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Entangled modes: Boundaries to effective international knowledge sourcing through technology alliances and technology-based acquisitions

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ABSTRACT

In today's globalized era, corporate technology strategy is increasingly oriented towards accessing international sources of knowledge that can improve the novelty and variety of firms' knowledge bases. Technology alliances and technology-based acquisitions have become two ubiquitous modes used in pursuing such an internationally-oriented technology strategy. We propose two boundaries to the effectiveness of pursuing geographically dispersed portfolios of alliances and acquisitions, arising from managerial complexities and knowledge redundancies that the combined portfolio of these modes may engender. We find support for our predictions in an analysis at the technology level of 165 leading firms across multiple industries. The findings of this paper highlight the need for managing the interrelatedness of diverse alliance and acquisition portfolios for their effective performance.

1. Introduction

Globalization has reshaped corporate technology strategies away from internally focused approaches towards more open innovation paradigms in which the focus is on external and international sources of knowledge (e.g. Boone et al., 2019; Chung and Yeaple, 2008; Lavie and Miller, 2008; Madhok, 1997; Mihalache et al., 2012; Monteiro and Birkinshaw, 2017; OECD, 2007). Engaging in global search for new technologies and acquiring highly sophisticated and partially tacit knowledge from multiple international sources are critical for firms to reconfigure and advance their capabilities (e.g. Lavie and Miller, 2008; Zhong et al., 2022; Jacob et al., 2013; Mihalache et al., 2012; Monteiro and Birkinshaw, 2017; Phene and Almeida, 2008). Such an approach of establishing a presence in locations with specialized knowledge bases, technological development activities, and customer requirements helps firms augment their ability to introduce new products for multiple international markets (e.g. Subramaniam and Venkatraman, 2001; Ardito et al., 2020). This shift in paradigm has entailed the orchestration of complex knowledge sourcing portfolios involving multiple modes and diverse geographies (Boone et al., 2019; Hoffmann and Habasche, 2017; Stettner and Lavie, 2014).

Technology-motivated cross-border mergers and acquisitions (Hitt et al., 1991; Shimizu et al., 2004; Stahl and Voigt, 2008) and collaborative international R&D alliances (Degener et al., 2018; Lavie and Miller, 2008; Mowery et al., 1996, 1998; Sampson, 2007; Steensma et al., 2000) are two widely used modes of international knowledge sourcing. There is growing evidence on the positive performance consequences of both technology alliances (e.g. Ahuja, 2000; Baum et al., 2000; de Man and Duysters, 2005; Huo and Motohashi, 2015; Lavie, 2007) and technology-based acquisitions (e.g. Ahuja and Katila, 2001; Cloodt et al., 2006; Grimpe, 2007). Studies further inform the advantages of simultaneously engaging in both alliances and acquisitions for accomplishing firms' multiple external knowledge sourcing goals (Boone et al., 2019; van de Vrande et al., 2011; Keil et al., 2008; Rothaermel and Hess, 2007; van de Vrande, 2012).

While recognizing the significant innovation benefits they confer on firms, studies also warn about major challenges associated with internationally oriented portfolios of alliances (Jiang et al., 2010) and acquisitions (Hennart and Reddy, 1997; Stahl and Voigt, 2008). In particular, research underlines that overextending diversity in a given mode can raise the costs and risks associated with the development of knowledge sourcing routines, coordination, and competition for resources (Ahuja and Katila, 2004; Huo and Motohashi, 2015; Rosenkopf and Almeida, 2003). Notwithstanding these important insights, there is

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a lack of systematic investigation of the effects of *combining* geographically diverse alliances and acquisitions on the effectiveness of these two modes. Since cross-border alliances and acquisitions require different approaches and routines of interaction and knowledge sourcing, pursuing these strategies in multiple international locations can give rise to critical interdependencies in the form of coordination problems (Agarwal et al., 2012; Hashai et al., 2010; Kogut and Zander, 1993). Furthermore, pursuing alliances and acquisitions for acquiring tacit local knowledge in the same country can result in duplication of research efforts and knowledge redundancies. Examining these factors that can reduce firms' ability to assimilate and reconfigure external knowledge as boundary conditions is therefore important to inform managerial practice as well as extant literature on knowledge sourcing.

Recent research underlines that significant interdependencies do exist in diverse multi-modal knowledge sourcing portfolios, such as the combined portfolios of alliances and Corporate Venture Capital (CVC) investments (Belderbos et al., 2018). We may expect a greater likelihood of the presence of interdependencies in the combined portfolios of acquisitions, as opposed to CVC investments, and alliances. This is because, different from CVC investments, acquisitions involve greater task-related scrutiny and resource commitment, with post-acquisition integration requiring substantial organizational and managerial attention (e.g. Keil et al., 2008; Bresman et al., 1999). This suggests that managing interdependencies in the combined alliance-acquisition portfolio can be a key challenge for firms' technology sourcing strategies.

In this paper, we seek to examine the interactive effects described above that may weaken firms' ability to take full advantage of their geographically diverse alliance and acquisition portfolios. Informed by an organizational learning perspective (Rosenkopf and Nerkar, 2001; Ahuja and Katila, 2004) and recent theorizing rooted in complementarity and sub-additivity within bundles of assets and activities (Argyres and Zenger, 2012; Lee and Kapoor, 2017; Vassolo et al., 2004), our point of departure is that the relationship between global knowledge search and technological performance is a complex one. We set up our research on the premise that exploring novel technologies from multiple international locations through both alliances and acquisitions yields significant benefits, particularly if it increases the variety in firms' knowledge inputs that are vital for knowledge recombination. We then propose two contingencies that can reduce the effectiveness of the combined knowledge-sourcing portfolio of geographically diverse technology-based acquisitions and technology alliances. The first of these is portfolio complexities that arise from the potentially conflicting routines and the extensive managerial oversight and attention required for concurrently engaging in technology alliances and acquisitions in multiple countries (Martin and Salomon, 2003; Hoang and Rothaermel, 2005; Hoffmann, 2007; Hashai et al., 2010). The second relates to knowledge redundancies that derive from geographic overlaps between knowledge sourcing through acquisitions and technology alliances in the same technology domain, resulting in the duplication of search efforts and reduced variety in firms' knowledge pool.

We perform our analysis at the firm-technology level for 165 leading firms operating in a broad spectrum of industries. We identify diversity of alliance and acquisition portfolios in a novel and detailed manner, focusing on the heterogeneity in knowledge search characteristics of the countries of alliance partners and acquisition targets within each technology domain. We do this by measuring the differences across countries in citations to prior art in a given domain. Such a fine-grained characterization of technology sourcing diversity allows for capturing the heterogeneous specialized strengths and search approaches in individual technologies across the multiple national innovation systems that firms interact with (Lundvall, 2016; Nelson and Nelson, 2002). The results of our analysis provide broad support for our predictions on the interdependencies between technology alliances and technology-based acquisitions that weaken the performance of these portfolios.

Our contingency approach is consistent with the recent theorizing on firms' portfolio choices as representing orchestration of complementary activities often involving multiple interrelated transactions within the overall bundle of activities (Argyres et al., 2012; Argyres and Zenger, 2012). We specifically contribute to the research stream on knowledge sourcing that adopts a portfolio approach to knowledge sourcing through alliances or acquisitions (e.g., Hagedoorn et al., 2018; Hoang and Rothaermel, 2005; Hoffmann, 2007; Luo and Deng, 2009). Research in this stream has begun to shift attention to the challenges of simultaneous knowledge-sourcing activities and has emphasized the importance of developing alliance management capabilities (Degener et al., 2018; Heimeriks and Duysters, 2007; Wuyts and Dutta, 2014) and acquisition capabilities (Cefis et al., 2020; Zollo and Singh, 2004; Trichterborn et al., 2016; Bresman et al., 1999) to deal with interdependencies *within* the portfolios of each of these modes and improve technology sourcing through them. Our study advances these insights by identifying the potential costs arising from the interdependencies *between* diverse portfolios of alliances and acquisitions.

2. Theoretical background and hypotheses

2.1. Background

There is a growing recognition that internally-focused approaches to technological development are inadequate to cope with the growing global competition as well as with the complexity of technology development processes (Chung and Yeaple, 2008; Herstad et al., 2014; Kafouros et al., 2012, 2018; Lahiri, 2010). Consequently, internationally-oriented technology sourcing, aimed at leveraging the globally distributed technological capabilities, has become the cornerstone of corporate innovation strategy.

From the theoretical perspective of organizational learning, variety in knowledge resources is critical for firms' recombination capabilities and, thus, for advancing their innovation processes (North, 1990; Hoffmann, 2007; Rosenkopf and Nerkar, 2001). Firms increasingly establish variety in their knowledge repertoire by accessing multiple national contexts characterized by different systems of innovation with their distinct patterns of knowledge search and development in the same technology domain (Freeman 1995; Nelson and Nelson, 2002). The different characteristics of national systems of innovation stem from the distinctive historical, political, and cultural contexts across countries, making knowledge emanating from them display specific local characteristics and idiosyncrasies (Balzat and Hanusch, 2004; Lundvall, 2016). Accessing such spatially embedded, partially tacit knowledge demands face-to-face interactions for its effective assimilation and application within the firm (Berchicci et al., 2016; Kafouros et al., 2018; Jaffe, 1989; Saxenian, 1994). As a means to access such location-specific knowledge from a variety of geographies, companies increasingly use international strategic technology alliances (e.g. Doz and Hamel, 1998; Oxley and Sampson, 2004; Kale and Singh, 2007) and cross-border acquisitions of R&D intensive firms (Bertrand, 2009; Duysters et al., 2015; Morosini et al., 1998; OECD, 2007; Stahl and Voigt, 2008; Zollo and Singh, 2004). Studies confirm that both cross-border technology-based acquisitions (e.g. Ahuja and Katila, 2001; Bertrand, 2009; Cloodt et al., 2006) and international alliances (e.g. Duysters and Lokshin, 2011; Lavie and Miller, 2008) can improve firms' technological performance, even more so than domestic alliances and acquisitions (De Man and Duysters, 2005).

