Research Policy 47 (2018) 1243–1255

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Geographic dispersion and co-location in global R&D portfolios: Consequences for firm performance

Mario Kafouros[a], Chengqi Wang[b,c,*], Eva Mavroudi[a], Junjie Hong[d], Constantine S. Katsikeas[a]

[a] Leeds University Business School, University of Leeds, Leeds, LS2 9JT, United Kingdom
[b] Nottingham University Business School, Jubilee Campus, Nottingham NG8 1BB, United Kingdom
[c] School of Business Administration, Dongbei University of Finance & Economics, Dalian 116025, China
[d] School of International Trade and Economics, University of International Business and Economics, Beijing, China

ARTICLE INFO

Keywords:
Innovation
R&D portfolio
Geographic dispersion
Co-location
Performance

ABSTRACT

We examine how the ways in which firms geographically configure their global portfolios of R&D units influence the effectiveness of firms' own R&D investments and of external technical knowledge in enhancing firm performance. Our analysis indicates that the strength of these effects depends on the extent to which firms spread their R&D units *across* countries (*geographic dispersion* of R&D) and the extent to which firms establish multiple R&D units *within* each country (*co-location* of R&D). We show that geographic dispersion and co-location are associated with distinct value creation and value capture mechanisms and in turn lead to different performance outcomes. Although geographic dispersion enhances the effects of a firm's own R&D on its performance, R&D co-location limits such effects. These relationships are reversed when we consider the effects of external technical knowledge on firm performance. R&D co-location, rather than geographic dispersion, is what renders the exploitation of external knowledge more effective in enhancing firm performance. Our results suggest that future research should shift its focus from the degree of R&D globalization to *how* a portfolio is globalized and geographically structured.

1. Introduction

In a quest to become more competitive, firms are increasingly establishing R&D units abroad. Although global R&D portfolios may assist firms in creating value (Phene and Almeida, 2008; Lahiri, 2010; Piening et al., 2016), they come with significant challenges and costs (Alcácer and Zhao, 2012; Berry, 2014; Kim, 2016). The literature acknowledges the positive and negative consequences of global R&D portfolios for firm performance, but it does not predict which effect is likely to dominate and through what mechanisms. Incomplete knowledge of this phenomenon prompts a need to better conceptualize how firms create and capture value when they conduct R&D in multiple countries rather than in a single market (Teece, 1986). In particular, little is known about whether and how different ways of geographically configuring R&D portfolios may lead to different performance outcomes. We therefore have limited understanding of why some firms succeed in benefiting from global R&D while others do not.

Our study furthers understanding of factors that facilitate or impede the success of global R&D by examining how the geographic configuration of a firm's global R&D portfolio influences the effectiveness of 1) its own R&D investments and 2) external (globally dispersed) technical knowledge in enhancing the performance of the entire firm (rather than just the performance of a given unit that has access to external knowledge).[1] Our study differs from work about the *direct* effect of R&D internationalization on firm performance and the different types of curvilinear relationships (Hitt et al., 1997; Lu and Beamish, 2001, 2004). It also differs from studies that document the benefits of external knowledge within a specific country or between two nations (Andersson et al., 2016; Almeida and Kogut, 1999; Iwasa and Odagiri, 2004) without considering the geographic configuration of a firm's *entire* R&D portfolio. Our study therefore seeks to advance research that suggests that global R&D enables firms to access knowledge from different countries (Cantwell and Piscitello, 2000; Piening et al., 2016; Anand et al., 2005; Kafouros et al., 2012) but has neither theorized nor

* Corresponding author.
E-mail addresses: m.kafouros@leeds.ac.uk (M. Kafouros), chengqi.wang@nottingham.ac.uk (C. Wang), bnem@leeds.ac.uk (E. Mavroudi), hongjunjie@uibe.edu.cn (J. Hong), csk@lubs.leeds.ac.uk (C.S. Katsikeas).

[1] Two other literatures examine how R&D and other factors affect patent output and citations (Griliches, 1989; Penner-Hahn and Shaver, 2005) and how patents affect firm performance (e.g., Hall et al., 2005; Greenhalgh and Rogers, 2007). Although these two literatures inform our analysis and argumentation, our study is situated within a distinct literature that examines the relationships between R&D, external knowledge (spillovers) and firm performance (e.g., Adams and Jaffe, 1996; Hall and Mairesse, 1995; Feinberg and Majumdar, 2001).

https://doi.org/10.1016/j.respol.2018.04.010
Received 24 February 2017; Received in revised form 4 April 2018; Accepted 5 April 2018
Available online 11 April 2018

empirically examined how firms can configure R&D portfolios in a way that increases the performance-enhancing effects of their own R&D and of external technical knowledge.

As opposed to single-location studies that disregard how innovating across multiple locations may differ from innovating within a single market, we account for each firm's entire portfolio of R&D units, its location choices across countries, and the ways in which a firm geographically configures its R&D portfolio. To understand sources of heterogeneity in the geographical configuration of R&D, we focus on two distinct dimensions of R&D portfolios that vary significantly across firms: the (global) *geographic dispersion* of R&D, which is defined as how widely a firm spreads its R&D units across countries; and R&D *co-location*, which refers to the placement of several R&D units in each country. Global geographic dispersion reflects the fact that while some firms spread their R&D units across multiple countries, others choose to innovate in only a few countries (Delios and Beamish, 1999; Tang and Tikoo, 1999; Jiang et al., 2016). It thus captures the international geographic scope of R&D portfolios (Kim, 2016). On the other hand, variations in the co-location of R&D units reflect the fact that some firms locate only one R&D unit in a given country while other firms co-locate several R&D units in each country. Co-location therefore captures the geographic concentration of R&D units in a portfolio. Because these two distinct dimensions together reflect the geographic configuration of R&D portfolios both *across* countries and *within* each country, it is important to examine both constructs in a unified framework.

Although the determinants and motives that may lead managers to structure R&D portfolios differently fall outside the scope of this study, we draw from research on value creation and value capture (Kim, 2016; Teece, 1986) to develop a set of hypotheses aimed at explaining how geographic dispersion and co-location influence the effect of a firm's R&D investments and that of external technical knowledge on firm performance. We test our framework by employing a longitudinal dataset on 601 R&D subsidiaries. We model performance outcomes as a function of technical knowledge originating from 25 countries and 28 manufacturing industries, thus capturing not only a firm's entire R&D portfolio but also most of the world's pools of technical knowledge. This approach involves the application of a mapping exercise that enables us to match countries in which a firm maintains R&D units to knowledge pools residing in these locations.

