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**DOI**

[10.1057/s41267-017-0109-5](https://doi.org/10.1057/s41267-017-0109-5)

**Publication date**

2017

**Document Version**

Final published version

**Published in**

Journal of International Business Studies

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**Citation for published version (APA):**

Scalera, V. G., Perri, A., & Hannigan, T. J. (2017). Knowledge connectedness within and across home country borders: Spatial heterogeneity and the technological scope of firm innovations. *Journal of International Business Studies*, 1-20. <https://doi.org/10.1057/s41267-017-0109-5>

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# Knowledge connectedness within and across home country borders: Spatial heterogeneity and the technological scope of firm innovations

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**Abstract**

We explore how knowledge-based connections to domestic and foreign locations affect the technological scope of firm innovations. Inspired by a blend of Economic Geography and International Business perspectives, we propose a theoretical framework that distinguishes between domestic subnational differences and cross-national spatial heterogeneity. Further, we combine the Penrosean view of managerial capabilities with the attention-based theory of the firm. Analyzing a sample of US-based firms between 1990 and 2006, we show that both domestic and international knowledge connectedness affect the technological scope of firm innovations, but their effects are different. The breadth of international knowledge connectedness appears to be positively associated with the technological scope of firm innovations. However, the breadth of domestic knowledge connectedness positively contributes to the technological scope of firm innovations up to a certain point, beyond which the bounded rationality of managers constrains firms' ability to further leverage subnational heterogeneity. Thus, domestic search is more likely to be challenged by limited managerial bandwidth. Lastly, domestic and international knowledge connectedness significantly interact with each other to explain the technological scope of firm innovations.

*Journal of International Business Studies* (2017).

doi:10.1057/s41267-017-0109-5

**Keywords:** international and domestic knowledge sourcing; knowledge connectedness; technological scope; knowledge recombination; spatial heterogeneity

## INTRODUCTION

Locations as knowledge repositories have unique and evolving profiles that serve unique and evolving roles in global innovation systems (Awate & Mudambi, 2018; Lorenzen, 2004). As the advance of technology brings about intensification of value chain linkages (Sturgeon, Van Biesebroeck, & Gereffi, 2008), innovation systems span geographic, organizational, and technological boundaries with higher orders of complexity (Cano-Kollmann, Cantwell, Hannigan, Mudambi, & Song, 2016). In this changing and



interdependent environment, of particular interest is the role of the firm's knowledge connectedness across locations in exploring new technologies and generating new ideas.

Knowledge connectedness refers to the set of knowledge-based linkages established between geographically dispersed innovative actors in order to source new knowledge inputs (Perri, Scalera, & Mudambi, 2017), and the breadth of knowledge connectedness captures the range of distinct locations connected through such linkages. Increasingly, scholars have begun to adopt the view that firms and locations co-evolve (Cano-Kollmann et al., 2016), and that tacit knowledge is not exclusively tied to the notion of "being there" (Amin & Cohendet, 2004; Gertler, 2003). Similarly, literature has explored innovation bonds across geographic space, and the role of people and organizations in generating knowledge conduits (Lorenzen & Mudambi, 2013). Knowledge connectedness sees the coalescing of knowledge that may have otherwise been adhered to locations. Thus, it is crucial to the infusion of new ideas and their recombination with knowledge resources already available within the firm.

Understanding the opportunities arising from the integration of knowledge of different geographic origin requires a careful account of the spatial dimension and of its implications for firm activities (Beugelsdijk & Mudambi, 2013). Within the literature on the geography of knowledge sourcing, International Business (IB) research has naturally focused on firm *international* knowledge sourcing (e.g., Almeida & Phene, 2004; Berry, 2014; Chung & Yeaple, 2008; Frost, 2001; Phene & Almeida, 2008), while Economic Geography (EG) scholars have mainly investigated the processes of *local* knowledge sourcing (e.g., Audretsch & Feldman, 1996; Maskell, 2001; Maskell & Malmberg, 1999). However, the international and subnational dimensions of space are not only substantially different, but also strongly intertwined (Beugelsdijk, McCann, & Mudambi, 2010).

Inspired by EG perspectives, IB scholars have begun to recognize the different dimensions of the geographic space (Beugelsdijk & Mudambi, 2013; Rugman & Verbeke, 2004; Stallkamp, Pinkham, Schotter & Buchel, 2017), and recently appreciated the importance of simultaneously accounting for spatial discontinuities that arise when firms cross national borders, and spatial heterogeneity that characterizes the subnational context (Beugelsdijk & Mudambi, 2013). Yet, in the IB literature on the

knowledge-location nexus of firm innovation processes, an explicit recognition of the geographic space as characterized by both international and subnational heterogeneity is still to be accomplished. Previous research on the geographical drivers of firm innovation (Lahiri, 2010, 2015; Singh, 2008) has mainly investigated the effect of the geographic distribution of firm R&D activities without distinguishing between domestic and foreign locations, but has generated inconclusive findings (Tzabbar & Vestal, 2015). Other studies have explored the distinct roles of foreign versus domestic knowledge sourcing in the context of multinational enterprises (MNEs) (Almeida & Phene, 2004; Frost, 2001; Phene & Almeida, 2008), but without consideration of the subnational heterogeneity embedded in firm home countries.

In this work, we unpack the geography of knowledge sourcing operated through knowledge connectedness to explicitly distinguish between within and across home country spatial dimensions. Specifically, we examine the breadth of connectedness to both domestic and international space and its role in the knowledge recombination processes of firms, as highlighted by the technological scope of their innovations<sup>1</sup> (Lerner, 1994). Technological scope represents higher order integrations of complementary knowledge sources within specific innovation projects (Cantwell, Gambardella, & Granstrand, 2004; Novelli, 2015), and when well-configured, drives firm performance (Miller, 2006).

Our study extends existing literature on the geography of firm innovation and knowledge sourcing (e.g., Almeida & Phene, 2004; Frost, 2001; Lahiri, 2010, 2015; Phene & Almeida, 2008; Singh, 2008) by adopting an approach that from both the theoretical and the empirical viewpoint distinguishes between domestic and international knowledge connectedness and explicitly accounts for different levels of spatial heterogeneity. On the one hand, failing to distinguish domestic from international knowledge sources may insinuate that these generate the same types of solicitations to firm innovation processes. On the other hand, overlooking the subnational heterogeneity of firms' home country means assuming that the domestic knowledge base contributes homogeneously to firm recombination activities, irrespective of how firms design their knowledge-sourcing strategies to exploit the home country's subnational distribution of technological resources (Carlsson & Stan-kiewicz, 1991). By simultaneously addressing these



relevant spatial dimensions, we provide more accurate guidance on the benefits and challenges associated to two knowledge-sourcing strategies, i.e., domestic and international knowledge sourcing, which we recognize as fundamentally different. Moreover, we explore how these strategies interact to explain the technological scope of firm innovations.

Theoretically, we combine the Penrosean view of managerial capabilities (Penrose, 1959) with insights from the attention-based theory of the firm (Ocasio, 1997), within a general spatial framework that acknowledges both domestic subnational differences and cross-national heterogeneity (Beugelsdijk & Mudambi, 2013). Empirically, we match Standard & Poor's 500 (S&P 500) US-based firms between 1990 and 2006 to patent data from the United States Patent and Trademark Office (USPTO) and firm information from the Compustat North America database.

Our results show that both domestic and international knowledge connectedness affect the technological scope of firm innovations, but their effects are different: while firms with greater breadth of international knowledge connectedness systematically experience higher technological scope of innovations, the breadth of domestic knowledge connectedness benefits firms' recombination capability only till a certain point. Moreover, domestic and international knowledge connectedness are interdependent rather than unrelated strategies for firm innovative performance.

