Gomes *et al.*, 2016). Similarly, contemporary research from the network perspective suggests that a firm's strategy emerges as a pattern of behavior influenced by a variety of network relationships and constellations (Rowley and Baum, 2008).

Since the pursuit of knowledge-intensive activities and the diffusion of innovation breakthroughs is a global phenomenon, internationally operating firms are challenged to respond to the evolving dynamics in the global business environment, that influence both the networks they operate in and the alliance relationships they need to manage. The inter-organizational governance approach to new knowledge search is particularly salient in nascent, science-driven industries at their embryonic and infancy stages, characterized by interdisciplinary collaboration and diversity of cumulative knowledge (Guan and Liu, 2016; Robinson *et al.*, 2007). Nanotechnology, for example, is a context where such inter-organizational collaboration is the norm for generating *de novo* innovations. Nanotechnological innovations not only traverse different disciplinary technological platforms, they also cross geographic, cultural and institutional boundaries, and as a result require interdisciplinary collaborative approaches among a continuum of organizations.

A dynamic capabilities theoretical lens (Teece, 2007, 2014, 2018) is particularly useful to understand how firms achieve evolutionary fitness with their external environment, thereby adapting to the changing landscape and the nature of their inter-organizational linkages that are in a constant state of flux (Helfat *et al.*, 2007). Dynamic capabilities thinking, is conceptually close to internalization theory, since augmenting firm-specific advantages (FSAs) through novel resource bundling across product and geographic market space is at the heart of both theories (Rugman and Verbeke, 2003; Verbeke, 2013). In this regard, it is important to distinguish between: the capacity of firms to develop and deploy capability subsets focused specifically on sensing and shaping of external opportunities and threats, and the capacity of seizing external opportunities (Teece, 2007). Distinguishing between both dynamic capability subsets can help explain how firms navigate the innovation and collaboration challenges in the global innovation landscape, especially through alliance collaborations and network collaborations (Dhanaraj and Parkhe, 2006; Lam, 2003; Pinho and Prange, 2016; Rothaermel and Hess, 2007).

Although there are many benefits to the firms that engage in inter-organizational collaboration (Parmigiani and Rivera-Santos, 2011), recent research has also revealed the "dark side" of such collaboration, resulting in unintended consequences and failures (Lunnan and Haugland, 2008; Mantovani and Ruiz-Aliseda, 2016). This is an especially poignant problem in the case of international alliances and international joint ventures (IJVs) (Makino *et al.*, 2007). As firms are turning to more flexible and disaggregated forms of value creation, and search the global ecosystems for sources of uniqueness through knowledge-based advantage, two research challenges loom large. The extant literature does not address: how the distinct features of the capabilities in the sensing vs seizing space function specifically; and how successful innovators deploy distinct capabilities across broad networks vs specific alliances.

It is these two challenges that we address in the present paper, and that lead to the following main research question:

RQ1. How do subsets of capabilities deployed in specific alliances (domestic and international) vs broader networks affect directly, and through interaction effects, firm-level innovation outcomes?

As a result, we are able to shift away from "individualist, essentialist and atomistic explanations" of sustainability of competitive advantage toward more "relational, contextual and systemic understandings" (Borgatti and Foster, 2003, p. 991) of innovation success. Furthermore, our new insights on dynamic capabilities also offer a starting point to understand better the process-related aspects of resource bundling in FSA creation. The critical process dimension of resource bundling is often neglected in both the mainstream strategy and international business strategy literatures (Matysiak *et al.*, 2018). We show that firms differ in their dynamic capability reservoirs for pursuing different types of inter-organizational, boundary-spanning relationships, which ultimately affects their innovation performance.

We investigate nanotechnology-driven R&D activities in the 1995–2005 period. Our findings indicate that potential synergies exist between dynamic capabilities present within a broader network, and those within specific dyadic contexts, but that these relationships are far more complex than currently portrayed in the mainstream literature. We contribute to the growing body of work on dynamic capabilities by unbundling the dynamic capability subsets, and investigating their complex interdependencies for managing different types of inter-organizational linkages. Insight into these linkages is particularly relevant in today's complex international business environments.

Theory development and hypotheses

To address the two research challenges identified above, we adopt a multi-theoretical approach, and conceptualize the complex system of linkages between capabilities deployed within alliances and networks, respectively. We integrate concepts from the two theoretical perspectives. First, we draw on the dynamic capabilities perspective, specifically on those two elements, that drive the firm's engagement with its external, cross-border environment, namely the sensing and seizing of new knowledge. Teece's (2007) framework deconstructs dynamic capabilities into three distinctive components, namely "[…] the capacity: (1) to sense and shape opportunities and threats, (2) to seize opportunities, and (3) to maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets" (2007: 1319). The current paper addresses the first two of these dynamic capability dimensions, namely opportunity-sensing and opportunity-seizing. These two capability dimensions are particularly salient to understanding how firms become aware of – and act upon – opportunities arising in the firm's external environments. Capitalizing upon such opportunities increasingly requires engagement in cross-border activities (Teece, 2014). By highlighting the value of incorporating dynamic capabilities insight into the study of internationally operating firms, Matysiak *et al.* (2018, p. 244) argue that: "the purpose of [multinational enterprises'] MNEs' sensing, seizing, and transforming is to achieve (ever new) resource–capability recombinations that confer competitive advantages in the form of non-location bound FSAs, CSAs, and location bound FSAs in dynamic industry and country environments."

Second, we draw on the social network perspective, thereby focusing on how firms leverage their ties to a broad range of actors in their environment. Membership in social networks can be based on shared experience, pre-existing social ties or some other form of familiarity that draws participants together (Grabher and Powell, 2004). The social network perspective illuminates how firm's collaborative ties can act both as pipes for knowledge flows and as prisms through which the qualities of knowledge are reflected (Podolny, 2001). In the context of increasing geographic dispersion of global value chain activities, internationally operating firms use strategic modularization to orchestrate complex webs of global intra- and inter-firm linkages that together enable the modern MNE to access, deploy and recombine knowledge, technology and capital resources (McDermott *et al.*, 2013).

The two above theoretical perspectives build upon distinct assumptions, but when taken together, they allow constructing a model that describes how capability subsets operate simultaneously and interact across different inter-organizational activities, thereby contributing to enriched theorizing (Okhuysen and Bonardi, 2011). First, we distinguish between firm-level capability subsets in sensing vs seizing of external, new-knowledge opportunities. Second, we argue that each of these two capability subsets needs to be attuned to the new-knowledge search activity occurring in the context of a specific, contractually governed alliance, vs the context of a broader, relationally governed network.

The contexts of specific alliances vs broader networks require different skill sets, which means that a distinction needs to be made among four capability subsets: alliance opportunity sensing; alliance opportunity seizing; network opportunity sensing; network opportunity seizing.

Linking alliance opportunity-sensing capability and innovation outcomes

Identifying opportunities involves constant scanning, probing, and exploring in local and distant search space (Nelson and Winter, 1982). In today's knowledge-based economy, these search efforts are often conducted through a variety of cross-border activities. Sensing routines are manifested in alertness to external opportunities embedded in the firm's broader systems of relationships (Zaheer and Zaheer, 1997). Yet, overcoming a narrow search horizon is difficult (Teece, 2007). Social network research (e.g. Burt, 1992; Granovetter, 1973; Uzzi, 1996) is a particularly suitable theoretical lens to adopt when examining the foundations of opportunity-sensing capabilities. Social networks are typically treated separately from strategic alliances, but the latter also do operate in a wider business ecosystem. As noted by David Teece (2007): "the search activities that are relevant to 'sensing' include information about what's going on in the business ecosystem" (p. 1324).

Park *et al.* (2002) submit that the sensing of opportunities to enter into strategic alliances is particularly critical for alliance success. Other researchers (Karol *et al.*, 2002; Mindruta *et al.,* 2016) found that having routines for evaluating and identifying partners *ex ante* may lead to higher alliance performance. However, the uncertainty concerning the likely contributions of potential partners is especially high in international environments with different legal, cultural, language and regulatory characteristics (Liu and Maula, 2016).