Our study challenges current thinking on the interplay between firm-specific idiosyncrasies and exogenously determined factors and offers new implications for theory by shifting the focus from the degree of R&D globalization to *how* a portfolio is globalized and geographically structured (Jiang et al., 2016). From a theoretical point of view, it advances research on global innovation by specifying the different mechanisms through which the geographic dispersion and co-location of R&D differentially influence the effect of a firm's own R&D and that of external technical knowledge on firm performance. It also extends prior research by considering the performance effects of external knowledge within a global context and by offering a more complete account of how firms benefit from spatially distant knowledge. From a practical point of view, this study can help R&D managers understand trade-offs between dispersion and co-location and thus structure R&D portfolios in a way that optimizes the value added derived from firm R&D and from globally dispersed technical knowledge.

2. Theory

2.1. Global R&D portfolios, external technical knowledge and firm performance

A firm's R&D investment can improve its performance by leading to the generation of new technologies, products, services and processes that may reduce cost, generate revenue and enhance firm competitiveness. However, firm performance is driven not only by a firm's own R&D activities but also by R&D conducted by other organizations (Audretsch and Feldman, 1996; Argyres and Silverman, 2004; Cassiman and Veugelers, 2006; Andersson et al., 2016). The R&D investments of other organizations in a given industry and country lead to the formation of globally dispersed "pools" of ideas and specialist knowledge regarding scientific and technological developments that stimulate spillovers, serve as seeds for creating new technologies and may therefore improve the performance of other firms as well (Feinberg and Majumdar, 2001; Singh, 2007). These industry-country-specific pools of external technical knowledge depend on each country's industrial structure and on the amount and type of R&D undertaken in each industry. They thus differ considerably across countries in terms of characteristics, size and growth patterns.

The channels through which external technical knowledge (spillovers) enhances firm performance include demonstration effects, targeted knowledge searches, reverse engineering, employee mobility, collaborative agreements and other forms of inter-organizational interaction (Audretsch and Feldman, 1996; Coe and Helpman, 1995; Chung and Yeaple, 2008). Nevertheless, environments that feature large pools of external technical knowledge also come with certain disadvantages related to the presence of a large number of R&D-intensive and technologically strong rivals. Hence, while a focal firm can access and benefit from external technical knowledge, such knowledge also benefits organizations that have developed it as well as other competitors. Therefore, it may negatively affect the performance of the focal firm (Kafouros and Buckley, 2008).

Although such technical knowledge is geographically localized and tied to the country in which it is created (Jaffe et al., 1993; Almeida and Kogut, 1999; Chung and Alcácer, 2002), a firm can use its R&D portfolio to achieve proximal access to it (Anand et al., 2005; Chung and Yeaple, 2008; Piening et al., 2016). Accessing, accumulating and bringing together diverse knowledge from multiple locations plays a crucial role in improving a firm's performance by further enhancing technical understanding (Frost, 2001; Kogut and Zander, 1993; Cantwell and Mudambi, 2005) and the development of new capabilities in international markets (Kotabe et al., 2007; Lu and Beamish, 2004; Meyer et al., 2009).

Independent of where knowledge is created, a portfolio of global R&D units provides a firm with opportunities to access technical knowledge but to also combine and transfer such knowledge throughout the organization and between its R&D units (Nobel and Birkinshaw, 1998; Tsai, 2001; Anand et al., 2005; Phene and Almeida, 2008). Nevertheless, the benefits of such spillovers and of knowledge transfer depend on the existence of formal and informal structures and processes that foster knowledge sharing between different R&D units and between these units and their headquarters. This in turn enables a firm to cross fertilize knowledge across different units (Hansen and Lovas, 2004). The literature also acknowledges that despite the above benefits, the internationalization of R&D (or of other functions) involves coordination, collaboration and monitoring costs. It also involves challenges associated with preventing the duplication of R&D projects and with innovating in different intellectual property rights (IPR) regimes. These challenges can overstretch a firm's capacity to manage diversity (Laursen and Salter, 2006; Love et al., 2014) and may require the use of additional costly resources. Hence, prior studies suggest that global dispersion beyond a certain level may have a *direct* negative effect on firm performance (see Hitt et al. (2006) for a literature review).

3. Hypotheses

3.1. Geographic dispersion and co-location in global R&D portfolios

We contend that the effects of (1) a firm's own R&D investments and (2) external technical knowledge on performance are not uniform across all firms but rather vary depending upon the *geographic dispersion* and *co-location* of a firm's global R&D portfolio (Fig. 1). The following sections present a set of hypotheses that specify the relevant

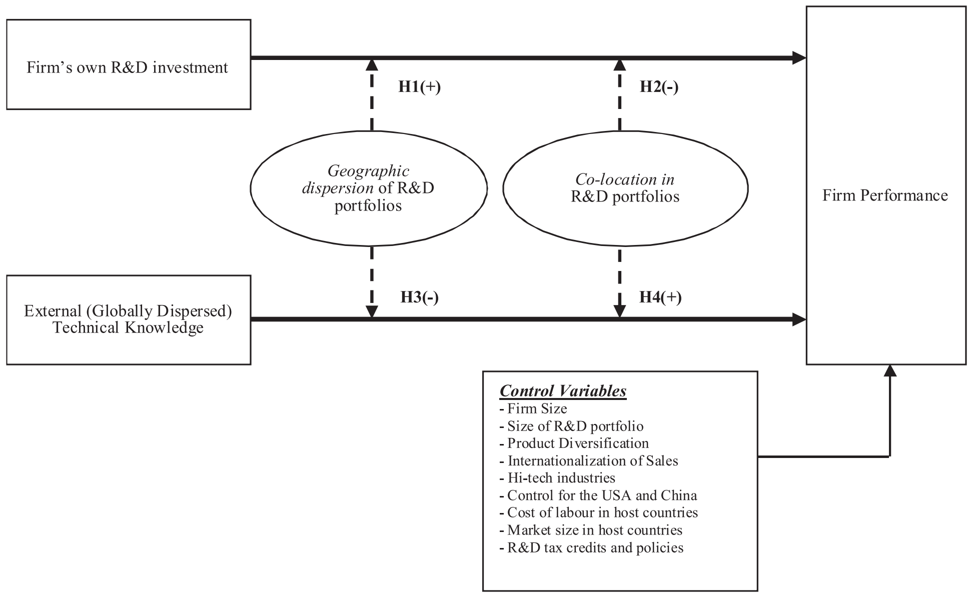

Fig. 1. Conceptual model: Geographic dispersion and co-location of R&D portfolios.

mechanisms and directionality of such moderation effects. The overarching theoretical basis for our predictions is that variations in the geographic structures of R&D portfolios influence the types and diversity of advantages and resources accessible to a firm and the ways in which a firm *creates* and *captures* value from its R&D activities and external knowledge (Teece, 1986; Lahiri, 2010; Kim, 2016).