We elucidate a theory of international and domestic knowledge connectedness as distinct (although not necessarily orthogonal) pathways to technological recombination. We argue that domestic and international knowledge-based linkages expose firms to different opportunities and threats. Compared to connections developed domestically, international linkages encompass greater recombinatory potential, but are also more difficult and expensive to find and maintain. Owing to these differences, knowledge sources accessed through international connections tend to attract more considerate managerial attention, and thus are less likely to be affected by managers' capability constraints. This has implications on the contribution domestic and international knowledge sources offer to firm recombination processes, as highlighted by the distinct shapes of their relationships to technological scope.

The remainder of this article is organized as follows. The next section reviews the extant literature and develops hypotheses. We then describe

our data and empirical strategy, and follow with an analysis of results. The article concludes with a discussion of our findings and implications for the field.

## THEORY AND HYPOTHESIS DEVELOPMENT

### Firms, Connectedness, and the Geography of Knowledge Sourcing

Literature suggests that learning is path dependent and the balance of routinized depth within existing lines of inquiry against the need to refresh and explore (March 1991; Nelson & Winter, 1982) is crucial to firm survival. As firms reach out to find new knowledge, recombination opportunities augment as novel insights become available to expand the technological scope of firm innovations (Galunic & Rodan, 1998). To this aim, leveraging geographically dispersed technology is important because of the diverse and often complementary nature of the local knowledge that accumulates over time in different regions (Cantwell & Janne, 1999). A varied knowledge environment allows firms to choose among a wider range of heterogeneous inputs for recombination, and provides the opportunity to overcome the constraints of local search (Levinthal & March, 1993; March, 1991; Stuart & Podolny, 1996).

Because of the increasing tendency of firms to be knowledge-driven, competition prompts to look for distinctive technological assets in a wider number of locations (Berry, 2014; Cantwell, 1989). For instance, the presence in diverse local contexts enables the MNEs to tap into different knowledge clusters. However, firms can access diverse knowledge pools not only by localizing their activity, but also by creating knowledge networks through individuals (i.e., inventors) located there. Not surprisingly, the geographical distribution of inventor networks has been investigated as a driver of the innovative performance of individual teams (Tzabbar & Vestal, 2015) and geographical regions (Fleming, King, & Juda, 2007; Lobo & Strumsky, 2008).

To the extent that knowledge spillovers are highly localized (Jaffe, Trajtenberg, & Henderson, 1993), collaborative relationships across space represent a flexible tool to facilitate access to distant knowledge. Advances in information and communication technologies have cracked – although not broken – the heretofore-tight link between tacit knowledge transfer and the prerequisite of co-

location (Amin & Cohendet, 2004). Yet managing geographically distributed knowledge linkages is still not an easy task for firms. Firms can be conceived as *administrative organizations* (Penrose, 1959; Simon, 1947), in which managers endowed with firm-specific internal experience may ignore the details and technicalities of specific plans and operations but, at the very least, are required to be acquainted with and authorize the firm's strategic actions (Penrose, 1959). Profiting from knowledge-based linkages thus requires allocating managerial resources to process (Piezunka & Dahlander, 2015; Sullivan, 2010) and filter (March and Simon, 1958; Salter, Criscuolo, & Ter Wal, 2014) the knowledge such linkages channel, as well as to take – or, at least, approve – strategic decisions regarding how to integrate (Penner-Hahn & Shaver, 2005) and coordinate (Narula, 2014) the resulting technological inputs. However, managerial resources are not unlimited. Starting from Penrose's (1959) seminal work, literature has provided evidence for the existence of managerial constraints to a firm's ability to effectively coordinate and manage its strategic moves and operations for growing levels of complexity, a phenomenon that is known as the *Penrose effect*. Thus, as the range of distinct locations with which firms maintain knowledge linkages increases, the firm's capacity to profit from such linkages could be severely challenged.

### Spatial Heterogeneity within Domestic and International Knowledge Networks

EG and regional studies research on clusters and regional systems of innovation (e.g., Boschma & Frenken, 2010; Malmberg & Maskell, 2002) has put forward the idea that countries are not internally homogeneous and that instead can be characterized by high degrees of subnational heterogeneity.

Even within the country borders, locations may be distinctive along several dimensions that are critical for innovation, as they generate non-trivial differences in the technological profile of subnational regions (Carlsson & Stankiewicz, 1991). These dimensions include the nature of innovative activities and the technological sophistication of co-located agents (Alcacer & Chung, 2007), the transactional rules governing their interaction, the R&D labor organization (Agrawal, Cockburn, Galasso, & Oettl, 2014), the endowment with knowledge generating factors, and the general socio-institutional infrastructure (Iammarino & McCann, 2013).

Subnational heterogeneity is strongly associated with the ability of certain within-country spatial scales to grow as engines of innovation. For instance, recent urban growth dynamics highlight the increasing relevance of cities (Agrawal et al., 2014) as repositories of advanced resources and facilitators of science and technology development (Berry & Glaeser, 2005).

Thus, while it is true that locations are embedded in larger national contexts that impose common institutional influences and technological patterns (Archibugi & Pianta, 1992; Bartholomew, 1997), subnational regions remain heterogeneous and retain unique characteristics (Beugelsdijk & Mudambi, 2013; Li & Bathelt, 2017; Morgan, 2004).

By establishing knowledge-based linkages with a growing range of subnational locations within their home country, firms may expand the variety of knowledge inputs available to feed their innovation funnel (Stallkamp et al., 2017). Moreover, in the domestic context, greater institutional and transactional pathways facilitate the connectedness process and limit the “hassle factor” of establishing knowledge-based linkages (Schotter & Beamish, 2013). Taken together, these arguments suggest that, as the breadth of domestic knowledge connectedness increases, also the technological scope of firm innovations should increase, as new and diverse ideas become available and can be integrated and reconfigured with existing competencies to generate broader innovations (Galunic & Rodan, 1998).

However, precisely because creating linkages within the home country is relatively easy due to a common institutional and transactional environment, firms may experience an overload of domestic connections. As the pool of diverse knowledge inputs potentially available to firms through domestic connections expands, the firm's ability to process, select, and recombine these inputs effectively should increase accordingly. While more technical tasks required for recombination purposes can be accomplished by frontline employees at different levels of the organization hierarchy based on their individual technological expertise (Burgelman, 1983; Choudhury, 2017), ultimately it is the firm management that has to take – or, at least, approve – the underlying strategic initiatives (Penrose, 1959). This requires firm managers to engage in complex decision-making processes spanning from the selection of recombination projects, to the design of coordination mechanisms and the identification of resource-allocation plans.





However, managerial resources and capabilities are limited, at least in the short run (Penrose, 1959). Widely documented problems of managerial bandwidth and bounded rationality (Cyert & March, 1963; March & Simon, 1958; Ocasio, 1997; Sullivan, 2010) imply that, in firms maintaining knowledge-based linkages to a very broad range of domestic locations, managers might not have enough resources (e.g., time, attention) to focus on and exploit the whole set of opportunities they are presented to. Specifically, among all available projects, those that span a very high range of knowledge domains are more likely to be discarded because their complexity more severely challenges managers' ability to process and evaluate them (Piezunka & Dahlander, 2015). Thus, extending the work of Penrose (1959), it can be argued that the capabilities of managers set a limit to the range of distinct domestic subnational locations from which the firm is able to benefit in any given period of time. Firms that overcome this limit will most likely fail to profit from the higher breadth of their domestic knowledge connectedness.

In other words, while firms may have the ability to search widely (Rosenkopf & Nerkar, 2001) at home by establishing knowledge-based linkages to a very broad range of domestic locations, the complexity of the decision-making tasks that have to be accomplished to truly benefit from a very ample domestic location set could be excessive for capability-constrained managers, ultimately limiting the firm's ability to process, filter and exploit the recombination opportunities embedded in such knowledge sources (Piezunka & Dahlander, 2015; Reitzig & Sorenson, 2013).

Combining these arguments, we suggest that:

**Hypothesis 1:** There is a positive curvilinear relationship between the breadth of firm domestic knowledge connectedness and the technological scope of its innovations.