Paradoxically, the extant research on the alliance context has looked disproportionately at the post-formation dynamics of alliances when addressing dynamic capabilities (Kale *et al.*, 2002; Reuer *et al.*, 2002; Rothaermel and Deeds, 2006), and has primarily examined "skills that are critical to managing an individual alliance *after it is up and running*" (Schreiner *et al.,* 2009, p. 1396, emphasis added). Partner selection is a particularly acute problem in the context of IJVs and international strategic alliances. In their critical assessment of the IJV literature, Nippa and Reuer (2019, p. 570) found that "much of the IJV literature takes a partner as given and then investigates topics such as entry mode, governance, post-formation dynamics and outcomes." Less attention has been devoted to the routines that promote sensing, shaping or calibrating the opportunities around which subsequently an alliance is formed. For example, calibrating complexities that stem from differences in sub-national institutions within emerging economies, such as China, is increasingly required when forming IJVs (Shi *et al.,* 2012). In Teece's (2007) conceptualization of dynamic capabilities, sensing is an essential component of such capabilities.

Scanning the organizational environment for potential partnering opportunities enables the focal firm to create *ex ante* awareness of such opportunities, which then serves as a subsequent admission ticket to an information platform relevant to a particular alliance. The research on dynamic capabilities suggests that managers are key orchestrators of firms' assets, and of its sensing activities (Teece, 2012). As innovation-related goals become more important, the firm's sensing capacity prior to any alliance formation also becomes more critical. Sensing routines lead to a firm-level ability to identify, evaluate and select appropriate alliance partners by scanning the global knowledge and innovation environment, generating awareness of potential opportunities, and interpreting the identified stimuli. Ultimately, these efforts should result in direct and positive effects on firm-level innovation outcomes. Formally stated:

H1. A firm's alliance opportunity-sensing capability will have a positive association with its innovation outcomes.

Linking alliance opportunity-seizing capability and innovation outcomes

As the interest in alliance skills has grown over time, much focus has been placed on the firm's ability to seize opportunities in an alliance context. Over time alliance scholars have investigated the mechanisms that lead to developing an "alliance capability" (Anand and Khanna, 2000; Kale and Singh, 2007) as well as the components of such capability (Hoffmann, 2007; Schreiner *et al.*, 2009). Researchers have used concepts such as "relational capability" (Capaldo, 2007), "alliance capability" (Kale and Singh, 2007), "alliance management capability" (Rothaermel and Deeds, 2006) and "alliance portfolio capability" (Hoffmann, 2007). A common thread in this literature is that alliance capability has been conceptualized as purposefully capturing and exploiting opportunities to either manage any individual alliance or to manage a portfolio of alliances with much emphasis placed on opportunities that emerge during the post-formation phases of an alliance life cycle. For example, scholars have found that having a dedicated alliance function positively affects alliance success (Kale *et al.*, 2002; Hoang and Rothaermel, 2005), while others have suggested that making appropriate choices about alliance structures (Argyres and Mayer, 2007; Hennart and Zeng, 2005) improves the probability of success of any given alliance. International alliances bridge substantively different legal and regulatory systems, as well as normative societal perspectives with respect to the protection of intellectual property. Here, scholars have focused on developing frameworks for designing, staffing and monitoring the collaborative interface between alliance partners so as to balance benefits and risks of sharing proprietary knowledge (Baughn *et al.*, 1997). Heimeriks (2008) found a positive relationship between alliance management mechanisms (such as alliance departments, alliance specialists, alliance databases and alliance procedures) and alliance performance. The above suggests that in addition to sensing, there should be a focus on capacities for seizing opportunities, which should also positively affect firm's innovation (and performance) outcomes. Formally stated:

H2. A firm's alliance opportunity-seizing capability will have a positive association with its innovation outcomes.

Linking network-related dynamic sub-capabilities and alliance-related ones

In this paper, broader organizational networks are conceptualized as consisting of a set of actors connected by a variety of ties[1]. Network research emphasizes that the performance of either an individual or an organization is largely dependent on how that actor is tied into a broader web of social connections that span technological, geographic, cultural, regulatory and broader institutional boundaries. According to the network perspective, the nature of relationships established between various parties in exchange interactions will indirectly influence a firm's strategic decisions and outcomes (Gulati *et al.*, 2000; Nambisan and Sawhney, 2011; Siegel, 2007). The network perspective further suggests that firm-level strategy emerges as a pattern of behavior influenced by a variety of network relationships and constellations (e.g. Burt, 1992; Granovetter, 1973; Uzzi, 1996). Finally, the broader network effects might be important, both in the context of innovations (e.g. Ahuja, 2000; Perri *et al.*, 2017), and specific alliances (e.g. Goerzen, 2007).

Loosely defined network boundaries and the patterns by which information, beliefs or behaviors are transferred and diffused through linkages of a network structure, influence the firm's strategic decisions as it scans its environment and as it forms inter-firm linkages (Ahuja *et al.*, 2008). As noted above, this perspective draws upon sociological antecedents, suggesting that networks can be seen as both pipes and prisms to access market information (Ahuja *et al.*, 2008; Podolny, 2001). Portraying networks as pipes means they are viewed as conduits or channels through which information flows. Conceptualizing networks as prisms refers to processes of inducing differentiation among network actors through selectively amplifying and transmitting information.

The benefits for the firm of viewing networks as pipes include modulating information volume, information diversity and information richness (Ahuja, 2000; Powell *et al.*, 1996; Reiche *et al.*, 2009; Wang *et al.*, 2014). The implicit assumption made, is that innovation ultimately emerges from the firm's recombinant search activities for new knowledge and information flows. A particularly salient aspect of the literature on FSAs (Rugman and Verbeke, 2003) emphasizes recombining and augmenting non-location bound, firm-specific resource bundles that are primarily knowledge-based, to achieve competitive advantage in international markets. If the firm can build organizationally on pipes that feature the most innovative and promising information flows, this will lead to a dynamic sub-capability of opportunity seizing. Here, the firm purposefully creates conditions for decisively acting upon identified opportunities (which may be dispersed across different geographic as well as technological boundaries).

In addition, viewing networks as prisms implies recognizing that they break up the information at hand along a spectrum of relative importance and induce differentiation among actors. Selectivity as to the choice of any organization with whom the firm connects, and the nature of the firm's engagement with that organization, also affects the firm's subsequent relations with other organizations (Podolny, 2001; Vissa, 2011). Here, innovation can emerge from unconventional search behaviors. A firm's ability to scan its networks and to understand the characteristics and substance of the informational content generated by associating with other actors is a functional parallel to a firm's dynamic sub-capability of opportunity sensing in the more specific alliance sphere. But in this case, opportunity sensing by the firm occurs in the realm of constant surveillance of its broader environment for informational clues, with a view to shaping, filtering and calibrating opportunities in its external environment.

Potential partner identification is one of the critical decisions a firm makes when forming an alliance (Li *et al.*, 2008). Partner identification is also a critical element in network research (Zott and Huy, 2007). Yet, partner identification in both research streams has been treated as exogenous. Firms incorporate new partners into their networks for various reasons, e.g., to reduce uncertainty (Podolny, 2001) or to learn about new technologies (Powell *et al.*, 1996). Beckman *et al.* (2004) submit that expanding networks by incorporating new ties vs reinforcing ties with existing partners is somewhat similar to March's (1991) distinction between exploration and exploitation. They argue that co-opting new partners is an exploration response, which broadens the scope of the firm by exposure to new ideas, knowledge and other resources. Scholars have found that firms facing uncertainties in their external environments are motivated to establish new relationships with new types of partners (e.g. universities, research institutions and suppliers) and sometimes even non-market network actors such as politicians (Fernández-Méndez *et al.*, 2018). Incorporating new ties within networks illustrates a degree of intentionality (similar to that found in the alliance context). Identifying new ties reflects the capability subset of sensing opportunities. Actually incorporating new ties in the firm's network functioning (i.e. acting upon the opportunities identified) reflects the capability subset of seizing opportunities.