3.2. Effects of firms' own R&D investment on performance

Our first hypothesis postulates that a higher degree of geographic dispersion of R&D across countries moderates (positively) the relationship between a firm's own R&D investments and its performance. First, a higher degree of geographic dispersion increases the variety and scope of resources, advantages and inputs that are needed to *create value* from R&D investment. As these inputs cannot be found in one country, the global dispersion of R&D enables firms to tap into alternative streams of innovation and into technological trajectories from different countries (Hitt et al., 1997; Cantwell and Narula, 2001; Cantwell and Mudambi, 2005) and to therefore exploit "the selective advantages of multiple countries" (Hitt et al., 1997: 774). Geographic dispersion also helps firms exploit the international division of labour and star scientists. Because innovation requires access to skills from markedly different scientific domains, a broader variety of division of labour bolsters the development of innovative goods and services (Beaudry and Schiffauerova, 2009) and therefore improves the effectiveness of a firm's R&D investments in enhancing its performance.

Higher levels of geographic dispersion of R&D can also create value by improving certain R&D combinations. The literature recognizes that there are limits to the value that R&D units can create by recombining the same set of inputs (Katila and Ahuja, 2002; Tallman and Phene, 2007; Phene and Almeida, 2008). Geographic dispersion helps R&D units create value and contribute to firm performance by increasing the likelihood of deploying complementary inputs, by offering R&D units the opportunity to cooperate with foreign universities and therefore by providing firms with new technological paths (Metcalfe, 1994) that lead to the formation of rare technological combinations (Teece, 1986; Katila and Ahuja, 2002). Such benefits are particularly pronounced when organizational mechanisms help facilitate inter-unit interactions and the transfer of resources (Phene and Almeida, 2008).

Second, geographic dispersion fosters value capture (appropriation) by enabling firms to fragment their technologies across their R&D units and to use such fragmentation to prevent imitation by rendering it difficult and costly for competitors to access globally dispersed technologies (Zhao, 2006). As a given innovation generated in an R&D unit is completed only when it is complemented by technologies held in other R&D units, higher geographic dispersion enables a firm to protect its technologies and to capture more value from its R&D investments. Reinforcing this logic, research on appropriability shows that geographic scope helps firms protect their innovations and capture more value from R&D investments (Zhao, 2006) because a higher degree of country heterogeneity increases causal ambiguity and prevents competitors from understanding which aspects of technology are valuable (Kim, 2016; Teece, 1986).

Higher levels of geographic dispersion also help R&D units avoid deficiencies and risks specific to a country, take advantage of different appropriation regimes in different countries, implement product adaptation in multiple markets and consequently increase the likelihood of benefiting from R&D investments (Kafouros et al., 2012; Zhao, 2006). Consistent with this reasoning, portfolio theory postulates that geographic diversification increases levels of operational flexibility and the capacity to hedge risks (Tang and Tikoo, 1999; Belderbos and Zou, 2009) and in turn helps firms capture value from their R&D investments.

The above discussion suggests that higher levels of geographic dispersion enhance the positive effects of a firm's R&D investments on firm performance by assisting R&D units in generating and in capturing more value. Accordingly:

Hypothesis 1. A higher degree of geographic dispersion in a firm's R&D portfolio enhances (i.e., positively moderates) the effects of its own R&D investments on the firm's performance.

R&D co-location can help a firm's R&D units increase their local embeddedness and understanding of the idiosyncrasies underpinning a particular market (Rosenkopf and Almeida, 2003). Despite these advantages, we assert that R&D co-location decreases the effects of a firm's own R&D investments on firm performance by significantly affecting the overall value that a firm can generate from its R&D portfolio (this premise does not suggest that firms will not benefit from their R&D; it suggests that the marginal contribution of R&D to performance will decrease).

First, when the level of R&D co-location is high (i.e., when a firm locates multiple units in a country), some of a firm's R&D units are likely to become partially redundant. Research on portfolios suggests that when investments overlap with one another (e.g., in terms of objectives and market focus), the marginal contributions of each new R&D

unit to firm performance decline (Belderbos and Zou, 2009; Vassolo et al., 2004). Value creation from R&D investments increases when each R&D unit provides a firm with advantages and inputs that the firm cannot source through other R&D units held in its portfolio. Establishing or acquiring R&D units in countries in which a firm already innovates reduces the likelihood of generating value over and above the overall value generated by each unit of the firm's R&D portfolio. In such situations, a new R&D unit may erode the marginal contributions of fellow units located within the same country (i.e., some R&D units become "sub-additive" to the firm's portfolio), reducing the aggregate effects of R&D investments on firm performance.

Second, consistent with the above logic, research on multi-unit organizations suggests that fellow R&D units not only collaborate on common projects but also compete with one another to obtain resources and funding from corporate headquarters. Such competition becomes significantly more pronounced when R&D units operate in the same market or develop technologies that serve similar consumers (Birkinshaw and Lingblad, 2005). In such situations, the success of one unit may negatively affect fellow (co-located) units either by disrupting their technological operations and focus or through a market-stealing effect that forces units to reduce technological outputs (Kafouros and Buckley, 2008). As a firm's overall value creation is negatively affected, R&D co-location decreases the contributions of a firm's R&D investments to firm performance.

Overall, while firms that locate multiple R&D units in different countries may still benefit from R&D, the cumulative or additive effects of establishing R&D units decrease as the degree of co-location increases. Hence, we expect the effects of R&D investments on firm performance to be less significant when the degree of R&D co-location is higher:

Hypothesis 2. A higher degree of co-location in a firm's R&D portfolio decreases (i.e., negatively moderates) the effects of its own R&D investments on the firm's performance.

3.3. Effects of globally dispersed technical knowledge on firm performance

The geographic dispersion of R&D units may enable firms to achieve proximal access to external knowledge pools in different countries, may assist firms in accessing ideas from diverse markets and contexts, and may facilitate knowledge re-combinations (Lahiri, 2010). Although we acknowledge such advantages, for several reasons we expect the net effect of geographic dispersion to limit the contribution of external technical knowledge to firm performance (once again, this premise does not suggest that firms will not benefit from external knowledge at all; it suggests that its marginal effects on firm performance decrease).

First, access to knowledge does not always enable firms to improve their performance. As innovation systems differ considerably across countries, search costs increase with increasing geographic distribution of R&D (Lahiri, 2010). In addition, the process of combining external knowledge from culturally and technologically diverse countries is challenging and time consuming (Piening et al., 2016) and may require firms to implement disruptive and costly organizational changes (Kim et al., 2015). Prior research supports this premise. It suggests that the bridging of distant knowledge can be arduous and creates little economic value (Miller et al., 2007) and that the integration of external knowledge across a range of existing technological routines may slow down innovation (Kafouros and Buckley, 2008). Hence, because geographic dispersion renders the identification, integration and combination of external knowledge more difficult and less compatible, it may reduce the usefulness of such knowledge for enhancing firm performance.