However, research on the effectiveness of *simultaneously* pursuing alliances and acquisitions remains limited. The few studies in this tradition point out the positive, yet independent, effects of alliances and acquisitions for firm technological performance (Keil et al., 2008; Rothaermel and Hess, 2007; van de Vrande, 2012). These results underscore that pursuing global search through a single sourcing mode alone is unlikely to provide the necessary solutions and capabilities due to the rapidity and sophistication of technological evolution and the unique benefits that different modes can bring to a firm (Stettner and Lavie, 2014; Shi and Prescott, 2011; van de Vrande, 2012). Technology alliances can be useful to discover new knowledge complementary to existing knowledge bases (Rosenkopf and Almeida, 2003; Hagedoorn et al., 2018) and when technological and market uncertainties are high. Alliances offer several advantages compared with acquisitions, such as limited resource commitment; flexibility of 'cherry picking' the desirable knowledge from the firm's partner; sharing of the risk of failure; and the option to increase the commitment later (Steensma and Corley, 2000; Tong et al., 2008; Vanhaverbeke et al., 2002; Villalonga and McGahan, 2005). Acquisitions, on the other hand, may be more suitable to gain immediate access to knowledge especially that is more distinct from that present internally, but they can also present major challenges in the selection of target and the integration of target's knowledge (Cefis et al., 2020; Vermeulen and Barkema, 2001; Bresman et al., 1999). These challenges can be especially serious if the acquired firm is foreign, with its different organizational cultures and practices compared with the acquirer firm (Hennart and Reddy, 1997; Shimizu et al., 2004; Stahl and Voigt, 2008).

While research on the joint effect of alliances and acquisitions has highlighted the independent benefits of alliances acquisitions, it has paid only little attention to the potential interdependencies that may arise in the combined portfolio of these modes. An organizational learning perspective alerts us of possible interdependencies stemming due to the differences between these modes in relation to required routines, resource commitments, control, and flexibility, but also the similarity between them in accessing location-specific tacit knowledge (Carayannopoulos and Auster, 2010; Hagedoorn and Duysters, 2002; Vanhaverbeke et al., 2002; Villalonga and McGahan, 2005). Building on these ideas, we propose two critical boundaries to the effectiveness of combined portfolios of geographically diversified alliances and acquisitions.

The first of these relates to the coordination challenges associated with a geographically diverse portfolio. As highlighted by the organizational learning perspective, firms' ability to effectively engage in external knowledge sourcing depends on their particular experiences and evolve over time in an idiosyncratic, path dependent manner (Chung et al., 2000; Gulati and Gargiulo, 1999). These capabilities emerge in the form of organizational routines and practices that tend to take unique forms across different knowledge sourcing modes and partners (Zollo et al., 2002; Ahuja and Katila, 2004; Belderbos et al., 2018; Dess and Beard, 1984). In line with these characterizations, studies demonstrate that firms develop distinct capabilities specific to alliances (Kale and Singh, 2007; Degener et al., 2018; Heimeriks and Duysters, 2007; Wuyts and Dutta, 2014) and acquisitions (Zollo and Singh, 2004; Cefis et al., 2020; Zollo and Singh, 2004; Trichterborn et al., 2016), which play a critical role in the performance of these knwoledge sourcing modes. We argue below that pursuing an internationally-oriented knowledge sourcing strategy through alliances and acquisitions may engender a multiplicity of routines and processes, creating significant coordination and knowledge integration challenges and reducing the effectiveness of the combined portfolio (Nickerson and Zenger, 2004).

The second boundary builds on the insight from the organizational learning perspective that a lack of variety in the acquired knowledge can compromise the quality of external search (Winter 1987; Zucker et al., 1998). Such a scenario, we will argue, can occur when a geographically diverse alliance-acquisition portfolio in a given technological domain leads to the accessing of similar knowledge from the same country through both alliance partners and acquisition targets. Before elaborating these arguments on alliance-acquisition interdependencies, we first discuss the baseline hypotheses that predict the independent effects of the geographic diversity of alliances and acquisitions on firm technological performance.

2.2. *Hypotheses*

Technological knowledge and expertise display a high degree of geographic dispersion in specialized knowledge hubs around the world (Florida, 1997; Chung and Yeaple, 2008; Dunning, 1994; Lahiri, 2010; Beaudry and Schiffauerova, 2009). To stay competitive, therefore, today's firms employ a global technology sourcing strategy that spans the frontiers of their local networks to scan international pockets of knowledge for new and promising technologies (e.g. Hitt et al., 1997; Monteiro and Birkinshaw, 2017; Kafouros et al., 2012; Herstad et al., 2014; Lavie and Miller, 2008). Carrying out knowledge search in multiple locations increases the likelihood of tapping into emerging technological developments in such different locations, increasing firms' ability to respond to the changing demands of the market place (Cantwell and Mudambi, 2005; Rosenkopf and Almeida, 2003). As national innovation system literature outlines, countries differ in their approaches to and patterns of innovation due to their different histories and institutions (Freeman 1995; Balzat and Hanusch, 2004). Accessing knowledge from diverse, dissimilar geographies can thus help firms accumulate a broad repertoire of knowledge and competences within individual technological domains (Kafouros et al., 2018; Beaudry and Schiffauerova, 2009). The variety of knowledge elements firms can access, in turn, creates opportunities for superior knowledge recombination and cross fertilization, which can hence enhance their technological capability and innovation performance (Santoro et al., 2020; Berry, 2014; Leiponen and Helfat, 2011; Ahuja and Katila, 2004; Lahiri, 2010).

Alliances and acquisitions are important means through which firms access knowledge elements from multiple geographic locations (Martínez-Noya and García-Canal, 2021; Duysters et al., 2015; Bertrand, 2009; Stahl and Voigt, 2008). They facilitate face-to-face contacts and personal interactions that are paramount for accessing the tacit and sticky location-specific knowledge (e.g. Berchicci et al., 2016; Kafouros et al., 2018; Jaffe, 1989; Saxenian, 1994). These interactions yield insights on not only technologies, but also partially tacit local demand characteristics and specific user information that are pertinent for R&D and product development processes.

Alliances' importance for international knowledge sourcing stems from their role as a 'radar' for firms by establishing relationships with a broad array of geographically dispersed sources and generating information on a wide range of relevant technological developments (Degener et al., 2018; Wuyts and Dutta, 2014; Ahuja, 2000; Freeman, 1991). Due to their low resource commitment needs, alliances enable firms to cooperate with multiple partners with varying specializations at relatively limited cost, augmenting firms' knowledge variety and hence the recombination potential of their knowledge base (Belderbos et al., 2018; Dushnitsky and Lavie, 2010; van de Vrande, 2012). Having the ability to engage with multiple partners also favors specializing across partners with different location-specific knowledge, increasing the efficiency of firms' overall R&D programs (Kafouros et al., 2012, 2018; Beaudry and Schiffauerova, 2009; Powell et al., 1996). An internationally-oriented alliance strategy could be particularly helpful for developing complex technologies by reducing the cost, resource demands, and uncertainties associated with such technologies (McCann et al., 2016; Vanhaverbeke et al., 2002).

Acquisitions can facilitate developing critical complementary assets needed for creating competitive advantage, based on targets' location specific knowledge resources (Cefis et al., 2020; Rothaermel and Hill, 2005; Teece, 1986). Acquiring foreign firms with such capabilities can mean filling key resource gaps within the firm, while also preempting the risk of those valuable capabilities falling into the hands of the firm's rivals (Moeen and Mitchell, 2020). Acquisition can also accelerate the speed of entry into new technological fields when rapid changes in the competitive environment may not favor developing new resources internally or through alliances (Capron et al., 1998, 633; Chaudhuri and Tabrizi, 1999; Vermeulen and Barkema, 2001). Developing such location specific capabilities without acquisitions may be a hard and time-consuming process because of the need for intensive interactions with local research networks, customers, and suppliers. Firms may also face internal constraints in developing such new capabilities, as routines and practices that have evolved specific to particular technological and contextual domains may not be appropriate in relation to new, fast-changing technologies developed in diverse locations. Hence, by allowing greater localized specialization, acquisitions may potentially serve as an instrument to redefine the R&D organization of the firm (Bertrand, 2009) and overcome organizational learning boundaries and established routines and processes that have outlived their usefulness (Morosini et al., 1998; Vermeulen and Barkema, 2001).

Despite these benefits, an increasingly diverse portfolio of alliances and acquisitions also implies elevated costs and risks. As a firm's external technology-sourcing portfolio becomes more diverse, it will be required to interact with a larger set of partners or targets with different characteristics, creating significant managerial complexity and coordination challenges (Hashai et al., 2010; Ahuja and Katila, 2004; Anderson, 1999; Dess and Beard, 1984). Differences in the nationality and culture of partners and targets can be a source of potential distrust and conflict (Hamel et al., 1989; Parkhe, 1993), which are more likely to feature in knowledge sourcing portfolios that have a greater geographic scope. Consequently, with an ever-increasing diversity of technology sourcing activities, the ability to take optimal advantage of learning opportunities may decrease.