New relationships enable the firm to diversify its information sources, but we know very little about how awareness of potential networking opportunities within broader networks affects the opportunity-sensing ability of a firm to select specific partners for particular alliances. Examining the "sequence" aspect of such relationships becomes important.

George and Jones (2000, p. 670) submit that "although theories in organizational behavior, more often than not, specify relationships among constructs in causal terms, the duration of effects, the time lag between causes and effects, and differences in rate of change are often left unspecified." This research concludes that examining causality without a temporal lens amounts to a conceptual deficiency. It is thus important not only to examine the role of network awareness for a firm's opportunity sensing sub-capability within this broader network, and how it affects this firm's innovation outcomes, but also how this is related subsequently with the firm's sensing sub-capability for specific partnerships.

As one example of this sequence, arising from our fieldwork, one industry expert involved in managing alliance relationships for his firm stated: "[…] we need to constantly scan the environment and the universe […] understand who are the change agents, who are the players already in the ecosystem, who are the players that can come in […] to build potential partner map." He further elaborated on this statement by stating that: "[…] after the alliance is formed, we [then] develop specific teams for managing partnerships [alliance function]."

One could thus argue that opportunity-sensing sub-capabilities specific to any particular alliance, are shaped in important ways within networks where most sensing, scanning, searching and identifying of opportunities may actually take place. Formally stated:

H3. A firm's network opportunity-sensing capability will have a positive association with its alliance opportunity-sensing capability.

The integration of the social network perspective into research on firm-level competitiveness has associated firm performance and firm innovativeness with the overall network structure (Schilling and Phelps, 2007), network composition (Phelps, 2010) as well as the position of the firm within a network (Tsai, 2001; Zaheer and Bell, 2005). Thus, architectural characteristics of networks have emerged as the properties of primary interest to scholars investigating network effects on firm performance and firm innovative potential.

For example, the research streams on structural holes vs network embeddedness, emphasize, respectively, how knowledge and resources that flow through non-overlapping network structures can improve creativity and innovation (e.g. Reagans and Zuckerman, 2001) vs how social cohesion and network range can ease knowledge transfer (e.g. Reagans and McEvily, 2003). Rojas *et al.* (2018) considered how the structural properties of ties between firms and government-sponsored institutions as well as those in firm–firm networks affect innovativeness. In the international context, Perri *et al.* (2017) argued that MNE networks have specific governance features and incentive structures as compared to networks of scientific institutions, which affects the nature of knowledge diffused in the innovation process. They also found that higher international connectivity of inventors is associated with the diffusion of more sophisticated knowledge. Cumulatively, these research efforts highlight key elements in the negotiation, development and execution stages of relationships where emphasis is placed on designing and applying mechanisms (including incentives and routines) to manage complements and to build commitment. These mechanisms represent execution skills for seizing of opportunities as defined by Teece (2007).

As in the case of network sensing, the capability subsets deployed to seize broader, network-related opportunities, are also predicted to affect the alliance-related sensing capabilities. Formally stated:

H4. A firm's network opportunity-seizing capability will have a positive association with its alliance opportunity-sensing capability.

Network dynamic capabilities and moderating effects on alliance dynamic capabilities

Prior research on networks highlights the importance of accessing diverse knowledge pools for generating novel ideas (Burt, 2004). Firms committed to developing radical innovations (i.e. developing new design concepts that break existing paradigms) seek to identify opportunities that can provide the basis for such innovations (Li *et al.*, 2008). For example, Li *et al.* (2008) found that with more radical innovation goals to be achieved through an R&D alliance, potential alliance partners that are unknown to each other (or strangers) are preferred to partner firms that had prior collaborative interactions (or acquaintances). One of the reasons is that strangers have high knowledge diversity and are embedded in wider range of knowledge and technological domains (Sosa, 2011). As such, they are not as familiar with their partner's technological or knowledge assets, thus reducing their ability to easily appropriate their partner's valuable knowledge or behave opportunistically once collaborative dyadic relationships are formalized (Li *et al.*, 2008). Baum *et al.* (2005) also found that organizations that are more distant from their performance aspiration levels (either below or above) are more likely to "dance with strangers" (p. 536) and form non-local ties which may sow the seeds of change.

The above suggests value in collaborating with partners that are not interconnected and that do not have prior, established collaborative linkages. Identifying such partners in a broad network space and developing skills that promote such network awareness enables firms to access distinct pools of knowledge and establish novel linkages that are more likely to generate innovative outcomes. For example, Golonka (2015) found that proactively searching for and selecting "strangers" as potential partners might enhance firm innovativeness as it positively affects alliance portfolios. Developing a dynamic capability subset to sense where such opportunities lie in the firm's broader environment, i.e., the ability to sense in which networks to participate, will also affect the firm's ability to sense and shape opportunities at the specific alliance level. This will in turn positively affect the firm's innovation outcomes. Formally stated:

H5. A strong firm's network opportunity-sensing capability will positively moderate the relationship between its alliance opportunity-sensing capability and its innovation outcomes.

H6. A strong firm's network opportunity-sensing capability will positively moderate the relationship between its alliance opportunity-seizing capability and its innovation outcomes.

Dyadic collaborative partnerships, most prominently found in alliances, have generally been viewed as a catalyst for novel knowledge recombination and subsequent innovation outcomes. Extant research, however, suggests that such outcomes are affected by more than the strength of linkages between partners (e.g. Granovetter, 1973; Reagans and McEvily, 2003). What also matters is the firm's position in networks (Hallen, 2008), e.g., in terms of centrality (Shipilov, 2009) and its spanning of structural holes (Burt, 2004). Firms that create the most beneficial network architecture will achieve the highest innovation outcomes. Furthermore, the firm's structural positioning in the network, in terms of network centrality, will affect the number of international strategic alliances that the firm engages in (Shijaku *et al.*, 2018). Such network management capability affects the firm's ability to sense and shape opportunities at lower levels – especially the alliance level – as it determines the information pipes the firm has access to and the prisms the firm will look through. Burt (2004, p. 5) states that "[…] the content of ideas reflects the social structure in which they emerge." Thus, a firm's ability to effectively manage its broad network structure will affect its ability to sense and seize opportunities at the alliance level, and its innovation outcomes. Therefore:

H7. A strong firm's network opportunity-seizing capability will positively moderate the relationship between the firm's alliance opportunity-sensing capability and its innovation outcomes.

H8. A strong firm's network opportunity-seizing capability will positively moderate the relationship between the firm's alliance opportunity-seizing capability and its innovation outcomes.

Data and methods

Nanotechnology exemplifies the broad-based, inter-disciplinary and geographically dispersed nature of scientific advances that fuel research trajectories and developments of nanoscale structures and components. From this perspective, nanotechnology provides an ideal context for studying the type of innovation that fundamentally challenges the traditional approaches to development and application of *de novo* inventions in both traditional and nascent industries. Companies that have been awarded patents in nanotechnology represent the population that is especially suitable to answer the questions developed in this paper. These firms usually rely on interdisciplinary, inter-industry and international collaborations and affiliations in order to discover and share new scientific developments and emerging technological trends, and to create awareness of the sources of knowledge and access various flows of knowledge.

We initially identified all nanotechnology patents granted by the US Patent and Trademark Office (USPTO) by application year for the period 1990 until 2010 using the USPTO's classification number 977[2]. Figure 1 tabulates the nanotechnology patents by application year and shows the rapid growth of nanotechnology patents since 1990[3]. The accelerated rate of nanotechnology-related patenting activity occurred 12–13 years after the key nanotechnology inventions of 1980s (Figure 1). The most active phase of patenting in nanotechnology was the period between 1995 and 2005. It was also the period characterized by the introduction of consumer products based on nanotechnology in the marketplace. The period after 2005[4] has been characterized by establishment of national and international several governing bodies and agencies for research and development (R&D) in nanotechnology, college-level educational programs, and nanotechnology signature initiatives in many industrialized nations around the world, indicating that the technology then reached maturity phase. Around the same time, the patenting levels started retreating to what could be considered normal levels of patenting for a maturing technology, and following the traditional S-curve lifecycle model.