Despite the fact that the world is increasingly connected, national borders still matter (Ghemawat, 2001). When these are crossed to establish knowledge-based linkages, firms are likely to confront both more fruitful opportunities and more challenging hurdles, compared to those arising from knowledge sourcing across domestic subnational areas.

While knowledge linkages within the firm home country do offer significant degrees of technological heterogeneity, such heterogeneity is likely to be limited by the common institutional and

technological context domestic locations share at the national level (Bartholomew, 1997). Thus establishing knowledge-based connections with international locations is likely to provide firms with much greater technological variety (Berry, 2014). Countries and their national innovation systems are very diverse in terms of technological specialization and capabilities (Archibugi & Pianta, 1992; Bartholomew, 1997; Cantwell, 1989; Furman, Porter, & Stern, Furman et al. 2002), and the set of foreign locations to which a firm connects is likely to offer "*knowledge and ideas from different perspectives, cultures, backgrounds, or knowledge clusters*" (Berry, 2014: 874). Thus reaching out to different international locations greatly expands the firm's recombination opportunities.

Yet just like opportunities are expanded at each new international location to which firms connect, also the complexity of managing such connections increases. Dealing with an increasingly broader range of "external elements" (in this case, international locations) exposes firms to significant challenges (Scott, 1992). Besides the heterogeneity of their technology base, different national environments also feature diverse cultural, economic, and institutional settings (Ghemawat, 2001). These differences generate "frictions" (Hutzschenreuter & Voll, 2008) arising, for instance, from the need for firm inventors to collaborate with peers who have dissimilar behaviors, beliefs, and values (Nurmi & Hinds, 2016). To benefit from such knowledge connections, firms need to adapt their routines, norms, and interaction mechanisms (Newman & Nollen, 1996). This adaptation process is costly and time-consuming, and the broader the range of different international locations, the greater the complexity firms have to confront (Hutzschenreuter & Voll, 2008; Hutzschenreuter, Voll, & Verbeke, 2011).

Thus in principle, the *Penrose effect* also affects the firm's ability to benefit from knowledge residing in international locations. However, in practice, because establishing and maintaining knowledge-based linkages to international locations is *per se* a costlier and more complex activity than connecting to domestic locations, the range of international locations to which firms connect is likely to be inherently smaller than the range of connected domestic locations.

Arguably, firms will carefully scrutinize the international space and identify the locations to which they want to connect, in search for highly



specialized and complementary knowledge that most likely is not available domestically (Gittelman, 2007). Thus, the process through which firms establish knowledge-based linkages to international locations is likely to be more rational and designed *ex ante*. Through this “cherry-picking” approach, firms establish linkages to selected foreign locations to source unique and valuable knowledge inputs.

This set of insights should be complemented with perspectives on the attention-based view of the firm (Ocasio, 1997), which suggests that decision-makers are selective in their focus of attention, such that the *nature* of the attention allocated to different inducements varies with their perceived salience. Typically, issues that are perceived as more critical for the organization receive more considerate attention. At the individual level, such issues are likely to be governed by a “controlled processing” approach (Shiffrin & Schneider, 1977), which requires the allocation of significant attentional capacity in the form of meticulous attention, as opposed to an “automatic processing” approach, which instead is more routinized and does not entail the active supervision of individuals. Drawing on these ideas, one could argue that, given the complexity they generate, knowledge-based connections to international locations are perceived to be more salient and thus attract more focused attention compared to connections with domestic locations. In other words, organizational decision-makers can be expected to devote more “*energy, effort and mindfulness*” (Ocasio, 1997: 190) to the knowledge sourced from international locations that, for this very reason, is less likely to be affected by problems of limited managerial bandwidth (Ocasio, 1997) and bounded rationality (Cyert & March, 1963).

More focused managerial attention, coupled with the considerable heterogeneity and technological variety of international locations, should enhance firm recombination capabilities, thus allowing the generation of broader innovations.

Taken together, these arguments suggest that:

**Hypothesis 2:** There is a positive relationship between the breadth of firm international knowledge connectedness and the technological scope of its innovations.

Since domestic and international knowledge connectedness generate distinct opportunities and challenges for firm recombination processes, firms may not rely exclusively on one of these two knowledge-sourcing strategies. It is therefore relevant to

understand how the technological scope of firm innovations could vary in presence of a mixture of domestic and international knowledge-based linkages.

We argue that when firms maintain connections to both domestic and international locations, the latter “substitute” for knowledge-based linkages developed domestically, such that the benefit arising from an increase in the breadth of domestic knowledge connectedness is likely to be more limited. This depends on the higher recombinatory potential knowledge sourced internationally entails, compared to knowledge sourced domestically.

As mentioned above, the knowledge sourced internationally is likely to be more diverse both in type and content (Phene, Fladmoe-Lindquist, & Marsh, 2006) compared to domestic knowledge, given the cross-country heterogeneity of national innovation systems (Bartholomew, 1997; Cantwell, 1989). Such marked diversity offers greater potential to expand the firm’s innovation processes in distant knowledge domains by enabling valuable associations to its existing technological competencies (Phene et al., 2006). Thus, compared to firms that rely mainly on domestic knowledge, firms that are also able to successfully exploit the technological variety embedded in international locations are likely to reap more limited benefits from an increase in the breadth of domestic connectedness, since knowledge of foreign origin should provide them with more valuable recombination opportunities.

In this respect, perspectives on the attention-based view of the firm suggest that, because managers are limited in their ability to attend to all external inducements they are exposed to (Ocasio, 1997), there is a competition for managers’ attention (Cyert & March, 1963). The *amount* of attention devoted to each specific stimulus thus depends on the attractiveness and value of alternative options (Li, Maggitti, Smith, Tesluk, & Katila, 2013). Since knowledge residing in international locations is more distant and, thus, more attractive for recombination purposes than domestic knowledge, firms will arguably privilege the former to the latter when allocating their attentional resources.

Thus, as firms increase the breadth of their international knowledge connectedness, the knowledge accessed through linkages to a broader range of domestic locations is more likely to be disregarded, and its marginal contribution to the firm’s recombination processes and technological scope is likely to be more limited.



Summarizing these arguments, we propose that:

**Hypothesis 3:** The breadth of firm international knowledge connectedness moderates the relationship between the breadth of firm domestic knowledge connectedness and the technological scope of its innovations by flattening the positive curvilinear curve.

## METHODS

### Data

To build the final sample employed to test our hypotheses, we followed a three-stage procedure. First, for each year included in the period 1990–2006, we identified all publicly traded firms based in the US that were part of the S&P 500 for at least one week. We used Compustat North America to collect this information. This sample frame was designed to capture the innovative patterns of large firms (by market capitalization) headquartered in the US, which represent a broad cross section of US business.

Second, using the identifier of the firms selected in the first stage, we gathered firm-level data from Compustat North America. Finally, we collected information about the innovative activities of the firms in our sample relying on USPTO patent data. Our empirical strategy was to use patent data to represent the inventor networks and the technological scope of the innovations of the firms in our sample, following previous literature that has already employed patent data to explore inventors' collaboration patterns and innovation performance (e.g., Fleming & Sorenson, 2004; Lahiri, 2010, 2015; Perri et al., 2017). Patent documents allow determining the location of the inventor(s), the organization(s) to which the patent is assigned, the grant and application dates, and the technological classes of the invention. Focusing only on utility patents, data on USPTO granted patents was gathered from the NBER patent citation data file (Hall, Jaffe, & Trajtenberg, 2001) matching the identifier of our sample firms. We complemented this data by gathering fine-grained inventors' information from the "Disambiguation and co-authorship networks of the US patent inventor database (1975–2010)" (Li et al., 2014).

Our final sample is composed of 554 firms, and the unit of analysis is the firm-year. Since the total number of observations in our sample results in a final usable observation count of 7432, our panel

dataset is unbalanced. This is due to the following two reasons: (1) not all the firms were listed in the S&P 500 for all years of observation; (2) missing data forced us to drop some firm-year observations.