Specific to alliances, increasing diversity raises the likelihood of a firm failing to guard against leakage or knowledge spillovers to its partners (Jiang et al., 2010). High levels of portfolio diversity may make it more difficult for the firm to deal with the conflicting requests from alliance partners, to strategically align the goals of multiple ties, and to monitor and evaluate the entire alliance portfolio (Hoffmann, 2005).

In regard to technology-based acquisitions, reconfiguration of targets' resources is often necessary to improve existing operations and to sustain competitive advantages in response to environmental changes and increased competition (Ahuja and Katila, 2001; Capron et al., 1998). Such a process of integrating target firms is more challenging with the increasing variety of target locations, each with their particular learning paradigms, cultures, and routines (Hennart and Reddy, 1997; Jemison and Sitkin, 1986; Stahl and Voigt, 2008; Vermeulen and Barkema, 2001).

Considering the above arguments, we expect that technology sourcing through geographically diverse portfolios of technology alliances and technology-based acquisitions improve a firm's technological performance, but that the marginal gains from greater diversity are lower at higher levels of diversity. Accordingly, we formulate the baseline hypotheses:

Hypothesis 1a. **(Baseline) (Geographic diversity of technology alliances)** *Geographic knowledge diversity of a firm's technology alliance portfolio in a technology domain has an inverted U-shaped relationship with the firm's technological performance in that domain.*

Hypothesis 1b. **(Baseline) (Geographic diversity of technology-based acquisitions)** *Geographic knowledge diversity of a firm's technology-based acquisitions in a technology domain has an inverted U-shaped relationship with the firm's technological performance in that domain.*

Both alliances and acquisitions call for distinct capabilities and routines for maximal knowledge sourcing benefits (Kale et al., 2002; Zollo, 2009; Reuer et al., 2002), but they can elevate managerial complexities and coordination challenges when a firm simultaneously operates geographically diverse portfolios of these knowledge sourcing modes. Research on alliances highlights the importance of specific capabilities and routines developed through deliberate learning mechanisms aimed at improving partner selection, monitoring and sharing of relevant knowledge, control and management processes, and the codification of best practices (Heimeriks and Duysters, 2007; Schilke and Goerzen, 2010). Such routines are essential for securing positive returns to firms' alliance portfolios (Hoffmann, 2005).

Acquisition is a much more complex mode, requiring effective routines for successful selection, due diligence, and integration of the target (e.g. Barkema and Schijven, 2008). Development of knowledge-sharing routines with a target is typically the result of a complex post-acquisition integration process that requires diverting a part of the acquirer's managerial resources away from their conventional roles. These investments are particularly significant when the acquired firm is foreign, owing to the difficulties arising from the differences between the two entities with respect to national culture and management practices (Cartwright and Cooper, 1996).

Routines and practices developed for *intra*-firm knowledge exchanges as in acquisitions may not be appropriate for *inter*-firm knowledge transfers. Hence, when a firm simultaneously undertakes alliances and acquisitions across a variety of geographic locations, effective knowledge assimilation may require costly investments in the development of routines for each mode, as well as for the locations where they are undertaken. Simultaneously engaging in geographically diverse alliances and acquisitions can also stretch a firm's managerial capacity due to the needs to coordinate between multiple actors, across modes and locations (e.g. Agarwal et al., 2012; Tushman and Nadler, 1978). Developing and deploying different, even contradictory, routines, can create significant complexity in the transfer and integration of external knowledge that may weaken the effectiveness of a firm's knowledge sourcing portfolio (Kogut and Zander, 1993; Martin and Salomon, 2003; Hashai et al., 2010).

In sum, expanding geographic diversity in both alliances and acquisitions could imply negative portfolio effects due to the costs of partner and mode-specific investments, and the coordination costs and complexity in simultaneously managing, transferring and integrating knowledge from multiple partners. Consequently, the benefits of diversifying knowledge sourcing in one dimension (e.g. technology alliances) diminish if the firm already operates a highly diverse knowledge sourcing portfolio in the other dimension (e.g. technology-based acquisitions), and vice versa. This leads to the following hypothesis:

Hypothesis 2. **(Complexity)** Geographic diversity of technology alliances and technology-based acquisitions negatively moderate each other's positive association with performance.

To develop a deeper understanding of the knowledge structure in a country or to increase the likelihood of identifying promising technological opportunities, firms' internationally-oriented search strategy in a given technological domain can feature both alliances and acquisitions in the same country (Barkema and Vermeulen, 1998). However, simultaneous pursuit of alliances and acquisitions in a given geographic area in the same technological domain increases the likelihood of accessing similar location-specific knowledge and competences. Indeed, research cautions that when firms pursue multiple sourcing channels with similar goals, they could accumulate redundant knowledge, which could weaken the value of their overall sourcing portfolio (e.g. Kafouros et al., 2018; McGrath, 1997; Vassolo et al., 2004).[1]

As alliances and acquisitions are characterized by different processes that require different capabilities for governance and hence are typically managed by different personnel with specialized skills problems can arise in the coordination of search and transfer of knowledge. This raises the prospects of duplication of knowledge sourcing across the two modes (Bingham et al., 2015). Since search practices and technology development approaches within a domain are not likely to be very different across local firms in a national innovation system, acquisition targets or alliance partners may bring overlapping knowledge. While alliances and acquisitions can both facilitate access to local inter-firm networks, helping firms triangulate and enrich the knowledge acquired from their partners and targets, in a given technology domain and location this knowledge is likely to be quite similar. Therefore, combining alliances

[1] Vassolo et al. (2004) show that a high correlation between the technological focus of an alliance and that of other alliances in the firm's portfolio increases the likelihood that the alliance is divested, which they attribute to redundancy in the portfolio.

and acquisitions to access the same national innovation system for knowledge inputs pertaining to a specific technology is unlikely to add much diversity in firms' knowledge search. Rather, overlaps in the geographic orientation of a firm's alliance and acquisition activities in a given technological domain are likely to generate knowledge redundancies in the firm's technology sourcing portfolio, reflecting the inefficient use of its (R&D) resources and managerial efforts. Critically, knowledge redundancy implies less variety in a firm's knowledge base, reducing its capacity for knowledge recombination and innovation. This suggests the following hypothesis:

Hypothesis 3. (Redundancy). Geographic overlap in technology sourcing via technology alliances and technology-based acquisitions in a technology domain is negatively associated with the firm's technological performance in that domain.

3. Sample and methods

We carry out our analysis at the firm-technology-year level. Our sample consists of 165 leading firms in a broad spectrum of manufacturing industries and selected technology-intensive services sectors (telecommunications and ICT services), spanning 34 technologies and seven years from 2001 to 2007.[2] The sample firms are among the top ten largest players in the European market in their respective industries, in terms of on manufacturing and service sales. The focus on European market leaders stems from the use of secondary data gathered to examine technology and market leadership in Europe (Commission of the European Communities, 2010). We identified 165 leading firms with information available on patent activity and R&D. 105 of these are headquartered in EU and the remaining 60 are non-EU firms. The largest number of firms is based in the US (33), followed by Germany (26), France (21), the UK (19) and Japan (15). Between five and nine firms are headquartered in small and internationalized economies such as The Netherlands, Finland, Italy, and Sweden. For the 165 firms patent data at the European Patent Office (as a measure of technological performance), information on technology alliances and technology-based acquisitions, and financial indicators such as R&D expenditures were collected.

Using yearly lists of affiliates and information on acquisitions from Zephyr, we constructed patent data at the consolidated firm level by comparing names and addresses of assignees and corporate units. To avoid double counting of similar patents, we constructed patent data at the family level, drawing on the PATSTAT database. We linked each patent to its patent family and traced the first year of patent application in the family (the priority year), yielding a total of 212, 631 unique patent families for the focal firms during 1998–2007.[3] While our period of analysis is 2001–2007, we have collected patent data from 1998 onwards in order to construct certain control variables that use three-year lagged patent portfolios.

We construct alliance and acquisition portfolios that span multiple years, following earlier studies that recognize that alliances and acquisitions are likely to impact firm performance over many years. Alliances typically last multiple years, so it may have a slightly longer impact than acquisition on firms' technological performance (Gulati, 1995; Lavie and Miller, 2008; Boone et al., 2019; Yang et al., 2011). Accordingly, we consider a firm's alliance portfolio in a given year t as spanning the years t-3 through t-1, while acquisition portfolio as constituting the years t-2 through t-1.