The 7,659 nanotechnology patents identified represent the population from which we then drew a sample for this paper. The patent assignees[5] were matched to COMPUSTAT (North America) database to ensure availability of public financial data. This filtering step resulted in 229 public firms patenting in nanotechnology spread across 89 different

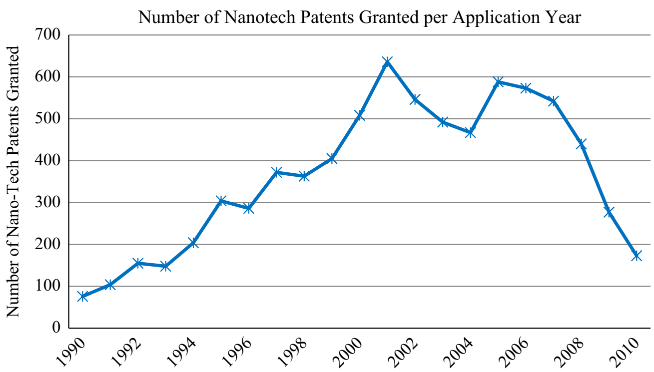

Figure 1. Evolution of nanotechnology patent applications 1990–2010

primary SIC codes. The final filtering step required, was the identification of appropriate industries where firms both: actively innovate in nanotechnology, and utilize collaborative linkages facilitated through alliances as well as networks to search for and create knowledge, and to gain and sustain competitive advantage. This filtering step was required to ensure: that firms engaged both in alliance activities and network activities, and that there were public data available necessary to construct the appropriate measures for four different capability subsets for each firm. Based on the studies by Bureau of Labor Statistics, and other studies in the strategic management field (e.g. Schilling and Phelps, 2007) and technology innovation (e.g. Chen and Roco, 2009), we identified those high-technology industries that are actively engaged in patenting in general, and utilize collaborative relationships. These are: chemicals and pharmaceuticals (SIC 28), electronics and electrical equipment (SIC 36).

The final data set consisted of 23 publicly traded firms in the electronics and electrical equipment industry (SIC 36) and 53 publicly traded firms in the chemicals and pharmaceuticals industry (SIC 28) that were granted at least one nanotech-related patent in the period 1995–2005 and that formed at least one alliance during the period of study. The observation period from 1995–2005 is particularly suitable to investigate the innovation-related questions posed in this paper based on the growth of nanotechnology patenting activity, where firms have engaged in very active inter-organizational collaborations. The 76 firms in the final sample applied for 580 nanotechnology-related patents during the observation period and built 2,459 alliances during this same observation period. The data on alliances were collected using the Thompson Corporation's SDC Platinum Database and manually verified using LexisNexis and Factiva databases to search for announcements and news on each firm. The dependent variable is a count variable and is zero-truncated. We used zero-truncated Poisson regression as the estimation method.

Variables

Innovation outcomes (dependent variable)

We used the annual number of nanotechnology patent applications granted to the firm as the dependent variable. Patents in nanotechnology are similar to those in the biotechnology industry, where patent counts are also a preferred proxy over patent citation measures for firm innovativeness (e.g. Rothaermel and Deeds, 2006). The citation-weighted measures are biased toward older patents as citations occur over time (Rothaermel and Deeds, 2006) but this bias may be attenuated in the sample for this study since patenting in nanotechnology is a relatively new phenomenon where firms did not have an opportunity to accrue many patent citations in nanotechnology.

Alliance opportunity sensing

Following past research, we utilized backward patent citations as a suitable measure for sensing activities, the scanning, creation and learning about new technological opportunities. Capabilities such as an opportunity sensing capacity cannot be observed directly. Godfrey and Hill (1995) argued that unobservable constructs are at the core of a number of influential theories, and that "empirical solutions" typically rest on observing the consequences (or the observable trail left behind) of such "unobservables." Backward patent citations are bibliometric fossils that identify the ideas upon which a focal firm draws when applying for a patent, and are an indication of intellectual lineage to specific science and technological domains (Rothaermel and Boeker, 2008). The extent to which a firm uses citations with which it has no prior experience, is also indicative of distant search. It demonstrates that the focal firm is endowed with some degree of opportunity sensing capabilities, which enable it to sense, recognize, assimilate and exploit these new sources of technological opportunities. To measure alliance opportunity sensing, a ratio was computed for each patent as the number of nanotech patent citations (patents cited in patent Class 977) divided by the total number of patent citations (P_{in}/N_{im}), whereby P_{in} is the number of nanotech patents in Class 977 that firm i is citing and P_{im} is the number of total cited patents for each patent application. This is consistent with prior literature that has used patent classes to identify new technological domains that firms explore (McGrath and Nerkar, 2004).

Alliance opportunity seizing

For measuring a firm's skills to seize opportunities within an alliance context, we built on research by Gulati *et al.* (2009) and others that measure partner distinctiveness in the alliance context by creating a continuous rather than discrete measure. Gulati *et al.* (2009, p. 1218) submit that interaction in alliances with new partners creates "reach" to new opportunities when the partners have distinctive attributes. Thus, partner distinctiveness can stimulate the seizing of opportunities for novel learning. Furthermore, Lien and Klein (2006) submit that continuous measures of business relatedness or distinctiveness are conceptually more sophisticated and preferable as compared to discrete measures, since relatedness or distinctiveness is a matter of degree. Primary four-digit SIC codes for each new alliance partner were compared to the focal firm's four-digit SIC code and assigned the scores of "0" for full match at the four-digit SIC level, "1" for the three-digit SIC match, "2" for two-digit SIC match, "3" for the one-digit SIC match and "4" for no match at the SIC level. The scores were averaged and the mean level for each firm was used as the measure of partner distinctiveness. Such continuous measure of partner distinctiveness is a more refined measure that captures heterogeneity (or degree of distinctiveness) among partners, even within the same industry. It is a relevant proxy for the firm's ability to 'reach "out" to new opportunities and to seize these opportunities by not only partnering with firms that operate in distinctive industries (if there is no match at the one-digit level), but also with other firms in distinctive segments of the same industry (as captured by the match at the two-, three- or four-digit level). The data to construct this measure were obtained from the alliances and joint ventures segment of the SDC Platinum Database. We identified and coded 2,459 alliances that were entered into during the period of this study by the companies in the sample.

Network opportunity sensing

In order to capture sensing of new opportunities through new information and new knowledge in the focal firm's ecosystem, we looked at the firm's board interlock changes and board-interlock composition, based on industry affiliations. Empirical research has in fact shown that board interlocks not only serve as an important knowledge resource (Howard *et al.*, 2017) but also significantly impact both firm R&D and patenting activities (Helmers *et al.*, 2017). From the biographical data in the proxy statements, annual reports, company websites and 10-K statements, we collected information on all inside and outside board of directors of the focal firms. We started with interlocks existing in the first year where data were available during the period 1995–2005 and coded interlock changes for every subsequent year. Each interlock with another company (through a sent or received tie) was assigned a SIC code based on the primary industry that the organization operates in. Since affiliations that a focal firm has through its board interlocks are with companies that may or may not be public, the data on company SIC codes were obtained from COMPUSTAT, Bloomberg, DataStream, Hoovers, Standard & Poor, Mergent Online and US Securities and Exchange Commission.

The measure we constructed to capture the proportion of ties with research institutes, universities or professional associations is a ratio (P_{ik1-6}/N_{it}), where P_{ik1-6} is the number of ties in the following six SIC codes (8221, 8299, 8621, 8611, 8732, 8733) that the firm i has, and P_{it} is the total number of affiliation ties across the entire portfolio of board interlocks for each firm in the sample. Looking at industry affiliations for each interlock change allowed us to capture not only the raw number of interlock changes every year (following prior research) but also the affiliations for each interlock change at the four-digit SIC code. The coding consisted of 1,096 rows, noting 1,827 ties.