Furthermore, although spreading R&D units across many countries does not necessarily constrain the absorptive capacity for a specific R&D unit to benefit from external knowledge in a host country, it may overstretch the overall absorptive capacity of a firm because it renders the integration of knowledge at the *global* level more challenging. Support for this reasoning is provided by attention-based theory (Ocasio, 1997), which posits that to achieve sustained performance, managers must focus on fewer issues due to their limited time and energy. When absorptive capacity is over-stretched, problems associated with attention allocation may lead to acquisition of inferior external knowledge resources (Makadok and Barney, 2001). This once again reduces the value of external knowledge and exacerbates difficulties associated with knowledge integration.

Similarly, higher levels of breadth render it difficult for firms to exploit external knowledge resources to their full potential. When there are many ideas and opportunities to choose from, few of these will be given the level of effort that is required for their implementation (Laursen and Salter, 2006). Spreading R&D units across many knowledge markets (countries) increases difficulties of managing complexities associated with diversity which, in turn, reduce the marginal contributions of such knowledge to firm performance. In such situations, the diversity of multiple external knowledge sources becomes a barrier to adoption (Edmondson et al., 2001). As a result, performance benefits of exploiting knowledge originating from different countries decline as the number of these countries increases.

Accordingly, we expect the effects of external knowledge on firm performance to be negatively affected when a firm's R&D portfolio is spread broadly across multiple countries. Hence:

Hypothesis 3. A higher degree of geographic dispersion in a firm's R&D portfolio decreases (i.e., negatively moderates) the effects of globally dispersed technical knowledge on the firm's performance.

Although a firm's co-located R&D units may collaborate and compete with one another, we expect R&D co-location to positively moderate the effects of external technical knowledge on firm performance. First, prior R&D investments in a given country facilitate a deeper understanding of that country (von Zedtwitz and Gassmann, 2002). Hence, firms that maintain multiple R&D units in a country can search deeply and understand the relevance of the new knowledge for problem solving (Lahiri, 2010). This increases the likelihood of finding valuable knowledge, enabling them to exploit external knowledge more effectively to enhance their performance (Katila and Ahuja, 2002). Furthermore, R&D co-location increases the likelihood of identifying technological opportunities that are not always apparent to organizations that are less committed to a given country and helps firms achieve "a richer knowledge structure" (Barkema and Vermeulen, 1998: 10). Because units with strong ties can better integrate external knowledge with internal complementary technologies (Alcácer and Zhao, 2012), R&D co-location enables a firm to achieve the focus needed to integrate external knowledge into its organizational routines and technologies (Kotabe et al., 2007), to accelerate organizational learning (Katila and Ahuja, 2002) and to increase the contributions of external knowledge to firm performance.

A second significant benefit of co-location in R&D portfolios relates to the importance of becoming embedded in local settings and technological networks (Rosenkopf and Almeida, 2003). Laursen and Salter (2006) suggest that drawing knowledge heavily from different sources is not just about getting access to a wide number of sources, but it also requires firms to be able to build exchanges with external actors and sustain a pattern of interactions over time. Such interactions facilitate embeddedness, which is positively associated with knowledge exploitation and with the transfer of competencies between corporate actors (Uzzi and Gillespie, 2002). Hence, maintaining multiple R&D units in one country can increase the overall embeddedness of a firm, enabling it to build deeper linkages with suppliers, users, and other institutions within the country's innovation system and to recognize, decode and combine external technologies (especially those that are location bound) with its own technological platforms. This in turn is likely to render the exploitation of external technical knowledge more effective and to enhance its effect on firm performance.

Overall, a higher degree of co-location of R&D units increases the likelihood of identifying external knowledge, enhances understanding of such knowledge, and assists its assimilation, sharing and integration. All else being equal, we expect higher levels of R&D co-location to facilitate the exploitation of external knowledge and to enhance its effects on firm performance. Hence:

Hypothesis 4. A higher degree of co-location in a firm's R&D portfolio enhances (i.e., positively moderates) the effects of globally dispersed technical knowledge on the firm's performance.

4. Data and methods

4.1. Sample

The empirical testing of our hypotheses involved the combination of firm-level panel data on R&D portfolios and detailed industry-level data on R&D activities undertaken in each industry across various countries. To obtain data over several years, we used Thomson One Banker to collect firm-level operating data on U.K.-headquartered manufacturing firms. To increase the variability and number of observations in the data, we employed a multi-industry sample of firms that report their R&D investments and international sales.

As Thomson One Banker does not report data on firms' global R&D portfolios, we identified firms that provided such information in their annual reports and websites, and collected data on the locations of U.K. and overseas R&D units. We resolved unclear cases of R&D locations through telephone contact with the firms to produce an accurate and comprehensive dataset of the geographic distribution of R&D portfolios. The final sample includes 601 globally dispersed R&D units owned by 101 firms. Unlike much of the prior research on R&D internationalization that is large based on cross-sectional data, we collected panel data over a period of five years (2004–2008). This method enabled us to observe whether external knowledge pools and R&D portfolios change from year to year. Table 1 presents the industrial breakdown of the sample and highlights differences in R&D portfolios across industries. Most of the firms included in the sample operate in high-technology sectors such as aerospace and electronics, but the sample also includes low-technology firms (e.g., from the textiles and toy sectors).

To construct industry- and location-specific pools of external knowledge for each firm included in the sample, detailed information on R&D investment for different industries and countries was required. To this end, we supplemented the firm-level data with information obtained from the O.E.C.D.'s Analytical Database. We collected data on aggregate R&D undertaken in 25 countries and in 28 distinct industries that include those in which the firms of our sample operate. Table 2 reports the countries incorporated into our analysis and shows how the distribution of the world's R&D activities differs across countries.

Table 1
Industrial breakdown of the sample (601 R&D units; 101 firms).

Industry	No of Firms	R&D units per firm (mean)
Aerospace	6	10
Chemicals	8	5
Computer and related activities	20	7
Drugs	17	4
Electrical Components & Equipment	6	6
Electronics	21	5
Food	5	5
Household Products	4	7
Machinery	6	9
Metal Manufacturers	4	6
Textiles	2	3
Toys	2	2

Note: Diversified firms were included in the closest industry according to their sales.

Table 2
International differences in R&D spending (2004).