We focused on alliances and acquisitions that have explicit knowledge sourcing objectives. This ensures the required alignment between the dependent variable (technological performance) and the knowledge sourcing strategies that are likely to affect it. Given that our focus is on differences in knowledge characteristics between countries of alliance partners and acquisition targets, we consider both domestic and international alliances and acquisitions. We compiled alliance records from Thomson's SDC Platinum database as well as the MERIT-CATI database. These two sources of alliance data overlap only modestly (Schilling, 2008). Combining complementary alliance information from the two databases strongly improved the accuracy of the alliance variables. In our examination of technology alliances, we found an overlap of less than 10 percent (304 out of 3202 alliances). We included only those alliances that recorded explicit information that technology development and technology sharing were among the objectives of the alliance. We considered an alliance as a technology alliance if it satisfied at least one of the following criteria: the alliance includes cross technology transfer (more than one participant transfers technology to another participant or to the alliance), a research and development agreement, or a cross licensing agreement (more than one participant grants a license to another participant). These criteria ensure that we are examining technology development collaboration and that the focal firm is using the alliance to gain technological knowledge. We did not include joint ventures if these were not associated with technology transfer, since joint ventures, more often than not, have joint production or marketing objectives rather than involving the pooling of R&D resources. For the firms in our dataset, technology alliances on average make up about 15 percent of total alliance activity in the SDC database and 85 percent of alliances in the MERIT-CATI database (which focuses on technology alliances). From the two databases we were able to identify some 2302 technology alliances undertaken by the sample firms between 1998 and 2006, for which period we calculated alliance portfolios over a three-year window.[4]

To collect information on technology-based acquisition we likewise used two complementary sources: the Zephyr database on acquisitions (published by Bureau van Dijk) and the Thomson SDC Platinum database. Zephyr focuses particularly on the acquisitions of European firms, while SDC is more globally oriented; the two databases complement each other well to provide the maximum coverage. In addition, we drew on annual reports to help identify further information on technology-based acquisitions. We counted the number of majority stake or full acquisitions in which the sample firms were acquirers or the dominant party in a merger. We defined as technology-based acquisition if an acquisition met at least one of the following conditions: the target firm has patent applications (Ahuja and Katila, 2001) or the target firm has engaged in a technology alliance within three years prior to the date of acquisition. The latter definition of technology-based acquisitions reflects the notion that even if technologically active firms do not patent, their acquisitions can enhance the technological performance of acquiring firms.[5] For the 1998–2006 period we were able to identify some 441 technology-based acquisitions of which 306 target firms had patent applications, 135 target firms had prior technology alliance experience, and 31 firms had both.[6]

Our primary source of financial data on firms was Compustat, subsections North America and Global. As Compustat has less than full

[2] We refer to a separate appendix for descriptives per technology domain.

[3] We used the Docdb patent family definition, which identifies, and bring together under one code, patents that have overlapping claims. Each family includes at least one application at the European Patent Office.

[4] Information on alliance and acquisition activities extend back to 1998 because of the time lag structure in the analysis.

[5] In identifying technology-based acquisitions using the criteria that targets have patents, our goal was not to exclude firms that are potentially technologically active. Hence, we did not impose a time window on targets' patent activities.

[6] In the absence of R&D data for the large majority of acquisition targets and in the absence of information on the motivation for acquisitions, it remains a challenge to design a measure that represents technology-based acquisitions as accurately as possible. We also note that we did not identify cases where a previous alliance partner was subsequently acquired (e.g. Van de Vrande, 2012).

coverage of European firms, we augmented the data with information retrieved from Worldscope and annual reports. In the case of R&D data, we additionally drew on the European R&D Scoreboard, which ranks European and non-European firms by R&D expenditures. We used exchange rate information from the IMF Financial Statistics to express figures that were in domestic currencies in dollar terms.

In a departure from the prior literature where the heterogeneities in firms' technology strategy and performance across domains are not accounted for (e.g. Sampson, 2007; Rothaermel and Deeds, 2004), we examine the implications of firms' alliances and acquisition activities for technological performance at the technology domain level. Studying knowledge sourcing at the firm-technology level is important because different locations have their specialized strengths and approaches within the same technological domains as well as because knowledge redundancy plays out at the technology level. We distinguish 34 coherent technology domains, using the World Intellectual Property Office's (WIPO) concordance table developed in Schmoch (2008) that groups IPC codes into technology domains. We then assigned patents, technology alliances and technology-based acquisitions of the focal firms to technology classes, using the IPC codes of patents and the information on technology domain in the SDC and CATI databases. We created a panel data set consisting of firm-year-technology combinations that generated at least one patent during the period of analysis, from 2001 to 2007.[7]

The focal firms are active in a wide range of technologies, with patent applications in about 25 technology domains on average. Each of the 34 technology domains is present in the patent portfolio of more than half of the focal firms. In total, the panel includes 22,802 firm-technology domain-year observations for the 165 firms. All the variables are constructed at the firm-technology level, except the interaction between the geographic diversity of alliances and acquisitions (complexity) and the control variables technological diversity and geographic diversity of R&D activities, which are created at the firm level. The complexity variable is an interaction term between alliance and acquisition diversities at the firm level, reflecting the overall costs to a firm associated with coordinating across, and acquiring knowledge from, a variety of partners, geographies, technologies, and modes.

3.1. Dependent variable

We measure our dependent variable, technological performance, as the citation-weighted number of a firm's patents in a given technology class in a year. We define patents at the level of the family (Docdb) and use the priority year as the year of invention, which provides a more accurate representation of the timing of inventive activity than the year of patent application used in previous studies (e.g., Schmookler, 1966; Sampson, 2007). We count the patent applications of the target firms as part of the acquiring firm from the year subsequent to the merger or acquisition.

There are numerous advantages in using patent indicators as measures of firms' technological activities (e.g. Griliches, 1990). Patent data are available in a consistent and longitudinal manner and provide 'objective' information, as inventions have been processed and validated by patent examiners based on novelty and utility of use. Furthermore, specific to our study, patent data provide information on the underlying technologies, which enabled us to link each patent to one of 34 technology domains. Drawbacks of the use of patents are that patent propensities vary across industries and firms and that patented inventions differ in value (Trajtenberg, 1990). This latter issue can be addressed by weighting patent counts by the number of forward patent citations received by these patents (Trajtenberg, 1990; Hall et al., 2005). Our analysis will furthermore control for industry, firm, and technology-specific differences in the propensity to patent.

[7] Information on alliance and acquisition activities extend back to 1998 given the time lag structure in the analysis.

3.2. Focal independent variables

Geographic diversity of technology alliances. We distinguish alliances by the geographic origin of the partners, which is the location of the participant-partner in the alliance, irrespective of whether this partner is independent or part of a larger group or ultimately owned by a parent firm based in another country (cf. Kogut and Singh, 1988; Makino and Beamish, 1998). We take this focus because the technological capabilities and local embeddedness of the direct partner firm are likely most important in the alliance.

We introduce a novel and fine grained measure of geographic diversity in knowledge sourcing associated with technology alliances and technology-based acquisitions. Our approach builds on the notion that learning and technology development evolves in a path-dependent manner specific to each location's idiosyncrasies, with the important consequence that different locations may exhibit different patterns of knowledge search and recombination in a technology domain (Ahuja and Katila, 2004; Freeman 1995; Lundvall, 2016; Phene and Almeida, 2008). A well-established approach to capture search patterns within a technology domain is using the technological configuration of patent citations in that domain; that is, using the distribution of "cited patents" (e.g. Fleming, 2001; Jaffe and Trajtenberg, 2002; Katila and Ahuja, 2002). In line with this approach, we measure search patterns within a technology domain in a country in terms of the distribution across 4-digit IPC codes of cited patents belonging to the patents invented in that country in that domain. We subsequently derive a geography-based measure of alliance (acquisition) diversity in a technology domain as the diversity in the distributions of cited patents among partners' (targets') countries in that domain. The logic we follow is that if country A exhibits a different pattern of knowledge search for technology development than country B in a technology domain, then approaches to innovation in the two countries in that technology domain are different, such that linking up with firms in these two countries provides diversity benefits. This approach to calculating diversity in the geographic dimension of knowledge search advances the common practice of using simple measures of diversity, such as the Blau index, that do not account for inter-country differences in knowledge search and technology development (eg. Lahiri, 2010).

Formally, the geographic diversity of a firm's portfolio of alliances over a three-year window in a technology domain is defined as:

$$\frac{\sum_{i,j}\left\{(n_i \bullet n_j) \bullet \left[1-\left(A_i.A_j' \Big/ \sqrt{\left(A_i.A_i'\right)\left(A_j.A_j'\right)}\right)\right]\right\}}{\sum_{i,j}(n_i \bullet n_j)}, j=i\ldots N \tag{1}$$

where A_i and A_j represent the distribution of patents across 4-digit IPC classes cited by patents in a given technology domain in countries i and j, and n_i and n_j are the number of alliances of the firm in countries i and j respectively in the technology domain. We omit year subscripts and technology domain subscripts for notional simplicity. $A_i=(A_i^1,.., A_i^k)$ and $A_j=(A_j^1,.., A_j^k)$, where A_i^k and A_j^k are the number of cited patents in IPC class k in countries i and j, respectively. The term $(A_i.A_j' / \sqrt{(A_i.A_i')(A_j.A_j')})$ is the cosine measure of technological similarity between the distribution of cited patents across IPC classes in countries i and j, indicating the extent of similarity in the technology search approaches to the development of the same technology domain (Ahuja and Katila, 2001; Jaffe, 1989; Sampson, 2007). Diversity is measured as 1 minus this similarity measure. The denominator weighs this diversity with the maximum number of cross-country and within-country alliance pairs. Alliances are measured in the three years prior to the measurement of the dependent variable (t-3 through t-1). The diversity index ranges between zero (in cases where alliances cover one partner country or where alliances span two or more countries that are perfectly similar to each other) and one (when a firm has an alliance in two or more countries that are perfectly dissimilar to each other). Hypothesis 1a predicts a positive effect for the linear term and a negative effect for the square term of this variable.

Geographic diversity of technology-based acquisitions is constructed in a similar manner as geographic knowledge diversity of technology alliances. Here we created a firm's acquisition portfolio using a two-year window, as we expect a more direct contribution to R&D capabilities and technological performance. Hypothesis 1b predicts a positive linear term and a negative square term of this variable.