An increase in interlock broadening activities suggests firm-level skills in creating opportunities for accessing potentially unique information; this is done through creating informational diversity in networks and broader ecosystems. Establishing interlocking directorates with a wide variety of firms in a range of different industries, generates an increased awareness of opportunities in the external environment. In many science-driven industries, especially those in early stages of development, new knowledge often emerges first in universities and research institutes that promote collaboration among scientists (Lavie and Drori, 2012), before its spillover effects can be detected in the mainstream economic landscape. Board interlocking ties with academic institutions, research institutes and professional associations expose the focal firm to informational clues about actions and processes outside of the focal firm's industry (and country) boundaries. Such connections are particularly useful when firms need to make decisions under high uncertainty and complexity, which characterize most high-technology industries. Interlocking directorates underscore a firm's capabilities in creating awareness of opportunities; they create access to the informational elements generated by other organizations in its ecosystem.

Network opportunity seizing

This variable is measured as eigenvector centrality to proxy for the firm's network management skills to connect to other firms (or nodes) in its network, and focuses on structural characteristics of a firm's affiliations in its network. First, we have constructed affiliation matrices for each firm based on its Board of Directors affiliations. The ties are between actors (the focal firms) and events (distinct industries they are affiliated with through their Boards of Directors). Then, the data were organized in 2-mode, 2-way matrices. Data like these involve two levels of analysis or two "modes." The two-mode matrices with "affiliation" data, describe which actors (micro modes) are members of which industries (or macro structures). These matrices were transformed in the *edgelist2* format in order to be analyzed using UCINET 6.0 software. The resulting *edgelist2* matrix consists of 76 rows and 349 columns.

In the UCINET 6.0 program eigenvector centrality is normalized by dividing each raw eigenvector score by the square root of one half, which is the maximum score attainable in any graph. The principal eigenvector analysis is equal to:

$$C_{E(i)} = \lambda \sum a_{ij} e_j.$$

UCINET 6.0 uses an algorithm to search for the largest eigenvalue of an adjacency matrix, where λ represents the array of eigenvalues in the matrix, and a_{ij} represents an adjacency matrix (Borgatti and Everett, 1997; Prell, 2012). A node has a high eigenvector score to the extent it is connected to many nodes which themselves have high scores. It is often interpreted as the popularity or status of a focal node, i.e., having ties not just to many other nodes, but also to many well-connected other nodes.

We have also considered three other alternative measures of connectivity in an ecosystem: degree centrality, closeness centrality and betweenness centrality, which capture more simplistic notions of connectivity, either as involvement in the network (degree centrality), independence in the network (closeness centrality), or placement in the network (betweenness centrality). These alternative measures produced similar coefficients to those of eigenvector centrality, but were less significant, leading us to retain the eigenvector centrality as our connectivity measure. In addition, the choice to retain eigenvector centrality as the measure of connectivity was derived from the assumptions of social network theory about a firm's ability to create the architecture of its connections (e.g. structural holes, bridging ties, central positions in networks, etc.). These connections supposedly allow accessing the flows of information and knowledge in the firm's ecosystems of ties and affiliations.

Control variables

We have controlled for common critical variables in this line of research, such as firm age, firm size, international alliances, and inter-industry differences.

Firm age. Following prior research, we operationalize firm age as the number of years between the incorporation year and the first time a firm has been granted a nanotechnology patent during the observation period.

Firm size. Absolute firm size is measured by focal firm's total assets, as commonly used in the research on firm alliances as well as firm networks (e.g. Gulati *et al.*, 2009). The variable is natural-log transformed.

International alliances. We measure international alliances as the proportion of the focal firm's alliances that involved foreign partners, in year *t*. We controlled for the proportion of international alliances for two reasons. First, international alliances tend to experience greater coordination and communication challenges as well as cultural distance, which can ultimately reduce information flows and cooperative behavior, and affect the firm's ability to learn and to generate innovations (Lane *et al.*, 2001). Second, and on the more positive side, international alliances provide access to more diverse knowledge flows, in line with the international business concept of "strategic asset seeking" (Dunning and Lundan, 2008).

Inter-industry differences. We use a dummy variable to control for any potential inter-industry differences between the two SIC codes. If the firm is in SIC 28, we code it as 1, and if it is in SIC code 36, we code it as 0.

Results

As noted above, the data set consists of 76 companies. There is considerable variance on control variables: firm size, age, proportion of alliance partners being foreign firms and R&D size. The companies in the sample have, on average applied for about 8 nano-tech related patents (mean 7.5) over the observation period (1995–2005), with a minimum of 1 nanotechnology patent and a maximum number of applied nanotechnology patents applied for, reaching 65 during the observation period. The average age for the companies in the sample is 37 years and slightly more than one half of their alliance partners (57 percent) over the observation period were foreign firms.

Examining the correlation matrix, we note that all correlation coefficients are below the suggested, 0.5 level (Cohen *et al.*, 2003). The highest correlation between any two independent variables is $\rho = 0.2372$ (correlation coefficient between the measure of network opportunity sensing and network opportunity seizing). This value is well below the 0.5 level, and suggests that these measures are indeed capturing different variables. Thus, the correlations do not suggest any obvious concerns about potential problem of multicollinearity in this data set.

To further examine whether multicollinearity might be present, we computed the variance inflation factor (VIF) for independent variables and control variables. The mean VIF for all the variables is 1.31 and no single VIF value is higher than 1.51, well below the generally usedthreshold value of 10, supposedly indicative of a multicollinearity problem (Kennedy, 1992).

In addition to the descriptive statistics presented above, we screened the network matrices used to compute the network opportunity-seizing variable, to ensure that the resulting matrices fit the *edgelist2* format, that there are no missing values in the data, and that the data were formatted correctly for use in UCINET 6.0 to construct the network centrality measures. The coding of the network opportunity-sensing variable consisted of 1,096 rows noting 1,827 ties across 349 unique SIC code for the 76 companies in the sample. Visual inspection of both the *edgelist2* matrix and the scaled network, suggest that there are no odd network properties and no missing linkages or values. The *edgelist2* matrix was used to compute the 2-mode network centrality measures.

The dependent variable (nano) is a count variable (count of nanotechnology patents applied for in the period 1995–2005) and is zero-truncated where the value of zero cannot occur. When the dependent variable is a count variable, the use of the Poisson model is indicated (Hausman *et al.*, 1984; Henderson and Cockburn, 1994). This model assumes that the number of patents filed by a firm in any given year is a random variable that is approximated via a Poisson process. The underlying assumption is that the mean is equal to the dispersion of the data. The dependent variable in this data set displays over-dispersion (the variance is greater than the mean). This violates the Poisson distribution assumption. However, Poisson regressions have the appealing property that, whether or not the distributional assumptions are met, the estimates of β will be consistent and asymptotically normal (Wooldridge, 2000: Chapter 17). Therefore, following prior research that used Poisson regression in similar estimations of smaller numbers of observations, we report robust standard errors for coefficients estimated through Poisson models, as these provide consistent estimates for the standard errors even under misspecification of the distribution (Hall and Ziedonis, 2001; Puranam and Srikanth, 2007).

Since the count variable in this data set is zero-truncated, we used zero-truncated Poisson regression to estimate the effect of alliance opportunity sensing, alliance opportunity seizing, network opportunity sensing and network opportunity seizing on the firm's patenting activity in nanotechnology. The estimation was performed using the *.tpoisson* command in STATA. The results are presented in Tables I–III.