Country	R&D spending ($ millions)
Australia	6 339.9
Austria	4 070.2
Belgium	4 165.6
Canada	12 155.4
Czech	1 564.7
Denmark	2 951.8
Finland	3 779.7
France	23 979.0
Germany	42 820.0
Greece	480.8
Hungary	591.4
Ireland	1 203.6
Italy	8 362.2
Japan	88 350.9
Korea	21 428.1
Netherlands	5 582.3
Norway	1 697.0
Poland	795
Portugal	559
Russia	12 278.3
Slovenia	415.4
Spain	6 412.7
Sweden	7 689.1
UK	20 042.8
US	208 301.0

Knowledge pools in a given country can be particularly large in one industry but relatively small in another. To capture such variations, we developed separate measures for each industry and country. This approach is consistent with the view that as countries specialize in different technological domains, a given location choice may be appropriate for one company but not for another.

4.2. Measures

4.2.1. Dependent variable

Drawing from the literature on R&D and knowledge spillovers (Audretsch and Feldman, 1996; Adams and Jaffe, 1996; Feinberg and Majumdar, 2001; Liu et al., 2009), the main dependent variable of our model is the productivity performance of a firm (total factor productivity, TFP). However, to explore the robustness of the results, we also estimated the model based on firm profitability (return on assets, ROA). TFP is an appealing measure of operational performance for several reasons. First, it accounts not only for the sale of products and services but also for a firm's investment in labour and assets and for the cost of intermediate inputs used by a company. Hence, it is sensitive to variations resulting from accessing geographically localized resources and advantages from different countries. Second, TFP captures the different benefits of investing in R&D. For example, R&D that leads to the development of new products may increase a firm's revenues whereas process innovations may affect a firm's cost base or alter the use of labour and assets. Finally, while a firm's profitability is volatile and may take negative values, productivity performance remains more stable across market fluctuations, exchange rate variations, transfer pricing, accounting standards and the treatment of royalties (Buckley, 1996).

Following common practice (e.g. Adams and Jaffe, 1996), we operationalize each firm's productivity performance by estimating a 'residual' that captures increases in firm output that cannot be explained by firm inputs. This residual used in our study (and in most prior studies) is the outcome of a function where the nominator is a firm's *value added* (defined as sales minus the cost of intermediate goods and inputs) while its denominator is a vector of two key firm inputs: labour (the number of employees) and capital (total assets). The estimation also includes industry- and year-specific dummy variables to account for exogenous shifts and sector-specific idiosyncrasies. As value added captures a firm's ability to generate revenue (output) while controlling for raw materials and intermediate inputs that a firm uses to achieve that level of output, it avoids biases associated with the fact that different outputs may exhibit different economies of scale. The estimation of TFP is based on the view that productivity is the intermediate transformation capacity level between inputs and outputs (Dutta et al., 2005) and thus reflects a firm' ability to transform and generate value from a given number of inputs.

4.3. Independent variables

4.3.1. R&D investments of a firm

Using the commonly employed perpetual inventory method that captures investments over time (Griliches, 1979, 1992), a measure of R&D is constructed for each firm by aggregating its current and prior R&D investments. This operationalization explicitly recognizes that firms develop and accumulate technologies and technical knowledge over time. To control for the declining usefulness of past technologies, we depreciate past R&D investments using a 20 percent rate drawing from prior research (Goto and Suzuki, 1989). To examine the robustness of our results, we calculated alternative R&D measures at rates of 15 and 25 percent. As R&D investments may take time to impact firm performance, we applied a one-year lag. To normalize the measure of R&D for firm size, we also divided it by each firm's total assets. As economic relationships are rarely linear, we employ a logarithmic specification to increase the interpretability of our results for this variable and other variables.

4.3.2. External (globally dispersed) technical knowledge

We needed to employ a variable that captures the globally dispersed knowledge pools that firms can access in each country through their R&D units. The firm-specific measure of external technical knowledge (ETK) accessible to a firm (i) at time (t) comprises two types of knowledge stocks (*intra-industry* and *inter-industry*), and it is estimated for the total number of countries (n) in which a firm maintains R&D units:

$$\mathrm{ETK}_{it} = \sum_{c=1}^{n} (\mathrm{ETK}_{\mathrm{intra-industry,it}} + \mathrm{ETK}_{\mathrm{inter-industry,it}})_c \tag{1}$$

Our operationalization of intra-industry technical knowledge uses the perpetual inventory method (Eq. (2)) and data on the aggregate R&D investment (R&D) that is made by other companies in the industry (s) in which the focal firm operates (Griliches, 1979, 1992). We subtracted each firm's own R&D investment from the total intra-industry measure to correct for double counting. We then estimated this measure as a stock. This takes into account not only R&D investments in year (t) but also R&D investments made in the previous years (the term l represents the lagged years and the term d refers to the depreciation of past R&D which is set at 20 percent annually):

$$\mathrm{ETK}_{\mathrm{intra-industry,it}} = \mathrm{R\&D}_{st} + \sum_{1}^{l} (1-\mathrm{d})^{l}\mathrm{R\&D}_{s(t-l)} \tag{2}$$

Because firms may use technical knowledge from several distinct industries and technological domains, rather than from just their own immediate area (Griliches, 1992), we further estimated measures of inter-industry technical knowledge. We again use the perpetual inventory method described in Eq. (2) but this time we capture the R&D investments made by companies in other industries (rather than in the main industry of the focal firm). As the usefulness of the knowledge of each industry may differ, we build on the practice employed in the literature and use input-output industry tables to estimate the technological distance between the industry of the focal firm and other industries. Using this approach, we created weights for each industry. Industries that are distant to that of the firm are given a smaller weight, whereas closely associated industries carry a higher weight. Such inter-industry measures therefore reflect the extent to which one industry (that of the focal firm) employs knowledge and technologies from distantly related sectors (see Griliches (1992) for a review). We estimated knowledge pools for each industry-country-year separately to capture patterns in the evolution of technical knowledge. This process resulted in the creation of 700 knowledge pools for each year (i.e., 25 countries × 28 industries). We then matched the countries in which each firm maintains R&D units to measures of the external technical knowledge that resides in these locations. We also constructed lagged measures (for up to four years) to allow for the fact that knowledge diffusion may occur overtime. We found that the effects of knowledge pools are maximized after three years. Therefore, the results reported in the following section are based on a three-year lag.

4.3.3. Geographic dispersion and co-location in R&D portfolios

First, we needed to capture the geographic dispersion of a firm's R&D portfolio *across* countries (i.e., how widely a firm spreads its R&D units). As per prior studies on the scope of foreign activity and investment (e.g., Allen and Pantzalis, 1996; Delios and Beamish, 1999; Tang and Tikoo, 1999; Reuer and Leiblein, 2000), we operationalized geographic dispersion using the number of countries in which a firm maintains R&D units. Hence, the greater the number of countries in which a firm locates R&D units, the more geographically dispersed its R&D portfolio is.