### Variables and Measures

#### *Dependent variable*

The dependent variable, *Technological scope*, measures the average technological scope of patents included in the firm's patent portfolio in year  $t$ , by considering all patents granted to firm  $i$  and applied for in year  $t$ . It is based on the measure originally proposed by Lerner (1994), who used the number of unique technological classes to which a patent is assigned. Compared to his approach, we chose to rely on the higher-level technological classification proposed by Hall et al. (2001), by which the over 400 US technological classes are aggregated into 36 two-digit technological subcategories based on the degree to which they relate to each other (Novelli, 2015). Thus for each patent  $j$ , we calculated the number of unique technological subcategories associated to the patent. Ultimately, the dependent variable was computed as the natural logarithm of one plus the average number of unique technological subcategories associated to each patent belonging to the firm  $i$  patent portfolio in year  $t$ . As an example of the *Technological Scope* calculation, consider firm  $i$ , which in year  $t$  has 2 patents, i.e., #1 and #2. Patent #1 has been assigned to classes 327 and 330 (Subcategory name: Electrical devices), while Patent #2 has been assigned to classes 604 (Subcategory name: Surgery & Medical Instruments), 536 (Subcategory name: Organic compounds) and 353 (Subcategory name: Optics). Therefore the *Technological scope* of firm  $i$  in year  $t$  is (the natural logarithm of)  $(1 + 3)/2 = 2$ .

It has been suggested that technological classes serve as proxies for the technological "building blocks" of the patented invention (Fleming, 2001). Technological classes are thus used to illustrate the outcomes of the processes through which firms combine distinct technological components.<sup>2</sup> A patent with broader scope is likely to have been developed through search processes that cross and recombine more diverse technological fields, and is positioned "across multiple technological domains" (Novelli, 2015: 498).

We chose the technological subcategory level to avoid overstating the actual scope of the technological domains a patent brings together, considering that each subcategory includes by definition several related US technological classes (Melero &



Palomerias, 2015). Thus patents with broader scope are likely to include more dispersed technological knowledge (Novelli, 2015) and be relevant to different technological fields.

### Independent variables

Following the approach of Lahiri (2010, 2015), we used the address of the patent inventors to determine the location of knowledge creation. Frequently, patents are assigned to a corporate headquarters, but the underlying inventions may stem from different geographical locations. Thus, by looking at the inventors' address reported in each patent document, we can identify the geographical position of the connected inventors.

The first independent variable, *Breadth of Domestic Connectedness*, measures the range of unique domestic locations in which the firm has established knowledge-based linkages in each year through its inventor(s). For firm  $i$  this variable was computed as the natural logarithm of one plus the number of unique US-based locations of its inventors. Our definition of a US-based location is the US core-based statistical area (CBSA).<sup>3</sup> CBSAs are defined by the US Office of Management and Budget and represent consistent geographical entities within the US. To identify these locations, we first considered the addresses of all US-based inventors of patents granted to firm  $i$  and applied for in year  $t - 1$ . Then, we aggregated these addresses at the CBSA level.

The second independent variable, *Breadth of International Connectedness*, measures the range of unique foreign locations in which the firm has established knowledge-based linkages in each year through its inventor(s). For firm  $i$ , this variable was computed as the natural logarithm of one plus the number of unique foreign locations of its inventors, identified using the addresses of all non-US inventors of patents granted to firm  $i$ , and applied for in year  $t - 1$ , which in this case were aggregated at country level.<sup>4</sup>

To test the first two hypotheses, we created the squared terms of both the independent variables, i.e., *Breadth of Domestic Connectedness Squared* and *Breadth of International Connectedness Squared*. Additionally, to test the third hypothesis, we computed the interaction terms by multiplying the two distinct independent variables (and their squared terms).

### Control variables

We controlled for the technological diversity of the firm patent portfolio as it is till the year  $t - 1$ . For each year the variable *Technological Diversity* was built as:

$$\text{Technological diversity}_i = 1 - \sum_{c=1}^C (s_{ic})^2$$

where  $s_{ic}$  is the percentage of patents granted to firm  $i$  and applied for until the year  $t - 1$  that belong to the technological subcategory  $c$  (for a similar approach, see Gambardella & Torrisi, 1998). This variable enables us to control for the range of technological fields in which the firm has patented inventions till the year  $t - 1$ , and represents the extent to which such technologies are dispersed across different subcategories within the firm's patent portfolio. Firms featuring higher technological diversity are likely to have developed broader technological capabilities over time. Thus, they may be better positioned to generate patents with greater technological scope, since the knowledge inputs that are already available within the firm for recombination purposes are more heterogeneous.<sup>5</sup>

We also included the variable *Patent Stock*, measured as the natural logarithm of one plus the cumulative number of granted patents that the firm  $i$  applied for until the observation year  $t$ .<sup>6</sup> This variable proxies firms' technological capabilities (Patel & Pavitt, 1997), and is expected to have a positive effect on the firm ability to produce patents with greater technological scope.

A set of firm characteristics was also controlled for in the models. *Firm Size* was calculated as the natural logarithm of one plus the firm's total assets in year  $t - 1$ . Previous literature does not provide homogeneous findings on the relationship between firm size and innovation performance. On the one hand, size is related to greater internal funds available for innovation and economies of scale in R&D. On the other hand, larger firms might experience loss of managerial control and reduction of incentives for scientists, leading to the deterioration of innovative activities (Phene & Almeida, 2008).

We controlled for the *Firm Intangible Asset Intensity*, measured as the amount of firm's intangible assets over total assets in year  $t - 1$ . Firms with higher intangible assets intensity are expected to have greater recombination capabilities, as intangible assets represent important inputs to the innovative process (Heirman & Clarysse, 2007).

To control the relationship between firm performance and innovation performance, we included the firm's return of assets (*Firm ROA*) in year  $t - 1$ .

The variable *Firm Leverage*, i.e., financial debt/equity ratio, in year  $t - 1$  accounts for the possible



effect of firm leverage on firm innovative performance (e.g., Kochhar & David, 1996).

Finally, as our sample collects firms over a 16-year period, we built a set of three time dummies aggregating the periods 1990–1995, 1996–2000, 2001–2006 and included two of them in our estimations.

**Estimation Approach**

The model specification we used to test the two main relationships (i.e., Hypothesis 1 and Hypothesis 2) is the following:

$$\begin{aligned}
 \text{Technological Scope}_{i,t} = & \alpha_0 \\
 & + \alpha_1 \text{Breadth of Domestic Connectedness}_{i,t-1} \\
 & + \alpha_2 \text{Breadth of International Connectedness}_{i,t-1} \\
 & + \alpha_3 \text{Breadth of Domestic Connectedness}_{i,t-1}^2 \\
 & + \text{Controls}_{i,t(-1)} + \mathbf{S}_i + \mathbf{T}_t + \mathbf{W}_i + \varepsilon_{i,t}
 \end{aligned}$$

where **Controls**<sub>*i,t(-1)*</sub> is the vector of our control variables presented in the above section; **S**<sub>*i*</sub> are industry dummies, which should be included in the model as the firms in our sample operate in different industries; **T**<sub>*t*</sub> are time dummies, capturing time-varying macroeconomic shocks; **W**<sub>*i*</sub> are unobservable firm-specific factors;  $\varepsilon_{i,t}$  are i.i.d error terms.

In our empirical analysis, we run within-group fixed effects (FE) estimation, which removes any potential concern about the time-unvarying endogeneity of independent variables due to their alleged correlation with **W**<sub>*i*</sub> (Wooldridge, 2002). Hausman’s (1978) specification tests to compare FE

and random effects model specifications suggested that the FE approach was appropriate for all regressions used in our analysis (e.g.,  $\chi^2 = 153.42$ ,  $p = 0.000$ , calculated using the model specification described above). As an additional precaution, all models were estimated with robust standard errors.