We first tested for the effects of control variables on the firm's nanotechnology patenting activities (Model 1, Table I). The Age variable is not statistically significant, suggesting that age of the firm does not have a significant impact on firm's patenting pursuits in emerging fields such as nanotechnology. The size of the firm (Size (log)) is positively and significantly ($p < 0.001$) related to firm's patenting in nanotechnology, suggesting that as firms grow in size, they are more likely to increase their patenting activity as they have more slack resources available for inventing. This finding echoes prior research that firms with more

	Zero-truncated Poisson regression (*H1* and *H2*)		
DV = nanotech patents	Model 1	Model 2	Model 3
Alliance opportunity sensing		2.4949*** (0.2966)	
Alliance opportunity seizing			−0.0187 (0.0568)
Network opportunity sensing		–	–
Network opportunity seizing		–	–
Control variables			
Age	0.0003 (0.0013)	0.0015 (0.0013)	0.0009 (0.0014)
Size (log)	0.1037*** (0.0287)	0.1078*** (0.0264)	0.1137*** (0.0256)
International alliances	−0.2978* (0.1369)	−0.5701*** (0.1467)	−0.3081* (0.1405)
Industry dummy	1.2134*** (0.0876)	0.9097*** (0.0981)	1.2252*** (0.0948)
LogLikelihood	−432.92	−400.61	−432.87
LR χ^2	254.63	319.27	254.74
Pseudo R^2	0.2273	0.2849	0.2274
n	76	76	76

Notes: $^*p < 0.05$; $^{***}p < 0.001$

Table I. Main effects model: zero-truncated Poisson regression results

	Ordinary least squares regression (*H3* and *H4*) Model 1	Model 2	Model 3
Alliance opportunity sensing		–	–
Alliance opportunity seizing		–	–
Network opportunity sensing		0.0486 (0.1068)	
Network opportunity seizing			0.5815* (0.2823)
Control variables			
Age	−0.0005 (0.0003)	−0.0003 (0.0003)	−0.0001 (0.0004)
Size (log)	−0.0026 (0.0063)	−0.0029 (0.0064)	−0.0069 (0.0066)
International alliances	−0.0800* (0.0414)	0.7812**** (0.1686)	0.0489 (0.0432)
Industry dummy	0.1044** (0.0295)	0.1089** (0.0312)	0.1069*** (0.0288)
R^2	0.18	0.19	0.23
Model F	4.09	3.27	4.27
n	76	76	76

Notes: $^*p < 0.05$; $^{***}p < 0.001$

Table II.
Main effects model: ordinary least squares regression results

physical assets invent more in emerging fields (Rosenkopf and Nerkar, 2001; Rothaermel and Thursby, 2005). The effect of the proportion of international alliances (International alliances) on firm's patenting in nanotechnology is significant ($p < 0.05$) and negative, suggesting that the increase in alliance activities with foreign partners tends to negatively affect the firm's ability to innovate in emerging fields. International alliances tend to experience greater coordination and communication problems as well as cultural conflicts, which can often reduce cooperation, information flows, and negatively affect the firm's capacity to learn and generate innovations (Lane *et al.*, 2001; Makino *et al.*, 2007). The dummy variable to control for inter-industry differences (Industry dummy) is significant ($p < 0.001$) suggesting that firms in SIC code 36 engaged in increased nanotechnology related patenting. The firms in the sample applied for 580 nanotechnology-related patents over the observation period, with firms in the SIC code 36 category (electronics, electrical equipment and semiconductors) applying for 349 (60.2 percent) nanotechnology patents, and firms in the SIC code 28 (chemicals and pharmaceuticals) applying for 231 (39.8 percent) patents. The effects of industry dummy variable largely remain in the tests of the direct effects model (Tables I and II) and tests of the interaction effects model (Table III).

H1 predicted a positive relationship between a firm's alliance opportunity-sensing sub-capability and it is patenting in nanotechnology. In Model 2 (Table I), the coefficient for alliance opportunity sensing is positive and significant ($p < 0.001$). *H1* is, therefore, supported.

H2 predicted a positive relationship between a firm's alliance opportunity-seizing sub-capability and it is patenting in nanotechnology. Model 3 (Table I) reveals that contrary to the expectations, the parameter coefficient for alliance opportunity-seizing goes in the opposite direction and is not significant ($p < 0.742$). Thus, *H2* is not supported. This suggests that the ability to build formal alliances with firms in many diverse industries may not significantly affect a firm's ability to patent in nanotechnology. One possible explanation is that managing formal collaborations with large numbers of distal partners may have counterproductive effects, similar to those experienced with foreign firms.

H3 predicted a positive relationship between a firm's network opportunity-sensing sub-capability and its alliance opportunity-sensing sub-capability. The network opportunity-sensing capability variable was regressed on the alliance opportunity-sensing capability. The regression coefficient is positive ($\beta = 0.0486$) but not statistically significant (Model 2, Table II). *H3* is, therefore, not supported.

Table III. Interaction models: zero-truncated Poisson regression results

DV = nanotech patents	Interaction models: zero-truncated Poisson regression (*H5*, *H6*, *H7* and *H8*) Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Alliance opportunity sensing	2.3127*** (0.3170)	2.9888*** (0.4901)	2.3073*** (0.3168)	4.4768*** (0.6697)	2.2608*** (0.3188)	4.6583*** (0.7041)
Alliance opportunity seizing	0.7339 (0.6061)	0.0832 (0.0614)	−0.0132 (0.0936)	0.6281 (0.7041)	−0.3688** (0.7041)	−0.4661** (0.1412)
Network opportunity sensing	−1.9920*** (0.3909)	−1.4975** (0.4763)	−3.1408** (1.0252)	−1.8065*** (0.3914)	−2.1277*** (0.3936)	−1.3200 (1.2440)
Network opportunity seizing	3.0253** (0.9685)	3.1748*** (0.9633)	2.9677** (0.9672)	5.8700*** (1.2210)	6.6861* (2.6255)	−7.1692* (3.5297)
Interactions						
Network opportunity sensing × alliance opportunity sensing		−4.5611* (2.5760)				−3.9767 (3.1949)
Network opportunity sensing × alliance opportunity seizing			0.5006 (0.4106)			−0.0743 (0.4875)
Network opportunity seizing × alliance opportunity sensing				−18.4298*** (5.1262)		−15.7293* (6.3571)
Network opportunity seizing × alliance opportunity seizing					4.2675*** (1.5301)	5.5566*** (1.4168)
Control variables						
Age	−0.0001 (0.0014)	0.0003 (0.0014)	−0.0001 (.0015)	−0.0002 (0.0015)	−0.0013 (.0016)	−0.0019 (0.1116)
Size (log)	0.1058*** (0.0288)	0.1025*** (0.0288)	0.1045*** (0.0288)	0.0943** (0.0289)	0.1015*** (0.0286)	0.0908** (0.0288)
International alliances	−0.6061*** (0.1681)	−0.5823** (0.1690)	−0.5906*** (0.1679)	−0.7010*** (0.1726)	−0.5239** (0.1685)	−0.5846** (0.1763)
Industry dummy	0.7323*** (0.1182)	0.7369*** (0.1191)	0.7099*** (0.1180)	0.7817*** (0.1204)	0.7026*** (0.1162)	0.7542*** (0.1199)
LogLikelihood	−385.58	−383.99	−384.84	−378.94	376.05	368.32
LR χ^2	349.32	352.50	350.79	362.60	368.39	383.83
Pseudo R^2	0.3118	0.3146	0.3131	0.3236	0.3288	0.3426
n	76	76	76	76	76	76

Notes: $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; $^{****}p < 0.10$

H4 predicted a positive relationship between a firm's network opportunity-seizing sub-capability and its alliance opportunity-sensing sub-capability. The network opportunity-seizing capability variable was regressed on the alliance opportunity-sensing capability. The regression coefficient is positive ($\beta = 0.5815$) and statistically significant ($p < 0.05$) (Model 3, Table II). *H4* is, therefore, supported.

In Table III (Models 2–5) we tested for the interaction effects predicted in *H5* through *H8*.