In order to test hypothesis 2, the variable capturing *complexity* in technology sourcing modes is constructed at the firm level by interacting the geographic diversity of the portfolios of technology alliances and that of technology-based acquisitions. A combined portfolio of alliances and acquisitions generate complexity due to multiplicity of, often conflicting, routines and practices across countries and knowledge sourcing modes. We conceptualize these challenges as those that a firm confronts in its overall knowledge-sourcing portfolio. In constructing this variable, we first computed firm level geographic diversity of the technology alliance portfolio, as 1 minus the Herfindahl index of the concentration of alliance partners' countries of origin (Goerzen and Beamish, 2005; Tallman and Li, 1996). Formally this can be expressed as $1 - \sum_{j\in L(t)}\left[\sum_{t-3}^{t-1} ta_{j,t} TA_t\right]^2$, where $ta_{j,t}$ refers to the number of technology alliances of a firm in country *j* at time *t*, and TA is the total number of the firm's technology alliances. Firm level geographic diversity of technology-based acquisition is constructed in a similar way, as one minus the Herfindahl index of concentration of the countries of origin of acquisition targets: $1 - \sum_{j\in L(t)}\left[\sum_{t-3}^{t-1} ta_{j,t} TA_t\right]^2$. hypothesis 2 (complexity) predicts a negative sign for the interaction term between these two firm level diversity variables, as a firm that increases the spread of acquisition for a given level of technology alliance, and vice versa, experiences greater challenges in the coordination of tasks, and complexity.

Redundancy in technology sourcing (hypothesis 3) is operationalized as the geographic overlap in a technology domain between the firm's alliance and acquisition modes in a given year, implying duplication of search efforts in the same locations in the combined portfolio. This measure is derived, specific to a technology domain, as follows:

$$\sum_{j\in(t)}\left(Rta_{j,t} + Rma_{j,t}\right) \times \left(\left[Sta_{j,t} + Sma_{j,t}\right] / 2\right)$$

where $Rta_{j,t}$ and $Rma_{j,t}$ refer respectively to the number of technology alliances and technology-based acquisition of a firm in country *j* at time *t*, and $Sta_{j,t}$ and $Sma_{j,t}$ refer to the contribution of country *j* to the firm's technology alliance diversity and technology-based acquisition diversity respectively.[8] In other words, the first part $(Rta_{j,t} + Rma_{j,t})$ of the equation measures the total number simultaneous occurrences of the two technology sourcing modes in a country, and the second part $([Sta_{j,t} + Sma_{j,t}]/2)$ gives a higher weight to such occurrences in a country that contributes more to the geographic diversity of a firm's alliance and acquisition portfolios.[9] Hypothesis 3 predicts a negative effect of redundancy on technological performance.

3.3. Control variables

The empirical model includes a full set of firm and technology domain fixed effects[10], controlling for both firm heterogeneity (such as general managerial capabilities) and technological heterogeneity (such as technological opportunities) in the process of international knowledge sourcing and technological performance. The analysis also controls for general temporal trends in technological performance and patenting behavior by including year dummies.

We also include several time-variant control variables for firm- and firm-technology level influences that are likely to affect performance. *R&D expenditures* for year t-1 accounts for variations in inputs into the R&D process. R&D data are available only at the firm level. Since the analysis is at firm-technology level we distributed R&D across technology domains by weighting firm level R&D with the share of a firm's patents in a technology class during the previous three years (t-3 to t-1). Past R&D expenditures are at the consolidated level and hence include R&D activities of the acquired firm in year t. Therefore, a positive effect of acquisitions reflects improvements in technological performance after controlling for R&D inputs of both firms.

In addition to geographic diversity, there are other sources of diversity that may influence technological performance, such as the technological and knowledge diversity of the firm. We control for this influence by including the variable *firm technological diversity*, derived as one minus the Herfindahl index of the distribution of patents during the years t-3 through t-1 across (34) technology classes. We also include the *geographic diversity of firms' R&D activities*, which is a measure of the geographic spread of the firm's existing R&D activities. Recent studies point out that geographic dispersion of a firm's R&D activities can enhance technological performance (e.g. Lahiri, 2010; Leiponen and Helfat, 2011). To construct this variable we use information on the country location of inventors of the firms' patents (e.g. Ahuja and Katila, 2004), counting the number of patents per country of inventors over a three-year time window. We counted patents applied by the acquired units only from two years following the acquisition in order to avoid overlaps in the effects acquisitions and overseas R&D activities. The diversity measure is then calculated as one minus the Herfindahl index of the distribution of patents across inventor countries.

In addition to technology-based acquisitions and technology alliances, CVC investments may be a source of technological learning (e.g. Belderbos et al., 2018). We include *CVC investments*, the number of CVC investments in the years t-3 through t-1 in each technology domain. Information on firms' CVC activities was retrieved from the widely used Thomson Financial's VentureXpert database (e.g., Gompers, 1995; Dushnitsky and Lavie, 2010; Dushnitsky and Lenox, 2005).

We control for the number of technology alliances and technology-based acquisitions the firm engages in each technology domain, in order to ensure that the impact of geographic diversity does not reflect the influence of the simple scale of technology sourcing activities. The variable *portfolio size-alliances* measures the number of technology alliances established by the firm in the years t-3 through t-1 per technology class. Similarly, the variable *portfolio size-acquisitions* indicates the number of acquisitions of the firm in t-1 and t-2 per technology class. We include an experience variable (*alliance & acquisition experience*) to control for the potential effect of alliance and acquisition experience on technological performance in a technology domain. This variable takes the value 1 if a firm has either past alliances (t-6 to t-4) or past acquisitions (t-4 to t-3) - before the period in which the focal acquisition and alliances variables are measured. Firms with an established record in alliances and acquisitions can leverage those experiences to engage in trustworthy and efficient engagement with their partners or targets and

[8] The contribution of country *j* to a firm's technology alliance diversity or acquisition diversity is defined as the ratio of the sum of country j's bilateral diversities with other partner countries of the firm to the sum of all bilateral partner country diversities of the firm. The bilateral partner country diversities are calculated as described by the numerator of equation (1).

[9] A different redundancy measure that treats the measure described above as a proportion of a firm's total portfolio of technology alliances and technology-based acquisitions in a given technology domain provided similar results.

[10] We include unconditional fixed effects (firm dummies) to control for time-invariant firm specific heterogeneity in technology performance, rather than the conditional fixed effects of standard negative binomial models that enter the variance term only. Since our panel contains fairly large group sizes, our analysis does not encounter a substantive 'incidental parameters' problem (see Greene, 2004).

thus enhance the performance of their knowledge sourcing portfolios (Bingham et al., 2015).

3.4. Methods

The empirical model relates a firm's patent applications to its lagged technology-based acquisitions and technology alliance activities, controlling for lagged (by one year) internal R&D expenditures and other firm characteristics. The dependent variable is a count variable with only non-negative integer values. In this case, count data models are preferred over standard linear regression models, as they explicitly take into account the non-negativity and discreteness of the dependent variable. The Poisson model is the more general specification and provides consistent estimates, but the assumption of equality between mean and variance is often violated (Cameron and Trivedi, 2008). A likelihood ratio test revealed that the dispersion parameter alpha is indeed different from zero (p value = 0.00), suggesting that the assumption of equality of mean and variance is rejected. A negative binomial model does not make such an assumption, but may not always yield consistent estimates. We examined the potential bias in the Negative Binomial estimates by conducting a test for equality of the coefficients obtained from the negative binomial model and the Poisson model. We could not reject the null hypothesis that the coefficients of the focal variables obtained via the two models are jointly equal (p-value 0.33). These factors have led us to prefer the negative binomial model.

The inclusion of firm fixed effects to control for unobserved firm heterogeneity, the elaborate set of time-variant firm variables, the lagged focal variables, and the focus on the interactions between alliance and M&A portfolios mitigate concerns over potential endogeneity bias in our estimates due to unobserved heterogeneity or reverse causality. However, we cannot fully rule out such endogeneity bias and therefore conservatively interpret the observed relationships as associations.

4. Results

Table 1 provides descriptive statistics. The firms in the sample have on average some 111 citation weighted patents per technology domain per year. Firms that are engaged in technology sourcing via alliances and acquisition have about four technology partners in their alliance portfolio per technology per year, while the average frequency of technology-based acquisition activity is about one. The largest portfolio in a year consists of 45 alliances and seven acquisitions. The geographic knowledge diversity of alliance activity is higher (0.09) than that of acquisition activity (0.02). The average value of the geographically overlapping portfolios of acquisitions and alliances (the redundancy variable) is about 0.79, while that of the complexity variable is close to 0.19 for firms active in alliances and acquisitions. Correlations between the covariates are quite moderate, but to rule out effects of potential spurious correlation we estimated the models by sequentially including each hypothesis-testing variable.

Table 2 reports the empirical results of the fixed effects Negative Binomial regression models on the relationship between the geographic diversity of technology alliances and technology-based acquisitions, and firms' technological performance across technology domains. Model I includes only the control variables and serves as point of comparison for the other models. Models II-V add hypothesis-testing variables. Likelihood ratio tests suggest that each model extension is a significant improvement, with the full hypotheses testing model (model V) providing the best statistical fit for the data.