**RESULTS**

Table 1 provides the descriptive statistics and correlation matrix for dependent, independent, and control variables used in our analysis. Consistent with our theoretical arguments, the sample means of our two main independent variables suggest that firms in our sample are more likely to establish linkages to a broader range of domestic rather than foreign locations. No issues of multicollinearity seem to appear, except for the correlation between *Patent Stock* and *Technological Diversity*. We run the common variance inflation factor (VIF) test to confirm the absence of multicollinearity in our data: the mean VIF is 1.57, and the maximum VIF is 3.41, indicating that all VIF values are pretty lower than the commonly used threshold of 10 (Neter, Kutner, Nachtsheim, & Wasserman, 1996).

Results of the first two hypotheses are presented in Table 2. All models report statistically significant values of the F statistic. Model 1 presents the baseline model that includes all our controls. As expected, *Patent Stock* positively and significantly ( $p < 0.001$ ) affects the technological scope of firm innovations. A positive and significant effect ( $p < 0.1$ ) is also shown by the *Firm Leverage*, while

**Table 1** Descriptive statistics and correlation matrix

Variable	1	2	3	4	5	6	7	8	9
Technological scope	1								
Breadth of Domestic Connectedness	0.4307*	1							
Breadth of International Connectedness	0.2569*	0.1860*	1						
Technological Diversity	0.4827*	0.3550*	0.2154*	1					
Patent stock	0.6368*	0.4421*	0.3946*	0.7402*	1				
Firm size	-0.0032	0.0298*	0.1521*	0.0840*	0.1968*	1			
Firm intangible asset intensity	0.0137	-0.0288*	0.0475*	0.0182	0.0091	-0.0313*	1		
Firm ROA	0.0281*	0.0252*	0.0094	-0.006	0.0024	0.0643*	-0.0115	1	
Firm leverage	0.0059	0.001	0.003	-0.021	-0.0086	0.0320*	-0.004	0.0071	1
Mean	0.5453	0.5256	0.0967	0.5842	4.0998	8.2511	0.1324	0.0363	0.6834
SD	0.4516	0.9404	0.2918	0.3173	2.6602	1.7660	0.6461	0.3218	42.1143
Min	0	0	0	0	0	0.0459	0	-24.5463	-3505.21
Max	1.6094	4.5326	2.0794	0.9487	10.730	14.2170	41.4837	2.8594	494.1111

*N* = 7432. \* *p* value < 0.05.



**Table 2** Results of the FE estimator (with robust standard errors)

	Model 1	Model 2	Model 3	Model 4	Model 5
Technological diversity	-0.0015 (0.0480)	-0.0614 (0.0500)	-0.0972* (0.0490)	-0.0614 (0.0500)	-0.0973* (0.0490)
Patent stock	0.1325*** (0.0126)	0.1330*** (0.0125)	0.1381*** (0.0121)	0.1330*** (0.0125)	0.1380*** (0.0121)
Firm size	-0.0169† (0.0101)	-0.0211* (0.0098)	-0.0200* (0.0094)	-0.0211* (0.0098)	-0.0200* (0.0094)
Firm intangible asset intensity	-0.0017 (0.0029)	-0.0014 (0.0026)	-0.0011 (0.0027)	-0.0014 (0.0026)	-0.0011 (0.0027)
Firm ROA	0.0007 (0.0049)	0.0012 (0.0047)	0.0001 (0.0050)	0.0012 (0.0047)	0.0001 (0.0050)
Firm leverage	0.0000† (0.0000)	0.0001* (0.0000)	0.0001* (0.0000)	0.0001* (0.0000)	0.0001* (0.000)
Breadth of domestic connectedness		0.0458*** (0.0067)	0.1694*** (0.0174)	0.0458*** (0.0067)	0.1700*** (0.0173)
Breadth of International Connectedness		0.0677*** (0.0145)	0.0696*** (0.0136)	0.0671* (0.0284)	0.0927** (0.0300)
Breadth of Domestic Connectedness sq.			-0.0446*** (0.0052)		-0.0448*** (0.0052)
Breadth of International Connectedness sq.				0.0006 (0.0235)	-0.0221 (0.0262)
Constant	0.0023 (0.0812)	0.0694 (0.0800)	0.0543 (0.0774)	0.0694 (0.0800)	0.0544 (0.0774)
Time dummies	Yes	Yes	Yes	Yes	Yes
Obs.	7432	7432	7432	7432	7432
Groups	554	554	554	554	554
F	35.81***	33.66***	36.83***	30.86***	33.95***
R <sup>2</sup> within	0.0804	0.0900	0.1002	0.0900	0.1002

Robust standard errors in parentheses; †*p* < 0.1, \* *p* < 0.05, \*\* *p* < 0.01, \*\*\* *p* < 0.001.

*Firm Size* has a negative and significant impact (*p* < 0.1) on the dependent variable. The effects of these controls remain robust across subsequent specifications. Model 2 includes the linear effect of our main independent variables, i.e., *Breadth of Domestic Connectedness* and *Breadth of International Connectedness*, and their coefficients are both positive and strongly significant (*p* < 0.001), in line with our predictions. These results provide the first evidence that knowledge connectedness favors the firm’s recombination activities and, in turn, its ability to produce innovations with greater technological scope.

To test Hypothesis 1, we used Model 3 by including the quadratic term of the *Breadth of Domestic Connectedness*. The results confirm our expectations of a positive curvilinear relationship between the *Breadth of Domestic Connectedness* and *Technological Scope*. Specifically, we found that the linear term of *Breadth of Domestic Connectedness* is positive and significant (*p* < 0.001), but also its quadratic term is significant (*p* < 0.001) and negative. Although this is enough to provide evidence

of a positive curvilinear relationship, it is not sufficient to exclude the existence of an inverted U-shaped relationship between the *Breadth of Domestic Connectedness* and *Technological Scope*. To test whether the relationship is actually inverted U-shaped, we performed the remaining two steps of the procedure proposed by Lind and Mehlum (2010) (suggested in Haans, Pieters, & He, 2016). We analyzed the slope of the curve on both ends of the data range by adopting the following test:

$$\alpha_1 + 2 \alpha_2 V_L > 0 \tag{1}$$

$$\alpha_1 + 2 \alpha_2 V_H < 0 \tag{2}$$

where  $\alpha_1$  and  $\alpha_2$  are the estimated coefficients of the variables *Breadth of Domestic Connectedness* and its squared term, respectively;  $V_L$  and  $V_H$  represent the minimum and maximum values of *Breadth of Domestic Connectedness*, respectively. If the test indicates that both inequalities are statistically significant, it provides evidence that both the left-hand and right-hand slopes are sufficiently steep for the presence of an inverted U-shaped



relationship. In our case, both conditions are satisfied as Inequality (1) is  $0.1694 > 0$  ( $p = 0.000$ ), while Inequality (2) is  $-0.2348 < 0$  ( $p = 0.000$ ). Additionally, we verified whether a turning point existed and was located within the data range. To do so, we calculated the turning point using the following formula:  $-\alpha_1 / 2 \alpha_2$ . It is equal to 1.8995 and the 95% confidence interval (1.7585, 2.0405) is within the data range of the variable *Breadth of Domestic Connectedness*, meaning that we could be reasonably sure that our analysis pointed out an inverted U-shaped relationship between *Breadth of Domestic Connectedness* and *Technological Scope*.

This analysis supports our idea that the breadth of domestic knowledge connectedness positively influences a firm’s ability to develop innovations with greater technological scope, but only up to a given point, corresponding to a certain range of domestic locations. However, the results show also that, after this point is reached, firms connected with a broader range of domestic locations experience a more limited technological scope of their innovations. Theoretically, we claim this effect has a twofold origin. First, in firms that maintain linkages to a too broad range of domestic locations, the Penrose effect might be so severe that capability-constrained managers are not only unable to exploit the full recombinatory potential of the available domestic knowledge inputs, but they also engage in poor decision-making (O’Reilly, 1980), for instance by privileging the use of a restricted range of familiar technological domains to limit managerial complexity. This leads to narrow, path-dependent innovations (Nelson & Winter, 1982). Second, existing knowledge-based connections drive further linkages with inventors sharing a common technological base (von Hippel, 1987). Because geographical proximity that characterizes linkages within the firm home country facilitates personal contacts and embedded relationships,

search (Rosenkopf & Almeida, 2003), thus being more inclined toward narrow innovation processes.