H5 predicted that a firm's strong network opportunity-sensing sub-capability will moderate the relationship between the firm's alliance opportunity-sensing sub-capability and firm's innovation outcomes, such that the relationship between a firm's alliance opportunity-sensing and its innovation outcomes is stronger at higher levels of its network opportunity-sensing sub-capability. The interaction between network opportunity-sensing sub-capability and alliance opportunity-sensing sub-capability was introduced in Model 2 (Table III). The coefficient for the interaction term is significant at ($p < 0.05$) level but the directionality of the effect is opposite the expectations (it is negative). This suggests that the relationship between a firm's alliance opportunity-sensing sub-capability and its innovation outcomes becomes weaker at higher levels of its network opportunity-sensing sub-capability. Thus, *H5* is not supported in its original form. This interaction is plotted in Figure 2.

H6 predicted that a firm's strong network opportunity-sensing sub-capability will moderate the relationship between firm's alliance opportunity-seizing sub-capability and firm's innovation outcomes, such that this relationship will be stronger at higher levels of its network opportunity-sensing sub-capability. The interaction between network opportunity-sensing sub-capability and alliance opportunity-seizing sub-capability was introduced in Model 3 (Table III). The coefficient for the interaction term is positive but not statistically significant. Thus, *H6* is, therefore, not supported.

H7 predicted that a firm's strong network opportunity-seizing sub-capability will moderate the relationship between a firm's alliance opportunity-sensing sub-capability and its innovation outcomes, such that this relationship would be stronger at higher levels of its network opportunity-seizing capability. The interaction between network opportunity-seizing capability and alliance opportunity-sensing capability was introduced in Model 4 (Table III). The coefficient for the interaction term is significant at ($p < 0.001$) level but the directionality of the effect is the opposite of what we expected (it is negative). This suggests

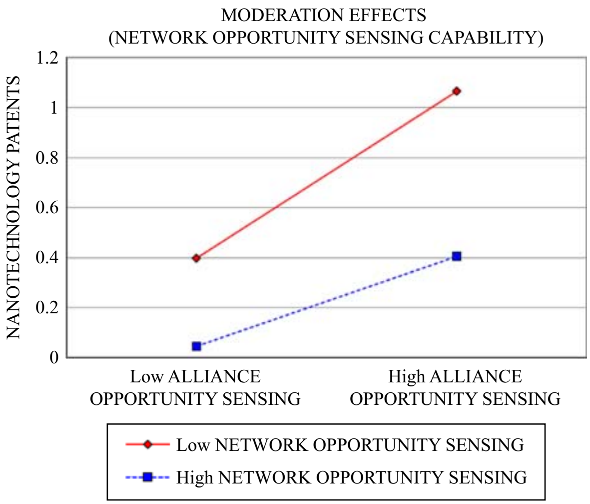

Figure 2.
Interaction Plot (H5) – Moderation effects of *network* opportunity-*sensing* capability on the relationships between *alliance* opportunity-*sensing* capability and nanotechnology patents (innovation outcomes)

that the relationship between a firm's alliance opportunity-sensing sub-capability and its innovation outcomes becomes weaker at higher levels of its network opportunity-seizing sub-capability. Thus, *H7* is not supported in its original form. This interaction effect is plotted in Figure 3.

H8 predicted that a firm's strong network opportunity-seizing capability will moderate the relationship between the firm's alliance opportunity-seizing capability and its innovation outcomes, such that this relationship is stronger at higher levels of its network opportunity-seizing capability. The interaction between network opportunity-seizing sub-capability and alliance opportunity-seizing sub-capability was introduced in Model 5 (Table III). The coefficient for the interaction term is positive and significant at ($p < 0.001$) level. Thus, *H8* is supported. This interaction is plotted in Figure 4.

Although we did not detect some of the main effects hypothesized (i.e. the effect of alliance opportunity seizing on innovation outcomes, and the effect of network opportunity sensing on alliance opportunity sensing), the presence of significant interaction effects

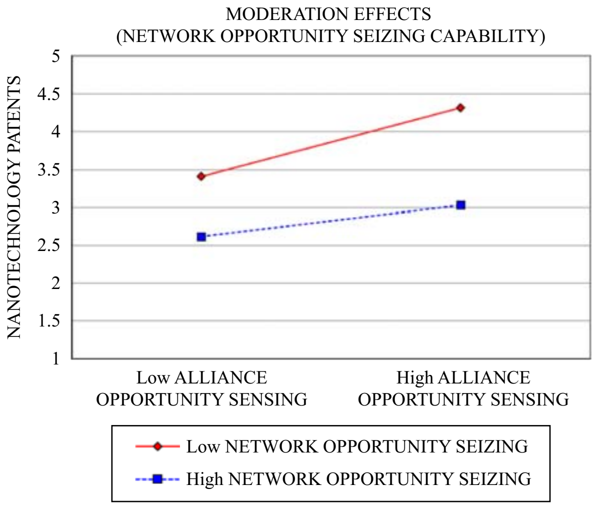

Figure 3.
Interaction Plot (H7) – Moderation effects of *network* opportunity-*seizing* capability on the relationships between *alliance* opportunity-*sensing* capability and nanotechnology patents (innovation outcomes)

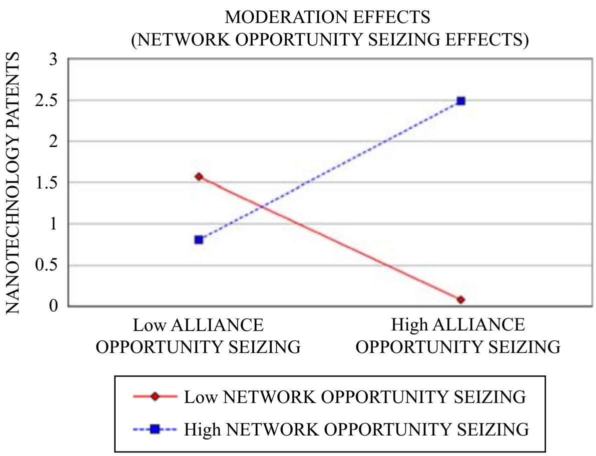

Figure 4.
Interaction Plot (H8) – Moderation effects of *network* opportunity-*seizing* capability on the relationships between *alliance* opportunity-*seizing* capability and nanotechnology patents (innovation outcomes)

indicates that the main effects are conditional on the value of the moderator variables, and thus our discussion and interpretation of results will mainly focus on the interaction effects. The summary of all hypotheses and findings is presented in Table IV.

Robustness tests

We conducted several auxiliary analyses to assess the robustness of the findings.

First, given the cross-sectional nature of the data we tested for reverse causality, whereby the patenting in nanotechnology would facilitate the awareness of nanotechnology developments (or alliance opportunity sensing), as well as the alliance collaborations with diverse alliance partners (or alliance opportunity seizing). The results of a Poisson regression model revealed a substantial decrease in the explanatory power of the model when the alliance opportunity sensing (measured as the cumulative number of backward patent citations with reference to nanotechnology) served as the dependent variable (from LogLikelihood = −400.61 and LR $\chi^2 = 319.27$ to LogLikelihood = −628.16 and LR $\chi^2 = 1{,}503.22$). Similarly, the explanatory power of the zero-truncated Poisson regression model declined (from LogLikelihood = −432.86 and LR $\chi^2 = 254.74$ to LogLikelihood = −1,132.74 and LR $\chi^2 = 1{,}679.33$) when alliance opportunity seizing (measured as the cumulative number of alliance collaborations) served as the dependent variable. These results suggest that alliance opportunity-sensing and alliance opportunity-seizing are driving the innovativeness potential in nanotechnology and are consistent with the hypothesized relationships in this paper.

Second, the non-significant findings for the moderating role of network opportunity sensing on the relationships between alliance opportunity seizing and nanotechnology patenting activity as well as the significant findings (but in the opposite direction) for the moderating role of network opportunity sensing and network opportunity seizing on the relationship between alliance opportunity sensing and nanotechnology patenting suggest that the benefits of collaborations within networks may have boundary conditions and that the relationship is non-linear.