In model I, the control variables R&D expenditure, firm technological diversity, the size of acquisition portfolio and alliance portfolio, prior alliance and acquisition experience, and CVC investments have positive signs and are statistically significant. These results remain consistent across the subsequent models, except the alliance portfolio variable, for which the coefficient loses significance in the more complete models. We return to this result in the discussion section.

In all hypothesis-testing models (II–V), the coefficient of the linear term of the geographic knowledge diversity of alliances is positive and significant (at the 1% level) while that of its square term is negative and significant (at the 5% level). For acquisitions, both the linear and square terms display no significant effect. These results lend support to hypothesis 1a but not to Hypothesis 1b. In the discussion section, we highlight some plausible reasons for not finding support for Hypothesis 1b, pointing to certain features of acquisitions that may counteract the beneficial effects of diversity, as well as the need for making use of firm samples with greater diversity of acquisitions. In models III and V (which contains the full set of variables), the variable measuring complexity of the knowledge-sourcing portfolio (the interaction between firm-level geographic diversity of alliances and acquisition activities) is negative and strongly significant (at 1% level), in support of Hypothesis 2. In models IV and V, we add redundancy (geographic overlap) in technology sourcing activities. This variable has a negative and significant coefficient (at the 5% level) in support of Hypothesis 3.

4.1. Magnitude of effects

We next examined the magnitude of the impact of each of the hypothesis testing variables, which reveals substantial performance effects. For the geographic diversity of alliances, a one standard deviation increase in its value from the mean level, keeping the values of all other variables constant, increases patent citations in a technology domain by about 30%. The positive effect of the geographic diversity of alliances continues until a value of 0.45 (about three standard deviations above the mean) from which point additional increases in diversity has a negative effect on technological performance. The negative effects of complexity and redundancy too have notable impacts. An increase in complexity from its mean value by one standard deviation reduces technological performance by about 5% for firms engaging in both

Table 1
Descriptive statistics and pairwise correlations.

No	Variables	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11
1	Technological performances	111.05	410.75											
2	Experience - Alliances & Acquisitions	0.94	0.23	0.06										
3	Portfolio Size – Alliances	3.79	5.26	0.24	0.03									
4	Portfolio Size – Acquisitions	1.28	0.69	−0.02	0.12	0.28								
5	CVC investments	4.78	8.59	−0.07	0.03	0.13	−0.06							
6	R&D expenditures	49.21	173.84	0.58	0.06	0.50	0.18	−0.01						
7	Geographic diversity - R&D activities	0.42	0.24	−0.01	−0.03	0.10	0.06	0.09	0.01					
8	Firm technological diversity	0.81	0.12	0.11	0.20	−0.10	−0.02	−0.18	0.03	0.01				
9	Geographic. diversity – Alliances	0.09	0.13	0.03	−0.01	0.2	−0.08	0.04	0.06	0.00	0.09			
10	Geographic. diversity - Acquisitions	0.02	0.08	0.03	0.09	0.05	0.38	−0.09	0.09	0.05	0.08	0.11		
11	Complexity (Geo diversity Alliances * Geo diversity Acquisitions)	0.19	0.21	0.13	0.10	0.05	0.13	0.05	0.07	0.07	0.11	0.06	0.16	
12	Redundancy	0.79	1.67	0.06	0.03	0.44	0.48	0.05	0.37	0.04	−0.11	−0.01	0.07	0.08

Notes: Means and standard deviations of the alliance- and acquisition-based variables are for firms that have positive values of acquisitions and alliances.

Table 2
Firm technological performance and geographic diversity of alliances and acquisitions at the level of technology domain.

	Model I	Model II	Model III	Model IV	Model V
Constant	4.457***	4.474***	4.464***	4.474***	4.464***
	(0.304)	(0.304)	(0.305)	(0.304)	(0.304)
Experience - Alliances & Acquisitions	0.146***	0.146***	0.147***	0.148***	0.149***
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
Portfolio Size - Alliances	0.037**	−0.006	−0.007	0.021	0.020
	(0.018)	(0.018)	(0.018)	(0.023)	(0.023)
Portfolio Size - Acquisitions	0.295***	0.305***	0.316***	0.407***	0.417***
	(0.075)	(0.081)	(0.081)	(0.090)	(0.091)
Portfolio Size - CVC investments	0.043***	0.048***	0.048***	0.045***	0.045***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
R&D	0.008***	0.008***	0.008***	0.008***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Geographic diversity - R&D activities	0.012	0.016	0.006	0.022	0.012
	(0.200)	(0.200)	(0.200)	(0.200)	(0.200)
Firm technological diversity	0.508*	0.500*	0.512*	0.497*	0.509*
	(0.267)	(0.267)	(0.267)	(0.266)	(0.267)
Geographic diversity - Alliances		3.817***	3.825***	3.132***	3.142***
		(0.995)	(0.996)	(1.004)	(1.005)
Geographic diversity - Alliances squared		−4.689**	−4.695**	−3.740**	−3.750**
		(1.858)	(1.859)	(1.864)	(1.866)
Geographic diversity - Acquisitions		−1.501	−1.276	−0.905	−0.633
		(3.353)	(3.292)	(3.246)	(3.200)
Geographic diversity - Acquisitions squared		3.853	3.377	1.717	1.172
		(7.307)	(7.153)	(6.838)	(6.681)
Geo diversity Alliances * Geo diversity Acquisitions (Complexity)			−0.264***		−0.256***
			(0.090)		(0.090)
Redundancy				−0.487**	−0.484**
				(0.191)	(0.192)
Firm fixed effects	included	included	included	included	included
Technology fixed effects	included	included	included	included	included
Year fixed effects	included	included	included	included	included
Observations	22,802	22,802	22,802	22,802	22,802
Log-likelihood	−87039	−87021	−87019	−87014	−87012
pseudo-R-squared	0.0761	0.0763	0.0763	0.0764	0.0764
Chi squared test of improved model fit[!]		36.41***	3.16*	14.35***	2.97*

Notes: Results of unconditional Fixed Effects Negative Binomial Regression. Standard errors in parentheses are cluster-robust at firm-technology level. *p < 0.1, **p < 0.05, ***p < 0.01. Chi-squared test of improved model fit for model IV is in relation to model II, while for the remaining models it is in relation to their previous models.

alliances and acquisitions. The effect of changes in redundancy is larger, with a one standard deviation increase in redundancy from the mean value causing a 55% decline in the number of patent citations.

4.2. Robustness tests

We carried out several tests to ensure the robustness of our findings, results of which are relegated to a separate appendix. We first employed alternative measures of geographic knowledge diversity of alliances and acquisitions, utilizing a different weighting scheme. Instead of using all acquisition and alliance pairs (i.e., both intra-country and inter-country) as weights, we used only inter-country acquisitions and alliances. The results are similar to those reported in Table 2. We also tested a linear specification of our original estimation by leaving out the square terms of the two geographic knowledge diversity variables. The insignificant effect of diversity in acquisitions remained, while the coefficient for diversity of technology alliance continued to be positive and significant.

Among the 165 firms in the sample, 67 firms did not engage in acquisitions and 55 did not form alliances during the sample period. In order to examine whether our results are sensitive to the inclusion of firms without acquisition or alliance activity, we re-estimated the full model on a subsample that included firms that engaged in technology alliances as well as in technology-based acquisitions. This restricted sample included 72 firms and 12,947 observations. The results from this estimation were highly comparable to the results obtained on the full sample. A Chi-squared test suggested that the null hypothesis that the coefficients of the hypotheses testing variables in the full sample and the restricted sample are equal could not be rejected ($Chi^2 = 10.13$, P-value = 0.12).

5. Discussion and conclusion

The increasingly intense global competition and shortening product cycles have made it crucial for today's firms to follow an internationally oriented knowledge sourcing strategy. Accessing specialized and partially tacit knowledge from diverse geographic locations enlarges a firm's knowledge pool, increasing the opportunities for successful knowledge recombination and innovation outcomes. Technology alliances and technology-based acquisitions (acquisition of firms with technological resources) have become two quintessential modes used for international technology sourcing. Although a growing literature on the performance contributions of alliances and acquisitions highlights their critical importance for learning and competitiveness in a fast-changing environment, it has not examined the potential interdependencies between geographically diverse portfolios of these two modes.

Taking an organizational learning perspective, this paper examined the performance consequences of geographically diversified knowledge sourcing portfolios of alliances and acquisitions. We focus on two interdependencies that can restrict the effectiveness of the combined portfolio. The first of these interdependencies reflects the substantial coordination problems and complexities owing to the wide array of routines deployed in alliances and acquisitions for interaction and knowledge sourcing in multiple locations. The second interdependency consists of redundancy in search efforts due to geographical overlap between alliances and acquisitions in a given technological domain, reducing the variety in a firm's knowledge repertoire and weakening its ability to reconfigure knowledge for innovation. We proposed that the negative performance effects associated with these interdependencies *between* the portfolios of internationally-oriented alliances and acquisitions add to those identified in the literature as occurring *within* the portfolio of an individual knowledge sourcing mode.

We tested our predictions in a fixed effects analysis of the technological performance of 165 leading firms in a broad spectrum of manufacturing and selected technology intensive services industries. Our empirical framework is at the firm-technology level, enabling us to relate a firm's sourcing strategies pertaining to a technology domain to its technological performance in that domain. We measured portfolio diversity of alliances and acquisitions in a novel manner, by taking into account the diversity in national patterns of search and innovation within the specific technological domains and across the countries of alliance partners and acquisition targets.