In Model 4, we tested Hypothesis 2 by adding to the regressors already included in Model 2 the quadratic term of *Breadth of International Connectedness* to exclude the presence of any curvilinear relationship with *Technological Scope*. The results are consistent with our expectations as only the linear term of *Breadth of International Connectedness* turns out to be positive and significant ( $p < 0.05$ ), while its quadratic term is not significant at conventional levels. This provides support to our theoretical arguments that knowledge sourcing through international connectedness positively affects the technological scope of firm innovations. Model 5 includes both linear and quadratic terms of *Breadth of Domestic Connectedness* and *Breadth of International Connectedness* to test jointly the effects tested separately in the previous models. The results are confirmed.

To provide evidence on Hypothesis 3, we tested the moderation effect of *Breadth of International Connectedness* on the relationship between *Breadth of Domestic Connectedness* and *Technological Scope*, starting from the specification reported in Model 3 of Table 2. As our results depicted the presence of an inverted U-shaped relationship between *Breadth of Domestic Connectedness* and the dependent variable, we applied the procedure suggested by Haans et al. (2016) to test the moderation. Table 3 reports the results of the FE estimations including the moderation effects.

Two possible moderation effects, i.e., the shift in the turning point of the inverted U-shape and the flattening (or steepening) of the curve, could be present and needed to be separately tested. Our Hypothesis 3 only theorizes a flattening effect, but for the sake of completeness we tested both. To test how the moderator affects the turning point of our inverted U-shaped relationship we used the following:

$$\text{Breadth of Domestic Connectedness}^* = \frac{-\alpha_1 - \alpha_3 \text{ Breadth of International Connectedness}}{2 \alpha_2 + 2 \alpha_4 \text{ Breadth of International Connectedness}} \tag{3}$$

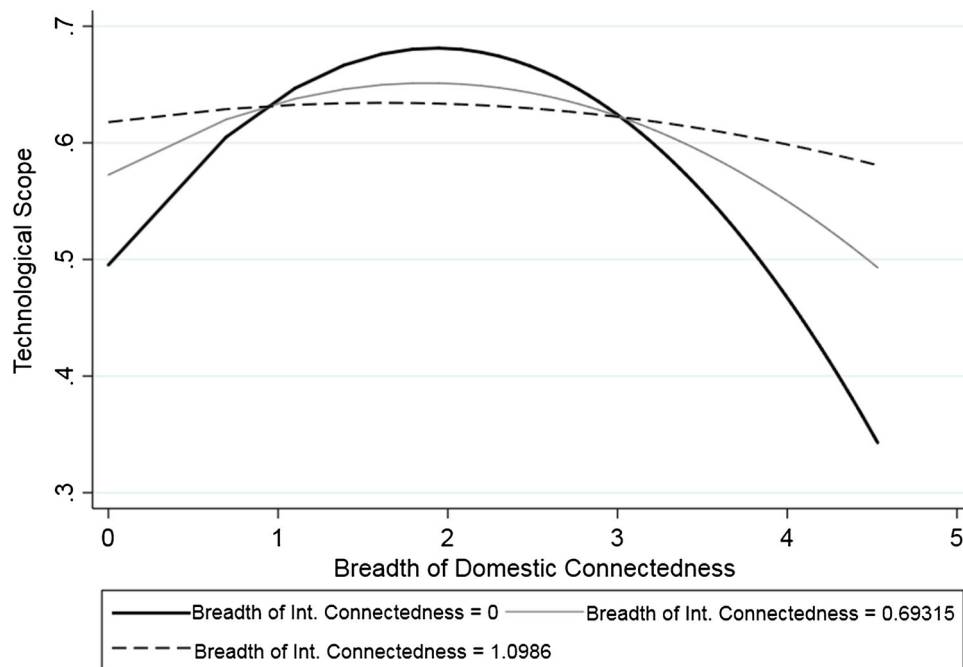
firms that maintain connections with a very broad range of domestic locations are likely to experience groupthink and an over-reliance on social networks that accentuate the organizational focus on local

where  $\alpha_1$  and  $\alpha_2$  are the estimated coefficients of *Breadth of Domestic Connectedness* and its squared term, respectively;  $\alpha_3$  and  $\alpha_4$  are the estimated coefficients of the interactions of *Breadth of*

**Table 3** Results of the FE estimator (with robust standard errors) with moderation of *Breadth of International Connectedness*

	Model 1
Technological diversity	-0.1032* (0.0488)
Patent stock	0.1378*** (0.0120)
Firm size	-0.0203* (0.0093)
Firm intangible asset intensity	-0.0014 (0.0027)
Firm ROA	0.0002 (0.005)
Firm leverage	0.0001* (0.0000)
Breadth of domestic connectedness	0.1927*** (0.0204)
Breadth of international connectedness	0.1114*** (0.0161)
Breadth of domestic connectedness sq.	-0.0499*** (0.0066)
Breadth of domestic connectedness × breadth of international connectedness	-0.1568*** (0.0212)
Breadth of domestic connectedness sq. × breadth of international connectedness	0.0397*** (0.0065)
Constant	0.0576 (0.0767)
Time dummies	Yes
Obs.	7432
Groups	554
F	32.12***
R <sup>2</sup> within	0.1032

Robust standard errors in parentheses; \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .



**Figure 1** Illustration of the moderation effect.

*International Connectedness* with *Breadth of Domestic Connectedness* and their squared term, respectively. As shown by Eq. (3), the turning point depends on the value of the moderator; for example, when the firm has no foreign knowledge-based linkages, the optimal value of the breadth of the domestic connectedness is 1.9297 (which equals to around 6 locations). To determine whether a shift in the turning point actually

occurs, we calculated the derivative of Eq. (3) with respect to the moderator, which turned out to be negative but not statistically different from zero. Therefore we can conclude that the shift towards left of the turning point is so miniscule that cannot be considered different from zero.

To analyze the flattening of the curve, it was sufficient to look at the coefficient of the





interaction between *Breadth of International Connectedness* and the squared term of *Breadth of Domestic Connectedness*. Table 3 shows that such coefficient is positive and significant ( $p < 0.001$ ), indicating that a flattening of the inverted U-shaped curve occurs as effect of the moderator. Figure 1 provides a graphical illustration of this for values of the *Breadth of International Connectedness* corresponding to 0, 0.6931 and 1.0986, which represent 0, 1 and 2 foreign locations, respectively.<sup>7</sup>

The results of the interaction show that, as the range of foreign locations in which the firm has knowledge-based linkages increases, the inverted U-shaped relationship between the breadth of domestic connectedness and its technological scope begins to flatten, as both the left- and right-hand sides of the curve tend to be less steep. As claimed in Hypothesis 3, the reliance on foreign knowledge sources seems to substitute for domestic knowledge thus dampening its positive effect, for low levels of the breadth of firm domestic knowledge connectedness. Yet our analysis shows that it also reduces the downside effect of high levels of the breadth of firm domestic knowledge connectedness. A possible explanation of the latter finding is that, in firms that rely too much on domestic knowledge connections, over-embeddedness in the home knowledge base prevents to disregard domestic knowledge sources and substitute them with international ones; yet, the access to international knowledge sources increases the set of recombination opportunities available to the firm for finding truly valuable and technologically broader uses to domestic knowledge inputs (Phene et al., 2006), which otherwise would only be recombined with each other. Under this condition, capability-constrained managers may find it easier to recognize the value of the resulting recombination opportunities and take effective decisions on their development.<sup>8</sup>

### Robustness Checks

The relationships between our independent and dependent variables might be the result of time-varying unobserved heterogeneity. This problem could be present as the technological scope of firm innovations may be closely related to unobservable characteristics such as breakthrough or radical ideas, the resources allocated to projects perceived as more promising than others, or a brilliant R&D manager. If these unobservable characteristics also influence the firm's knowledge connectedness

strategy, a spurious correlation between our independent and dependent variables might follow due to unobserved heterogeneity. Hence to provide further evidence of the robustness of our main model specification, we use an instrumental variables (IV) procedure, by means of a two-stage least-squares within-group estimator (with heteroskedastic-robust standard errors), which represents a more solid empirical approach to account for potential endogeneity issues (Wooldridge, 2002).