Furthermore, for each firm we needed to capture the co-location of its R&D units (which reflects the concentration of the firm's R&D units *within* each country). Building on previous studies (e.g., Allen and Pantzalis, 1996; Tang and Tikoo, 1999), we measured the co-location of R&D by constructing a record of the number of R&D units in each country in which the firm maintains R&D activities. The greater the number of R&D units a firm maintains in a country, the higher the level of co-location is. In addition, a firm may maintain a different number of R&D units in different countries (e.g., it may maintain 2 units in some countries and 4 units in some other countries). Given the need to capture co-location for the firm's entire R&D portfolio, we estimated the mean value of co-location for all the countries in which the firm maintains R&D activities. To capture potential changes over time, we estimated geographic dispersion and co-location separately for each year. Although the R&D portfolios and location choices of firms can in theory change over time, we observed that with few exceptions firms keep their R&D portfolio the same over the five-year period of the sample.

The correlation between geographic dispersion and co-location is positive and significant (0.21 with p-value of 0.000), which suggests that dispersion and co-location do not necessarily substitute for one another. The above measures, which are in line with a large number of studies that examine foreign investment and internationalization (e.g., Goerzen and Beamish, 2003; Lu and Beamish, 2001; Wan and Hoskisson, 2003), are important for our study because they help us capture the diverse advantages and knowledge resources that reside in different countries and which are critical for innovation (Cantwell and Mudambi, 2005; Zhao, 2006).

Although our measures of performance and R&D are normalized for firm size, one concern associated with this relates to the fact measures of geographic dispersion and co-location can be related to firm size. For instance, as larger firms tend to operate a higher number of R&D units, they are more likely to operate in multiple countries or to maintain several units in each country. Notwithstanding that similar measures have been used extensively in the international business literature, we examined the extent to which dispersion and co-location are correlated with firm size (as measured by a firm's sales). As these correlations were found to be very low (0.09 for dispersion with p-value of 0.04; and 0.003 for co-location with p-value of 0.94), this issue does not pose a serious problem to our study. Nevertheless, we have also added other measures to control for potential scale effects (we discuss this issue below).

4.4. Control variables

4.4.1. Firm size

In addition to normalizing key measures such as a firm's R&D for firm size, we include a firm's annual sales to capture potential effects that a firm's overall size may have on its performance.

4.4.2. Size of R&D portfolios

Although we normalized a firm's R&D investment for size and have controlled for the overall size of a firm, we wanted to ensure that the measures of geographic dispersion and of the co-location of R&D were not affected by the size (scale) of a firm's R&D portfolio. For instance, firms with several R&D units in their portfolios may also exhibit a higher degree of dispersion and co-location. To avoid a potential bias, we control for the overall size of a firm's R&D portfolio by capturing the total number of R&D units that a firm possesses in each given year.

4.4.3. Product diversification

Product diversification may directly impact firm performance and in the case of multiunit organizations it may also affect cooperation and competition within a firm. For instance, a lower degree of product diversification increases the likelihood that activities of one R&D unit will overlap with the activities of other units. We operationalize product diversification by constructing the commonly used entropy measure of diversification (Hitt et al., 1997).

4.4.4. Internationalization of sales

Although the cost of developing new technologies is similar whether offered to one country or to many, firms presenting more internationalized sales are better able to appropriate the fruits of such technologies. They can charge premium prices for their discoveries (Kotabe et al., 2002), spread the costs of global innovative activities (Hitt et al., 1997), and increase returns to R&D by offering their products to customers in multiple markets (Lu and Beamish, 2004). Following prior research (e.g., Tallman and Li, 1996), we constructed a record for the internationalization of sales by using each firm's ratio of foreign sales to total sales to control for such effects.

4.4.5. Control for the U.S.A and China

Our results may be influenced by R&D location choices that involve large countries with diverse regions. We identified in our dataset two countries that are large and diverse (the U.S.A. and China). To control for any potential effects on performance driven by these location choices, we added a dummy variable to the model that takes a value of 1 when a given firm performs R&D in the U.S.A. and/or China.

4.4.6. Cost of scientific labour in host countries

As R&D location choices may also be cost-driven, another factor that may influence the results is the cost of scientific labour across countries. Lower costs of scientific labour may increase returns to R&D, render a firm more competitive and contribute to firm performance. To ensure that our results are not affected by these effects, we collected data from the Union Bank of Switzerland survey of International Wage Comparison (Union Bank of Switzerland, 2006, 2009, 2015). The survey controls for various factors that influence employment costs, including age, education and experience. We used the annual gross cost for hiring scientists and engineers, which captures wages and salaries and indirect costs (e.g., bonuses, holiday pay and family allowances) that vary across countries. We estimated the variable separately for each firm based on costs of employment in the countries in which the firm operates R&D units.

4.4.7. Market size of host countries

Countries differ not only in terms of the availability of knowledge pools but also in terms of market size or demand. Market size may affect firm performance by influencing scale economies in the exploitation of innovations. To capture the size of the market in host countries (i.e., in countries in which firms maintain their R&D units), we used gross domestic product (GDP) data drawn from the World Bank's national accounts electronic database. This measure is in line with studies on R&D location-specific factors (Kumar, 2001; Shimizutani and Todo, 2008). Once again, we estimated this variable for each firm based on the R&D locations of each firm.

4.4.8. R&D tax credits and policies

R&D tax credits and policies vary across countries (Brown et al., 2017) and can influence not only the R&D location choices of firms, but also firm performance directly by affecting the real cost of conducting R &D. We used the B-index (McFetridge and Warda, 1983) to construct this variable. The B-index captures different types of R&D incentives, such as allowances, credits and deductions, by evaluating the corporate income tax rate and reductions to tax liabilities for each country (Thomson, 2009). The B-index therefore reflects how much a $1 R&D investment actually costs to firm and it thus takes lower values for countries that are generous in their R&D tax treatment. Following the literature (Brown et al., 2017), we used the yearly estimates of the B-index from Thomson (2009) to estimate this variable for each firm based on its R&D locations (we have used one minus the B-index so that a higher value of our measure reflects more beneficial R&D tax credits and policies).

4.4.9. Time and industry effects

We include a set of year-specific dummy variables to control for time effects associated with variations in demand and business cycles. Furthermore, high- and low-technology industries exhibit significant variations in the type and rate of technological advances (Dosi et al., 2006). Following prior studies (e.g., Zahra, 1996; Dosi et al., 2006), we used Klevorick et al.'s (1995) taxonomy to develop a dummy variable that takes a value of 1 for *high-tech industries* (i.e. for industries that exhibit greater technological opportunities such as drugs, electronics, and aerospace) and a value of 0 for low-tech industries (e.g., toys and textiles). In addition, in models in which we do not control for high-tech industries, we used separate industry dummies (at the two-digit level of SIC) to control for industry-specific effects. Finally, to explore whether our results hold in high-tech industries, we also run regressions for a sub-sample of high-tech firms only.