Results on the performance effect of the portfolios of geographically diverse alliances and acquisitions support our baseline expectations of an inverted-U effect of the former, but no significant impact of the latter. Rather, it is the size of the acquisition portfolio that has a positive association with technological performance. Our findings on the geographic diversity of the alliance portfolio are consistent with the insights from the alliance portfolio literature that identifies the tradeoffs of portfolio diversity in other dimensions, such as partner type (e.g. Degener et al., 2018; Hagedoorn et al., 2018; Berchicci et al., 2016). The lack of a significant positive association between geographic diversity of the acquisition portfolio and technological performance highlights the severity of risks and costs in such a portfolio. Internationally oriented acquisitions are vulnerable to information asymmetry and the attendant transaction hazards, such as adverse selection and overpayment (Capron and Shen, 2007; McCann et al., 2016; Reuer and Ragozzino, 2012), as well as to difficulties in the post-acquisition integration of targets' knowledge (De Man and Duysters, 2005; Keil et al., 2008; Bresman et al., 1999). These vulnerabilities are accentuated in a geographically diverse acquisition portfolio, characterized by high levels of heterogeneity in relation to the different activities associated with the acquisition process such as due diligence, negotiation, financing, and integration (Barkema et al., 1996). These heterogeneities impede firms' ability to leverage lessons from past acquisitions and to transfer best practices within their current acquisition portfolio, reducing their capability to manage acquisitions (Zollo and Winter 2002; Lippman and Rumelt, 1982; Barkema and Schijven, 2008).

The results from our analysis provide strong support for the boundaries that complexity and redundancy form to the effectiveness of geographically diverse portfolios of alliances and acquisitions. Our findings complement studies that have identified the costs of high levels of diversity of a single mode, in particular alliances (Degener et al., 2018; Hagedoorn et al., 2018; Lavie and Miller, 2008; Penney and Combs, 2020), and those that have focused on the advantages of deploying multiple modes in external knowledge search without considering the costs (Keil et al., 2008; Rothaermel and Hess, 2007; Shi and Prescott, 2011; van de Vrande, 2012). In this regard, our findings suggest that the benefits of a multi-modal, multi-country knowledge-sourcing strategy need to be weighed against the possible costs of such a strategy. In particular, our results point out that a high level of diversity in the acquisition portfolio may not only fail to add tangible knowledge sourcing benefits, but also exacerbate complexities and redundancies of the combined portfolio of alliances and acquisitions (Stettner and Lavie, 2014). These results extend previous findings on inter-modal interdependencies between internationally-oriented CVC investments and alliances (Belderbos et al., 2018; Dushnitsky and Lavie, 2010), pointing to their wider occurrence in firms' external knowledge sourcing portfolio. Importantly, we refine these studies through conducting our analysis at the firm-technology level, enabling us to insulate our findings on knowledge search in diverse geographies from the possible influence of search in diverse technology domains. Another important novelty of our approach is that we define geographic diversity in terms of the differences in the process of learning and knowledge search across countries, measuring it in terms of heterogeneity in cross-country citation patterns in each technological field. This is in the spirit of the national innovation system literature (e.g. Lundvall, 2016; Nelson and Nelson, 2002), which stresses the distinctive national approaches to problem solving within individual technologies.

Theoretically, our findings connect with the predictions of organizational learning perspective that diversity in external knowledge sourcing creates significant benefits, but also entails substantial costs. We identify the distinct costs of a multi-modal knowledge search in heterogeneous contexts, in terms of the complexities and redundant knowledge such a strategy may engender. Our research also informs the economic geography literature which stresses the importance of geographic proximity and face-to-face interactions for effective access to location-specific knowledge (Cockburn and Henderson, 1998; Nonaka, 1994; Jaffe, 1989; Saxenian, 1994). Although alliances and acquisitions are widely seen as suitable for establishing proximate learning in distant settings, our research highlights the limits to their effectiveness when pursued simultaneously.

A key managerial implication of our findings is that firms that engage in internationally-oriented alliances and acquisitions may need to eschew the compartmentalized approach of focusing on developing capabilities specific to managing alliances and acquisitions (Sarkar et al., 2009; Wassmer, 2010; Cefis et al., 2020; Zollo and Singh, 2004; Trichterborn et al., 2016). While this approach has the advantage that firms' experience and knowledge in a given mode can help them enhance the performance of that mode, such an approach does not address the inefficiencies firms encounter in coordinating across different knowledge-sourcing modes. Addressing such difficulties and creating synergies between alliances and acquisitions may demand important organizational innovations. This can mean, for instance, organizing alliances and acquisitions under a common knowledge management team to create an effective internal communication structure Bingham et al., (2015); Moreira et al. (2018), and bringing diversity into top management teams to raise awareness and deepen knowledge of the different geographies in which a firm engages in knowledge sourcing (Boone et al., 2019). Overall, managers may need to concurrently develop expertise in alliances and acquisitions, such that they may be able to build a balanced and integrated portfolio of these modes that could reduce complexity and redundancy.

We need to acknowledge this paper's limitations, which suggest several avenues for future research. While an advantage of our sample is that it includes firms from a variety of industries, a drawback of this approach is that the limited number of firms per industry does not allow for investigating industry differences in the role of technology-based acquisitions and technology alliances. In addition, although our sample includes large as well as smaller firms, they are leaders in their core markets in Europe so we suggest caution in generalizing our findings to larger populations of firms. A related limitation of our sample is that we relied on secondary data with a limited time span. Although this insulates the results from the influence of shocks, such as the global financial crisis of 2008, and we do not expect that structural relationships we examined will differ in more recent years, the construction of substantially larger, more diverse, and updated databases is certainly a worthwhile, but time consuming, endeavor for future research.

Our analysis took into account the technological diversity of alliance partners and acquisition targets in a broad sense by focusing on their distinctive national technological characteristics. Future research may provide further insights by considering the technological characteristics of alliance partners and acquisition targets themselves. We were unable to do this owing to the limited technological information, such as patents, pertaining to alliances partners and acquisition targets. Our study also did not account for potentially important location-specific characteristics other than knowledge search. Although we argued that search patterns in a country subsumes the historical, cultural, and political settings of that country, contextual factors such as the nature of the intellectual property rights protection regime and the degree of competitive threats from local firms may impact foreign firms' interactions in that country and their ability to access local knowledge

(Belderbos et al., 2021a,b). Thus, investigating the interplay between the characteristics of the firm, its alliance partners and acquisition targets, and the host countries could help us better understand the interactions between international alliances and acquisitions.

In constructing acquisition portfolios, we adopted the established practice of using a two-year window, which is based on the notion that acquired firms enhance post-acquisition innovative performance during the first two years (e.g. Ahuja and Katila 2001; Cloodt et al., 2006) and a longer window may overestimate the ability of firms to learn from their past acquisitions (Barkema and Schijven, 2008). While data limitations did not allow us to validate our chosen time window, future research may experiment with a variety of time windows.

While there may be plausible conceptual explanations for the insignificant effects of acquisition diversity (against the predicted inverted-U effect), we suggest that the identification of an inverted-U effect in the context of our sample may also be hampered by the fact that the diversity of the acquisition portfolio is relatively low compared with that of the alliance portfolio (on average, the former is about a fifth of the latter). This suggests a need for future research to explore the possibility of gathering data on samples of firms that have higher levels of geographic diversity in their acquisition portfolios. Testing our theoretical predictions on such a sample therefore can be an important step towards a better understanding of the benefits and costs that diversity renders to firms' acquisition portfolio.

Our core findings on the challenges posed by interdependencies arising from combining diverse alliance and acquisition portfolios point to the need for a better understanding of the capabilities needed for mitigating those interdependencies. Recent research on strategic capabilities has suggested that firms need to possess fungible, general-purpose capabilities that have applications in multiple uses in order to be successful in dynamic environments (Pisano, 2017). In a similar vein Cohen and Levinthal (1990) call for a "structure of communication" within the organization between heterogeneous tasks (see also Moreira et al., 2018). In this respect, studies may, for example, investigate the role of generalists (e.g. Bingham et al., 2015) who possess tacit knowledge of firms' alliance and acquisition strategies and could therefore guide managers in concurrently managing the portfolios of alliances and acquisitions. Research may also investigate other possible ways to minimize interdependencies, including selectively deploying alliances and acquisitions in multiple locations depending on the type of knowledge search and the distinctiveness of the knowledge endowment of the partners' and targets' countries. Examining the effectiveness of these and other approaches to mitigating interdependencies can further our understanding of the nature of capabilities needed for today's firms to navigate the challenges of external sourcing of knowledge through multiple modes.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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Appendix I. Descriptives and Robustness Analysis

Table A1 lists the technologies considered and the average values of key variables. Table A2 presents results of models with alternative geographic diversity variables based on inter-country diversity weights only. Table A3 presents results of models with only linear terms of the diversity variables included. Table A4 shows results of a restricted model including only firms with technology alliance and technology-based acquisition activity.