We applied the IV procedure on Model 3 presented in Table 2. Even though the allegedly endogenous variables are three (i.e., *Breadth of Domestic Connectedness*, *Breadth of Domestic Connectedness squared* and *Breadth of International Connectedness*), we employed four instruments (i.e., *Number of CBSA Patents*, *CBSA Cross-organization Collaborations*, *International Flight Departures*, *International Flight Departures Squared*) in order to have an over-identified model to properly test the validity of the selected instruments. The detailed description of the IV procedure is provided in Appendix A. Table A1 (shown in Appendix A) displays the results of the IV estimates, which are consistent with our main findings presented in Table 2, confirming the robustness of our main results. Several key tests also confirm the validity and goodness of the instruments (for more details, see Appendix A).

We also checked the sensitivity of our results to firm size, by splitting the sample, and eliminating very large or very small firms from the sample (for more details, see Appendix A). These additional tests confirmed the results obtained in our main findings (results are available upon request from the authors).

## DISCUSSION AND CONCLUSIONS

Focusing on firm connectedness behavior, this article contributes to the literature on innovation and knowledge sourcing at the intersection between IB (e.g., Almeida & Phene, 2004; Frost, 2001; Singh, 2008; Lahiri, 2010, 2015) and EG (e.g., Audretsch & Feldman, 1996; Maskell & Malmberg, 1999; Maskell, 2001) by explicitly accounting for the geographic space as characterized by both international and subnational heterogeneity (Beugelsdijk & Mudambi, 2013; Beugelsdijk et al., 2010; Rugman & Verbeke, 2004; Stallkamp et al., 2017). Merging the Penrosean view of managerial capabilities (Penrose, 1959) with insights from the attention-based theory of the firm (Ocasio, 1997), our theoretical development suggests that the inherent differences that separate domestic



and foreign space interact with the managerial capacity to attend to inputs originating in these distinct knowledge contexts. The knowledge firms access through linkages to both domestically and internationally distributed inventors creates potential basis for wider technological scope of their innovations, by increasing the availability of diverse technological inputs that may be combined with the firm existing technological competencies. However, while domestic space makes the establishment and maintenance of knowledge-based linkages relatively easy, foreign space provides more valuable recombination opportunities but also generates significant challenges to firm ability to find and manage linkages to international locations. Such differences reflect in the attention managers choose to allocate to foreign versus domestic knowledge sources, with foreign knowledge sources being privileged to the domestic ones. Hence knowledge sourced through domestic connections is more likely to be affected by managers' capability constraints, while knowledge accessed through international connections more easily finds a productive use in the firm innovation funnel. Our theoretical explanation of the mechanisms that govern the relationships between domestic and international connectedness and the technological scope of firm innovations offers a contribution to the literature on the geography of innovation and knowledge sourcing (e.g., Almeida & Phene, 2004; Frost, 2001; Lahiri, 2010, 2015; Singh, 2008) by highlighting the importance of incorporating insights from traditionally distinct strands of research, such as those focusing on managerial capabilities (Penrose, 1959) and the allocation of attentional resources (Ocasio, 1997).

Our results document an inverted U-shaped relationship between the breadth of firm domestic knowledge connectedness and the technological scope of its innovations. This is consistent with the idea that the capabilities of managers set a limit to the range of distinct domestic subnational locations from which firms are able to profit in any given period of time. Firms that overcome this limit experience a narrower technological scope, as their recombination activities are likely to be jeopardized by poor decision-making (O'Reilly, 1980), path-dependency (Nelson & Winter, 1982), and an over-reliance on social networks that accentuate the organizational focus on local search (Rosenkopf & Almeida, 2003). Conversely, the relationship between the range of unique foreign locations to which firms maintain knowledge-based linkages and the technological scope of their innovations is

positive. The focused managerial attention these linkages receive "*facilitates perception and action*" (Ocasio, 1997: 190) toward the knowledge inputs they channel. As a consequence, firms can more effectively exploit the recombinatory potential embedded in diverse national contexts (Bartholomew, 1997; Cantwell, 1989; Furman et al., 2002).

Thus besides confirming that domestic and international knowledge sourcing are very different strategies, our results also provide evidence on the shape that the relationships between the breadth of a firm's knowledge-based connections to domestic and international locations and its technological scope take. In so doing, our study offers insights to the empirical literature on the relationship between the geographical dispersion of R&D and firm technological performance (Lahiri, 2010, 2015; Singh, 2008). This literature has not clearly distinguished between domestic and foreign geographical locations, and has provided inconclusive findings. By documenting two distinct relationships for the breadth of domestic and international knowledge connectedness, our results suggest that more consistent findings could emerge if domestic and foreign R&D geographical dispersion are treated separately.

By explicitly distinguishing between domestic and international connectedness, our study further adds to the literature on the geography of knowledge sourcing (e.g., Frost, 2001; Phene et al., 2006) as it is able to explore the interplay between domestic and international knowledge-based linkages. Far from being independent on each other, they interact to explain how distinct knowledge inputs contribute to firm recombination processes. More specifically, our results show that the knowledge sourced through international connections may both substitute for and complement domestic knowledge, thus altering the latter's contribution to the technological scope of firm innovations for different degrees of the breadth of firm domestic connectedness.

As with all research, this study is not without its shortcomings, which in turn open up avenues for future research. First, in this article, we do not account for the distribution of firm domestic and international operational activities (e.g., manufacturing, sales, and distribution), due to data limitation. Future studies could better investigate the effects on firm innovation performance of a closer overlap between the geographical spread of firms' operational network and the geographical breadth of knowledge-based connections.

Second, while we have explored the impact of the breadth of connectedness, an exploration of



connectivity by focusing on the qualitative characteristics of linkages (Lorenzen & Mudambi, 2013) would add greater insights. Patent data do not offer the possibility to scrutinize such qualitative characteristics of linkages, but primary data collected through interviews or large-scale survey might provide very interesting perspectives.

Third, while our study advances existing research by simultaneously accounting for domestic subnational heterogeneity and foreign cross-national heterogeneity, future works could improve the granularity of our approach. In fact, an exhaustive analysis of the impact of crossing national borders on firms' activities requires considering both international spatial variation and within host country subnational heterogeneity (Beugelsdijk & Mudambi, 2013). Because a homogeneous definition of subnational locations is not available worldwide, we were limited in our ability to account for this further dimension of spatial heterogeneity, but future progress in available data could improve researchers' capability to account for this relevant aspect.

Our study also bears relevant implications for managers and practitioners. Managers should be aware that both domestic and international search strategies are explorative, even though with different paths. The non-trivial nature of international knowledge search suggests that at key junctures, firms solving intractable problems will search far and wide (Gittelman, 2007). Domestic search is more likely to be constrained by bounded rationality (Levinthal & March, 1993; March, 1991), such that the bandwidth challenges that managers face may constrain the usefulness of local search simply on account of the ease through which it can be accessed. Thus, managers should either seek to reduce the range of domestic locations to which their firms establish connections, or develop more effective internal procedures that alleviate their decision-making burden. As a further alternative option, managers of firms that maintain connections to a wide range of domestic locations should combine them with knowledge-based linkages to international locations that, as our results show, expand the firm's recombination set and boosts the technological scope of its innovations.