4.5. Statistical method

Given that we use panel data, we check for autocorrelation using the Wooldridge (2002) test. This test shows that first-order autocorrelation (AR1) is present in the data, which suggests that the use of ordinary least squares (OLS) is not appropriate for our analysis. Furthermore, as the AR1 process often varies across sectors (Cheng and Nault, 2007), it may cause panel-specific AR1 (PSAR1). Indeed, the likelihood ratio test rejects the hypothesis that the AR1 coefficients are common across panels, which confirms that panel specific autocorrelation does exist in the data. Moreover, unobservable factors (e.g., managerial efficiency) that vary across firms may affect performance. Thus, the variance of the disturbance term may be heteroskedastic across panels. The likelihood ratio test indicates that heteroskedasticity is present in our data. To overcome these limitations, we employ the feasible generalized least squares (FGLS) technique to estimate our models. The FGLS technique allows us to specify whether there is panel-specific first-order autocorrelation (PSAR1) in our data. This method produces efficient and consistent estimates when the disturbances of the model are not independent and identically distributed (Wooldridge, 2002) and is widely used in the internationalization and spillovers literature (e.g., Lu and Beamish, 2004; Cheng and Nault, 2007). Panel data models can be addressed by Fixed Effects (FE) or Random Effects (RE) estimators. The

Table 3
Descriptive statistics and correlation matrix.

		Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	TFP	0.027	0.518														
2	Firm Profitability	0.275	0.770	0.32													
3	R&D investment	4.767	11.125	0.09	−0.39												
4	External technical knowledge	17189	62843	−0.01	−0.52	0.74											
5	Geographic dispersion of R&D portfolio	4.261	3.449	0.00	0.34	−0.15	−0.11										
6	Co-location of R&D portfolio	1.315	0.554	0.03	0.11	0.14	0.05	0.21									
7	Firm size	3345	18147	0.16	0.35	−0.24	−0.37	0.09	0.00								
8	Size of R&D portfolio	5.840	5.492	−0.01	0.30	−0.05	−0.07	0.83	0.55	0.03							
9	Product diversification	0.669	0.592	−0.04	0.26	−0.47	−0.49	0.30	0.00	0.30	0.19						
10	Internationalization of sales	0.576	0.258	0.02	0.16	−0.13	−0.17	0.23	−0.05	0.07	0.19	0.04					
11	High technology industries	0.772	0.420	0.01	−0.18	0.51	0.44	−0.09	0.13	−0.01	−0.01	−0.34	−0.06				
12	Control for the U.S.A. and China	0.404	0.491	−0.03	−0.18	−0.08	−0.20	−0.55	−0.20	−0.13	−0.41	−0.12	−0.19	0.01			
13	Cost of scientific labour in host countries	57238	15288	0.05	−0.16	0.15	0.30	−0.26	0.04	0.00	−0.18	−0.20	−0.02	0.10	−0.19		
14	Market size of host countries	1.E+13	8.E+12	0.03	0.25	−0.05	0.14	0.70	0.17	0.12	0.56	0.18	0.20	−0.05	−0.83	0.07	
15	R&D tax credit and policies	0.065	0.034	−0.07	−0.04	0.15	0.13	−0.17	−0.04	−0.43	−0.06	−0.10	−0.17	0.05	0.36	−0.04	−0.26

FE estimator is more efficient than the RE estimator because it allows the individual specific effects to be correlated with the independent variables (Wooldridge, 2002). However, the FE model provides consistent estimates only for time-varying regressors. Because key variables in our models, including R&D dispersion and co-location, are largely time-invariant, the FE model is not an appropriate method and it will lead to less efficient estimates. Hence, we estimate the models using the RE method.

5. Results

Table 3 presents the descriptive statistics while Table 4 presents the regression results. To test Hypothesis 1–Hypothesis 4, Models 1–4 include separate two-way interactions between geographic dispersion, co-location, a firm's R&D investments and external technical knowledge. Model 5 includes all these interaction terms together. The effects of R&D on performance can be affected by a firm's internationalization of sales. Firms that have expanded into foreign markets have better opportunities to exploit their innovations, which might in turn increase the effects of R&D on firm performance. Furthermore, a firm's own R&D investments may increase its ability to exploit external technical knowledge and scientific advances (Penner-Hahn and Shaver, 2005). As a firm's research efforts increase its absorptive capacity, the effects of external knowledge on firm performance might depend upon its own R&D investments. Additionally, the effects of R&D on firm performance might also depend on the size of a firm's R&D portfolio (i.e., the number of R&D units), as size changes economies of scale in R&D. To ensure that the results are not biased by these factors, Models 1–5 also include interaction effects between R&D and the internationalization of sales, between R&D and external knowledge, and between R&D and the size of a firm's R&D portfolio.

In both Models 1 and 5, the coefficient of the interaction term between R&D and geographic dispersion is positive and statistically significant at the highest possible level. It thus provides strong support for Hypothesis 1. This finding confirms that R&D portfolios with higher levels of geographic dispersion increase the effects of a firm's own R&D on firm performance. The coefficient of the two-way interaction for R&D and co-location is negative and highly significant in Models 2 and 5. These results provide support for Hypothesis 2. A higher degree of co-location in a firm's R&D portfolio decreases the effects of R&D on firm performance. This suggests that maintaining multiple R&D units in the same country has negative consequences for the value that a firm derives from its R&D activities.

Furthermore, in Hypothesis 3 we asserted that higher levels of geographic dispersion in a firm's R&D portfolio should decrease the role of external knowledge in enhancing firm performance. The coefficients of the interaction terms in Models 3 and 5 are negative as expected, but only the coefficient in Model 5 is statistically significant. These results provide some support to Hypothesis 3. The results in Models 4 and 5 corroborate Hypothesis 4. They confirm the premise that the effects of external technical knowledge on firm performance are positively moderated by the degree of co-location in a firm's R&D portfolio. These results are consistent with the view that maintaining multiple R&D units in a country enables a firm to exploit external knowledge more successfully.