In order to test for the curvilinear effects of network opportunity sensing and network opportunity seizing, we created a quadratic term, applied in the zero-truncated Poisson regression analysis. Nanotechnology patenting activity appears positively related to network opportunity sensing ($\beta = 6.040$, $p < 0.001$) yet negatively associated with its quadratic term ($\beta = -20.625$, $p < 0.001$), suggesting an overall inverted U-shaped effect of network opportunity-sensing on nanotechnology innovations. Similarly, patenting in nanotechnology is positively related to network opportunity seizing ($\beta = 24.987$, $p < 0.001$) yet negatively associated with its quadratic term ($\beta = -87.785$, $p < 0.001$), suggesting an overall inverted U-shaped effect of network opportunity-seizing on nanotechnology innovations. These results suggest that non-linear models of the effects of dynamic capability subsets on innovative outcomes should receive more careful consideration and investigation in future research.

Direct effects model	Results
H1	Supported
H2	Not supported
H3	Not supported
H4	Supported
Moderation effects model	Results
H5	Opposite sign (–)
H6	Not supported
H7	Opposite sign (–)
H8	Supported

Table IV. Summary of hypothesized relationships and results

Third, the presence of a statistically significant direct path from alliance opportunity sensing to the outcome variable (*H1*), and the presence of a statistically significant path from network opportunity seizing to alliance opportunity sensing (*H4*), may initially suggest that alliance opportunity sensing could be a mediator variable between network opportunity seizing and innovation outcomes. We conducted an alternative test to investigate whether such effects are indeed present. We found some weak support for mediation at ($p < 0.1$) level, though this relationship was not hypothesized.

Fourth, due to the cross-sectional nature of the data, tests for time-variant effects within each firm could not be performed. However, we included a control variable that measures the expenditures of each firm for R&D for the period of observation. The variable was log transformed. All hypotheses were re-tested using the log transformed R&D expenditures as an additional control variable. The results obtained from the zero-truncated Poisson regression estimations using this additional control variable, reveal an overall model robustness and a log-transformed R&D expense variable that is positively and significantly ($p < 0.001$) related to a firm's patenting in nanotechnology. This finding echoes prior research that a firm's R&D expenditures are significant predictor of nanotechnology patenting.

Discussion and conclusion

We have suggested a novel, exploratory approach to studying linkages between firm-level dynamic capabilities and innovation outcomes. We have conceptualized, and then empirically tested, the direct effects of distinct capability subsets for opportunity sensing and opportunity seizing. Importantly, we have addressed the complex nature of the dynamic capability construct by examining two distinct, but interrelated, contexts, namely that of alliances and networks.

We have identified a statistically significant effect of commanding an alliance opportunity-sensing capability that explains why some firms may be better able to manage their collaborations for innovation and why so many alliance collaborations are deemed unsuccessful. We have found strong support for the notion that the firm's skills in creating awareness of external developments in the environment and its ability to deliberately shape opportunities for innovation, play a critical role in a firm's innovative outcomes.

Our less intuitive findings highlight the importance of distinguishing between different subsets of skills underlying dynamic capabilities for opportunity sensing and for opportunity seizing. Prior research that had investigated primarily the uni-dimensionality of the dynamic capability construct has omitted significant and crucial multi-dimensional aspects of the dynamic capability construct. In addition, adopting multi-dimensional analyses of constructs across two different contexts (in this case alliances and networks) has important implications for the international business literature as well. MNEs operate in contexts that cross many boundaries, and the ability to identify in a conceptually sound fashion the distinctive and interactive effects of different contextual variables on non-location bound FSA, CSAs and location-bound FSAs provides a starting point for future research (Verbeke, 2013).

Our research reveals that examining and understanding trade-offs is also important. For example, investing more resources in sensing routines may produce decreasing marginal gains when it comes time to seize identified opportunities. Similarly, too much seizing in the network and strategic alliance contexts simultaneously may also come at a cost. Furthermore, the real challenge of inter-organizational relationships is transforming collaborations into productive and effective relationships to generate strategically valuable outcomes, including in the context of IJVs and international strategic alliances. For example, Lavie and Drori (2012) examined collaborations between university scientists and industry partners and identified significant trade-offs between collaboration and new knowledge applications, with the relationship between both being curvilinear, meaning that knowledge creation in networks will initially increase but then decrease with the increase in collaborations between scientists and their industry partners. Overinvesting in sensing through networks, may reduce subsequent seizing in particular alliances. In a similar vein, i.e., demonstrating the difference between commanding ties and earning beneficial outcomes, Siegel (2007) examined whether political network ties could in some cases act as a liability, rather than strengthening companies, with an application to South Korea. He found that network ties to political opponents of the regime in power significantly decreased the rate at which South Korean companies formed international strategic alliances. However, an unexpected regime change could rapidly turn such liability into an asset.

On the positive side, our analysis reveals that a network opportunity-seizing capability does not compromise the firm's alliance opportunity-seizing capability. Potential synergies may, therefore, exist between the subsets of dynamic capabilities that are more macro oriented (i.e. seizing of opportunities within broader network) and those that are more micro oriented (i.e. seizing of opportunities within dyadic contexts). Operating in international environments may require additional micro-level and macro-level capabilities (e.g. managing diverse institutional and regulatory contexts of host country economies or regional differences with respect to high-tech clusters, etc.). However, at the sensing side, stronger network sensing clearly occurs at the expense of the more narrow alliance sensing. One explanation for this could be that the firm's ability to understand the characteristics and the substance of the informational elements generated by associations with other actors in a network, can be conditioned by managerial cognition (Nadkarni and Barr, 2008). Here, any potential synergies may be disrupted by cognitive biases that reside in individual managers of those firms that engage in sensing activities across contexts. The research within the social network perspective has established that many weak ties create "vision" advantage for idea generation and innovation, but that these benefits tend to be short lived and immediate, because of divided attention (Reagans and McEvily, 2008, p. 276). This challenge is amplified especially in international contexts (Maitland and Sammartino, 2015).

Future research on dynamic capabilities (or FSAs) should, therefore, pay greater attention to the complexities of inter-organizational linkages. Since the control variable international alliances is significant, future research should also explore in more depth this particular angle, and focus on more nuanced dimensions of international collaboration, and how organizations build, upgrade and leverage capabilities for collaborating with a wide range of foreign partners. On the one hand, it may be useful for firms to deliberately scan the broader business environment across its technological, industry and geographic boundaries in order to identify innovative opportunities in tune with organizational changing needs. On the other hand, after having let a thousand flowers bloom through networks, it may be best to focus on specific alliances when moving from the opportunity sensing to the opportunity seizing stage, in order to boost innovative performance in emerging fields.

We posit that firms will optimize innovation performance (in our work measured by patents) when they effectively develop separate capability subsets for sensing and seizing of opportunities that are best suited for different types of contexts, such as alliances or networks. The best performing organizations, in terms of innovation outcomes, will be those that effectively develop and cater to four subsets of dynamic capabilities. Our findings set the stage for unbundling dynamic capabilities as a generic variable, into capability subsets in sensing and seizing, and focused either on networks or on strategic alliances.

Notes

1. Organizational networks have been defined in various ways. The common theme in most of these definitions is the presence of both structural and relational sets of ties with dynamic boundaries.
2. The nanotechnology patent Class "977" was established by USPTO in November 2005 together with the cross-reference art collection subclasses 700 through 963 as a method of classification to capture the breadth of nanotechnology inventions which could not be properly classified under the

existing USPTO classification system since the term nanotechnology is multi-faceted and encompasses an array of interdisciplinary technologies at the nanoscale.

3. The number of nanotechnology patents started to rapidly accelerate after the key milestone invention of the atomic force microscope (AFM) in 1986. The first commercialized AFM, the Digital Instruments NanoScope®, became available in 1989. The period between 1989 and 1995 has been often deemed as "embryonic phase."
4. National nanotechnology initiative, Nanotechnology timeline, available at: www.nano.gov/timeline
5. Since the focus of this paper is on firms, patents that have been granted to universities, research institutes, research foundations, individuals, government agencies or representatives acting on behalf of government agencies were excluded. This initial filtering resulted in approximately 35 percent of nanotechnology patent assignees being excluded.

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