### ACKNOWLEDGEMENTS

We would like to thank the Special Issue Editors, in particular Professor Shige Makino, and the anonymous reviewers for the insightful and constructive comments provided in the review process. Further, we would like

to acknowledge the valuable guidance of the JIBS Area Editor Ram Mudambi. We are also grateful to John Cantwell, Francesco Castellaneta and Samuele Murtinu, as well as to the participants of the 2016 Academy of International Business Annual Meeting and the 2016 Academy of Management Annual Meeting for their developmental inputs and suggestions on an earlier version of the manuscript.

### NOTES

<sup>1</sup>It is worth underlining that, following established research (Lerner, 1994; Novelli, 2015), in this article we refer to the technological scope of firms' individual innovation projects, rather than to the technological scope of the firm as a whole. In other words, we look at firms' ability to recombine different technological domains within the same innovation, rather than their ability to generate a broad portfolio of single-technology innovations.

<sup>2</sup>Patents are assigned to one or more technological classes that identify the technological domains into which the patented invention's claims fall (USPTO, 2014). US technological classes are updated each year, through a retrospective process that allows historical consistency (Fleming, 2001).

<sup>3</sup>CBSAs "consist of the county or counties or equivalent entities associated with at least one core (urbanized area or urban cluster) of at least 10,000 population, plus adjacent counties having a high degree of social and economic integration with the core as measured through commuting ties with the counties associated with the core" (source: [https://www.census.gov/geo/reference/gtc/gtc\\_cbsa.html](https://www.census.gov/geo/reference/gtc/gtc_cbsa.html)).

<sup>4</sup>A more accurate approach would be based on the consideration of subnational heterogeneity associated also with foreign connections (Beugelsdijk & Mudambi, 2013). Empirically our approach is justified by the impossibility to find a coherent within-country categorization of subnational locations applicable worldwide and comparable to the CBSAs definition.

<sup>5</sup>In other words, the technological diversity of the firm's patent portfolio offers a proxy of the breadth of the technological knowledge that the firm has developed over time and that can be used and recombined with external knowledge sources to generate new patented innovations. In turn, each of these innovations may feature different levels of technological scope, as measured in our dependent variable.

<sup>6</sup>We expect the technological scope of firm innovations to be affected not only by prior patent production, but also by the firm's ability to generate



innovations in the observation year (e.g., firms that do not apply for patents in year  $t$  automatically score zero in their innovations' technological scope). Nonetheless, robustness checks (available upon request from the authors) showed that using a one-year lag of the *Patent Stock* variable does not change our results.

<sup>7</sup>As a robustness check, we re-estimated the regressions presented in Tables 2 and 3 by means of models where the main independent variables are not logarithmical transformations, but rather count variables of the number of domestic and foreign locations in which the firm has established knowledge-based connections. The results of this model specification are in line with the main findings and available upon request from the authors.

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## APPENDIX

### Appendix A. Description of the Robustness Checks

We applied the IV procedure on Model 3 presented in Table 2 of the main text. We employed four instruments for our three allegedly endogenous variables (i.e., *Breadth of Domestic Connectedness*, *Breadth of Domestic Connectedness Squared* and *Breadth of International Connectedness*). Therefore, the application of the IV procedure consisted in four regressions jointly estimated. In the first three regressions, each potentially endogenous variable is the dependent variable in a regression which contains the instrumental variables and all other control variables. In the fourth regression, the dependent variable is *Technological Scope* and regressors are the estimated values of the potentially endogenous variables, along with all other control variables.

The first instrument employed is the knowledge endowment of the CBSA in which the firm is located, and it is computed as the number of granted USPTO patents measured at the CBSA level in year  $t - 1$ . To identify the CBSA in which the firm is located, we gathered information about the address of each firm from Compustat North America. Then, following previous studies (e.g., Agrawal et al., 2014), we retrieved all USPTO patents applied for (and subsequently granted) between 1989 and 2005, and featuring at least one US-based inventor.

We used the ZIP codes of the patents' inventors to identify their precise location (and corresponding CBSA). If a patent had at least one inventor from a particular CBSA, we assigned such patent to the relative CBSA. This measure intends to proxy the amount of technological knowledge available locally (i.e., within the firm's CBSA) to feed the firm's innovation processes, but it does not account for the technological composition of such knowledge and, in turn, the technological specialization/diversity of the CBSA. We expect that the local knowledge endowment is correlated with the firm ability and propensity to connect with other domestic or foreign locations (Perri et al., 2017), but it is not directly correlated with firm ability to produce innovations with higher (lower) technological scope as the instrument does not include information about the technological distribution of the locally produced knowledge. The second instrument is the number of USPTO patents measured at CBSA level in year  $t - 1$  featuring multiple assignees, i.e., patents involving formal cross-organization collaborations. This variable is expected to be correlated with the firm's ability and propensity to establish future knowledge-sourcing collaborations, but to have no direct influence on the technological scope of firm innovations (Fritsch & Lukas,



**Table A1** Results of the two-stage least-squares within-group estimator (with heteroskedastic-robust standard errors)

	IV estimates
Technological diversity	-0.2513 (0.2083)
Patent stock	0.0660** (0.0274)
Firm size	-0.0137 (0.0167)
Firm intangible asset intensity	-0.0265 (0.0172)
Firm ROA	0.0050 (0.0135)
Firm leverage	0.0001 (0.0001)
Breath of Domestic Connectedness	0.8689* (0.4676)
Breath of International Connectedness	3.5847*** (0.7554)
Breath of Domestic Connectedness sq.	-0.2741* (0.1581)
Time dummies	Yes
Obs.	7409
F	12.16***

Robust standard errors in parentheses; \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

2001). The third instrument is the number of international flight departures from airports based within the US State in which the firm is located and computed in year  $t - 1$ , using the US International Air Passenger and Freight data published by the US Department of Transportation. This variable is expected to be correlated with the ability and propensity of the firm and its inventors to establish geographically dispersed knowledge-based connections by facilitating individuals to travel from a specific location (Ejeremo & Karlsson, 2006), but to have no direct influence on the technological scope of firm innovations. Finally, we have also included the squared term of the number of flight departures.

Table A1 displays the results of the IV estimates, which are consistent with our main findings presented in Table 2 of the main text. The sample used for the IV estimates has fewer observations than the sample used for the main analysis (7409 instead of 7432) due to missing values related to the instrumental variables.

Several key tests confirm the validity and goodness of the instruments. First, the F-tests of the first-stage regressions reject the null hypothesis that the exclusion restrictions are jointly null ( $p < 0.001$ ), reassuring the reader on the goodness of the selected instruments. Second, we can reject the null hypothesis that the system of equations is under-identified ( $p < 0.001$ ), concluding that the model is well identified. Third, the Hansen test does not reject the validity of our instruments

( $p > 0.4$ ), proving that they are not correlated with the error term and that the excluded instruments are allegedly excluded from the main equation.

We also checked the sensitivity of our results to firm size. We split the sample by firm size and tested our full model specification on two subsamples, using as sample-splitting criterion the threshold of the 75th percentile of the Firm Size distribution. By doing so, we separated the subsample of the small and medium enterprises (SMEs) with fewer than 500 employees (in line with the definition provided by the Statistics of US Businesses, SUSB), from the subsample of large firms. The subsample analysis provided results that are very much consistent with the main analysis, showing similar effects as regards to the relationship between the independent and the dependent variables. Second, we tested our full model specification on a reduced sample that comprises only observations with values of Firm Size within the 5th and the 95th percentiles of the distribution, in order to exclude very large and very small companies from our sample. We also repeated the same test using as exclusion criteria the 2nd and the 98th percentiles of the variable distribution. These additional tests confirmed the results obtained in our main findings (results are available upon request from the authors).

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*Accepted by Shige Makino, Guest Editor, 16 August 2017. This article has been with the authors for three revisions.*