Table A1
List of technologies and average values of key variables

Technology Class	Number of firms	Number of Patents	Alliance Portfolio	Acquisition Portfolio
Audio-visual technology	107	30	0.294	0.009
Basic communication processes	76	12	0.610	0.051
Basic materials chemistry	108	12	0.370	0.034
Biotechnology	81	7	0.278	0.039
Chemical engineering	111	6	0.000	0.000
Civil engineering	91	2	0.058	0.009
Computer technology	114	38	0.376	0.029
Control	112	9	0.008	0.011
Digital communication	80	43	0.000	0.000
Electr. machinery, apparatus, energy	120	19	0.174	0.030
Engines, pumps, turbines	87	13	0.056	0.010
Environmental technology	77	4	0.000	0.000
Food chemistry	63	4	0.133	0.070
Furniture, games	105	3	0.014	0.008
Handling	110	3	0.000	0.003
IT methods for management	84	5	1.935	0.165
Machine tools	112	6	0.000	0.003
Macromolecular chemistry, polymers	99	11	0.156	0.009
Materials, metallurgy	103	6	0.079	0.033
Measurement	125	17	0.181	0.010
Mechanical elements	99	3	0.000	0.003
Medical technology	106	11	0.086	0.055
Micro-structural and nano-technology	64	2	0.652	0.024
Optics	89	17	0.068	0.011
Organic fine chemistry	84	22	0.043	0.000

(continued on next page)

Table A1 (*continued*)

Technology Class	Number of firms	Number of Patents	Alliance Portfolio	Acquisition Portfolio
Other consumer goods	110	5	0.038	0.007
Other special machines	124	8	0.466	0.034
Pharmaceuticals	76	23	2.215	0.082
Semiconductors	89	16	0.300	0.018
Surface technology, coating	107	6	0.000	0.000
Telecommunications	97	34	0.969	0.071
Textile and paper machines	93	7	0.017	0.015
Thermal processes and apparatus	51	2	0.003	0.019
Transport	101	19	1.120	0.045
Technology class average	99	13	**0.295**	**0.025**

Note: A firm can be active in multiple technological domains at the same time.

Table A2
Firm technological performance and geographic diversity of alliances and acquisitions at the level of technology domain – geographic diversities measured using only inter-country weights

	Model I	Model II	Model III	Model IV	Model V
Constant	4.457***	4.475***	4.465***	4.474***	4.465***
	(0.304)	(0.305)	(0.305)	(0.304)	(0.305)
Experience - Alliances & Acquisitions	0.146***	0.146***	0.147***	0.147***	0.149***
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
Portfolio Size - Alliances	0.037**	−0.012	−0.013	0.016	0.015
	(0.018)	(0.019)	(0.019)	(0.024)	(0.024)
Portfolio Size - Acquisitions	0.295***	0.314***	0.325***	0.411***	0.421***
	(0.075)	(0.080)	(0.081)	(0.090)	(0.091)
Portfolio Size - CVC investments	0.043***	0.046***	0.046***	0.043***	0.044***
	(0.009)	(0.008)	(0.008)	(0.009)	(0.009)
R&D	0.008***	0.008***	0.008***	0.008***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Geographic diversity - R&D activities	0.012	0.016	0.006	0.022	0.012
	(0.200)	(0.200)	(0.200)	(0.200)	(0.200)
Firm technological diversity	0.508*	0.500*	0.512*	0.498*	0.509*
	(0.267)	(0.267)	(0.267)	(0.266)	(0.267)
Geographic diversity – Alliances[!]		3.828***	3.833***	3.118***	3.126***
		(0.971)	(0.971)	(0.995)	(0.996)
Geographic diversity - Alliances squared[!]		−4.849***	−4.849***	−3.830**	−3.836**
		(1.781)	(1.782)	(1.800)	(1.802)
Geographic diversity - Acquisitions[!]		−1.908	−1.690	−1.262	−1.005
		(3.328)	(3.266)	(3.182)	(3.133)
Geographic diversity - Acquisitions[!] squared		4.370	3.907	2.178	1.657
		(7.296)	(7.140)	(6.756)	(6.597)
Geo diversity Alliances * Geo diversity Acquisitions (Complexity)			−0.263***		−0.256***
			(0.090)		(0.089)
Redundancy				−0.477**	−0.475**
				(0.193)	(0.194)
Firm fixed effects	included	included	included	included	included
Technology fixed effects	included	included	included	included	included
Year fixed effects	included	included	included	included	included
Observations	22,802	22,802	22,802	22,802	22,802
Log-likelihood	−87039	−87020	−87019	−87013	−87012
pseudo-R-squared	0.0761	0.0763	0.0764	0.0764	0.0764

Notes: Results of unconditional Fixed Effects Negative Binomial Regression. Standard errors in parentheses are cluster-robust at firm-technology level. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. [!] The geographic diversities of alliances and acquisitions are measured using only inter-country weights.

Table A3
Firm technological performance and geographic diversity of alliances and acquisitions at the level of technology domain – with only the linear terms of the geographic diversity of alliances and acquisitions

	Model I	Model II	Model III	Model IV	Model V
Constant	4.457***	4.468***	4.458***	4.468***	4.459***
	(0.304)	(0.304)	(0.304)	(0.304)	(0.304)
Experience - Alliances & Acquisitions	0.146***	0.145***	0.147***	0.148***	0.149***
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
Portfolio Size - Alliances	0.037**	0.007	0.006	0.033	0.032
	(0.018)	(0.018)	(0.018)	(0.021)	(0.021)
Portfolio Size - Acquisitions	0.295***	0.292***	0.304***	0.415***	0.426***
	(0.075)	(0.076)	(0.077)	(0.089)	(0.090)
Portfolio Size - CVC investments	0.043***	0.047***	0.047***	0.044***	0.044***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
R&D	0.008***	0.008***	0.008***	0.008***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

(*continued on next page*)

Table A3 (*continued*)

	Model I	Model II	Model III	Model IV	Model V
Geographic diversity - R&D activities	0.012	0.018	0.008	0.024	0.014
	(0.200)	(0.200)	(0.200)	(0.200)	(0.200)
Firm technological diversity	0.508*	0.504*	0.516*	0.500*	0.512*
	(0.267)	(0.266)	(0.267)	(0.266)	(0.267)
Geographic diversity – Alliances		1.767***	1.772***	1.473***	1.480***
		(0.442)	(0.442)	(0.432)	(0.432)
Geographic diversity - Acquisitions		0.424	0.408	−0.096	−0.101
		(0.986)	(0.984)	(1.020)	(1.019)
Geo diversity Alliances * Geo diversity Acquisitions (Complexity)			−0.266***		−0.256***
			(0.090)		(0.090)
Redundancy				−0.542***	−0.538***
				(0.184)	(0.185)
Firm fixed effects	included	included	included	included	included
Technology fixed effects	included	included	included	included	included
Year fixed effects	included	included	included	included	included
Observations	22,802	22,802	22,802	22,802	22,802
Log-likelihood	−87039	−87025	−87024	−87016	−87015
pseudo-R-squared	0.0761	0.0763	0.0763	0.0764	0.0764

Notes: Results of unconditional Fixed Effects Negative Binomial Regression. Standard errors in parentheses are cluster-robust at firm-technology level. *p < 0.1, **p < 0.05, ***p < 0.01.

Table A4
Firm technological performance and geographic diversity of alliances and acquisitions at the level of technology domain – only firms with alliances and acquisitions

	Model I	Model II	Model III	Model IV	Model V
Constant	4.253***	4.263***	4.182***	4.268***	4.188***
	(0.637)	(0.642)	(0.645)	(0.638)	(0.641)
Experience - Alliances & Acquisitions	0.445***	0.451***	0.458***	0.451***	0.457***
	(0.051)	(0.051)	(0.051)	(0.051)	(0.051)
Portfolio Size - Alliances	0.032*	−0.006	−0.007	0.013	0.012
	(0.017)	(0.018)	(0.018)	(0.022)	(0.022)
Portfolio Size - Acquisitions	0.301***	0.294***	0.308***	0.382***	0.396***
	(0.073)	(0.080)	(0.080)	(0.091)	(0.092)
Portfolio Size - CVC investments	0.042***	0.047***	0.047***	0.044***	0.044***
	(0.010)	(0.009)	(0.009)	(0.010)	(0.010)
R&D	0.007***	0.006***	0.006***	0.006***	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Geographic diversity - R&D activities	1.044***	1.058***	1.033***	1.066***	1.041***
	(0.297)	(0.299)	(0.299)	(0.299)	(0.299)
Firm technological diversity	−0.083	−0.096	−0.009	−0.104	−0.018
	(0.623)	(0.627)	(0.632)	(0.623)	(0.627)
Geographic diversity - Alliances		3.863***	3.863***	3.356***	3.356***
		(0.989)	(0.991)	(0.994)	(0.996)
Geographic diversity - Alliances squared		−4.962***	−4.951***	−4.271**	−4.259**
		(1.808)	(1.813)	(1.813)	(1.819)
Geographic diversity - Acquisitions		0.364	0.601	0.348	0.625
		(2.919)	(2.851)	(2.867)	(2.807)
Geographic diversity - Acquisitions sq.		0.995	0.488	0.129	−0.442
		(6.357)	(6.175)	(6.086)	(5.902)
Geo diversity Alliances * Geo diversity Acquisitions (Complexity)			−0.299***		−0.297***
			(0.086)		(0.086)
Redundancy				−0.343**	−0.342**
				(0.169)	(0.169)
Firm dummies	included	included	included	included	included
Technology dummies	included	included	included	included	included
Year dummies	included	included	included	included	included
Observations	12,947	12,947	12,947	12,947	12,947
Log-likelihood	−57574	−57556	−57553	−57551	−57549
pseudo-R-squared	0.0702	0.0705	0.0705	0.0705	0.0706

Notes: Results of unconditional Fixed Effects Negative Binomial Regression. Standard errors in parentheses are cluster-robust at firm-technology level. *p < 0.1, **p < 0.05, ***p < 0.01.

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