5.1. Robustness checks

First, Model 6 re-estimates the main model (Model 5) after including industry dummies. As Model 6 shows, the results remain qualitatively similar. Second, in Model 5, we implicitly assume that the *direct* effects of geographic dispersion and co-location on firm performance are linear. However, as geographic dispersion and co-location come with a set of benefits and costs, their effects on performance can be curvilinear (i.e., reflecting a U-shaped or inverted U-shaped relationship). Although the direct effect of internationalization is beyond the scope of the study, we wanted to investigate how the results pertaining to Hypothesis 1–Hypothesis 4 are affected by the specification of the model. In Models 7–9, we introduce squared terms of geographic dispersion, co-location, size of R&D portfolio and internationalization of sales. The results pertaining to the hypotheses in these models are not affected by this change (i.e. they remain similar to Model 5) with the only exception being the coefficient of Hypothesis 2, which loses its statistical significance in Model 7.[2]

Third, our sample of manufacturing firms includes organizations

[2] Model 7 shows that the squared terms for all measures of R&D internationalization (i.e. except the internationalization of sales) are negative and significant. These results suggest that the geographic dispersion of R&D has an inverted U-shaped relationship with firm performance. This finding is in line with previous studies (Hitt et al., 1997), suggesting that positive performance effects begin to decline when the internationalization of R&D extends beyond a certain level. However, it is not consistent with other studies that find U-shaped (Lu and Beamish, 2001) or S-shaped relationships (Lu and Beamish, 2004). The literature has attributed such mixed findings to differences in motivations for internationalization and to variations in industry coverage and across different time periods (Hitt et al., 2006).

Table 4
Regression Results.

	TFP									Sales		ROA	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13
Hypothesis 1: R&D X Geographic dispersion of R&D portfolio	0.296***				0.352***	0.264**	0.435***	0.274***	0.304***	0.500***	0.538***	1.919***	1.613**
	(0.051)				(0.068)	(0.092)	(0.071)	(0.084)	(0.107)	(0.076)	(0.083)	(0.460)	(0.529)
Hypothesis 2: R&D X Co-location of R&D portfolio		−0.394***			−0.416***	−0.348*	0.038	−0.558**	−0.671**	−0.237	−0.632***	0.561	0.550 (1.045)
		(0.100)			(0.122)	(0.15)	(0.162)	(0.211)	(0.219)	(0.185)	(0.192)	(0.856)	
Hypothesis 3: External technical knowledge X Geographic dispersion of R&D portfolio			−0.019		−0.122***	−0.081*	−0.129***	−0.173***	−0.111*	−0.359***	−0.422***	−0.846***	−0.702**
			(0.023)		(0.029)	(0.0398)	(0.033)	(0.036)	(0.053)	(0.039)	(0.036)	(0.214)	(0.241)
Hypothesis 4: External technical knowledge X co-location of R &D portfolio				0.123*	0.201***	0.154*	0.152*	0.237***	0.282**	0.250***	0.445***	0.524	0.640 (0.479)
				(0.056)	(0.049)	(0.069)	(0.071)	(0.072)	(0.093)	(0.069)	(0.067)	(0.374)	
R&D investment	0.068*	0.022	0.063†	0.050	0.059***	0.090†	0.151**	0.300***	0.394***	0.103*	0.120†	0.427†	1.290***
	(0.028)	(0.040)	(0.035)	(0.031)	(0.043)	(0.052)	(0.050)	(0.078)	(0.101)	(0.043)	(0.067)	(0.248)	(0.379)
External technical knowledge	−0.039***	−0.041***	−0.012	−0.029**	−0.002	−0.030	0.010	−0.013	−0.003	−0.498***	−0.508***	−0.928***	−0.886***
	(0.011)	(0.011)	(0.020)	(0.010)	(0.023)	(0.030)	(0.025)	(0.029)	(0.040)	(0.029)	(0.029)	(0.161)	(0.156)
Geographic dispersion of R&D portfolio	0.372***	0.306***	0.372***	0.320***	0.676***	0.586***	1.060***	1.523***	1.337***	1.040***	0.950***	4.240***	4.328***
	(0.056)	(0.048)	(0.084)	(0.049)	(0.110)	(0.151)	(0.167)	(0.170)	(0.209)	(0.143)	(0.136)	(0.642)	(0.871)
Co-location of R&D portfolio	0.407***	0.356***	0.264***	−0.097	−0.221	−0.101	−0.226	−0.215	−0.142	−1.501***	−2.504***	−2.426	−3.883†
	(0.079)	(0.086)	(0.080)	(0.182)	(0.165)	(0.227)	(0.317)	(0.352)	(0.425)	(0.349)	(0.327)	(1.887)	(2.234)
Firm size	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***			0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)
Size of R&D portfolio	−0.025***	−0.024***	−0.024***	−0.025***	−0.020***	−0.023***	−0.024	−0.039*	−0.041	0.120***	0.096***	0.131	0.839 (0.094)
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.005)	(0.016)	(0.019)	(0.021)	(0.021)	(0.015)	(0.102)	
Product diversification	−0.075***	−0.068***	−0.070***	−0.074***	−0.064*	−0.071***	−0.063*	−0.060**	−0.100**	0.131***	0.118***	−0.544***	−0.742***
	(0.013)	(0.014)	(0.014)	(0.014)	(0.015)	(0.020)	(0.015)	(0.021)	(0.027)	(0.015)	(0.015)	(0.099)	(0.129)
Internationalization of sales	0.216***	0.183***	0.190***	0.185***	0.160***	0.157***	−0.280***	0.263**	−0.350***	0.271**	0.208*	1.102**	1.357***
	(0.031)	(0.028)	(0.031)	(0.027)	(0.033)	(0.036)	(0.075)	(0.090)	(0.105)	(0.092)	(0.090)	(0.369)	(0.423)
High technology industries	−0.111***	−0.109***	−0.115***	−0.107***	−0.132***		−0.102***			0.252***		0.211*	
	(0.016)	(0.017)	(0.018)	(0.018)	(0.018)		(0.019)			(0.023)		(0.099)	
Control for the U.S.A. and China	0.116**	0.096*	0.071†	0.063†	0.113**	0.051	0.204***	0.284***	0.187***	−0.341***	−0.452***	−0.633*	−0.472
	(0.040)	(0.040)	(0.038)	(0.038)	(0.042)	(0.050)	(0.041)	(0.046)	(0.055)	(0.044)	(0.053)	(0.252)	(0.290)
Cost of scientific labour in host countries	0.110***	0.111***	0.087***	0.082***	0.106***	0.089***	0.089***	0.102***	0.084**	−0.151***	−0.185***	−0.039	−0.307†
	(0.019)	(0.018)	(0.014)	(0.012)	(0.014)	(0.018)	(0.021)	(0.022)	(0.029)	(0.023)	(0.022)	(0.164)	(0.158)
Market size of host countries	0.012	0.023	0.022	0.025	0.005	0.006	0.042*	0.101***	0.073**	0.133***	0.175***	0.389**	0.635***
	(0.020)	(0.018)	(0.019)	(0.018)	(0.019)	(0.023)	(0.019)	(0.019)	(0.028)	(0.018)	(0.022)	(0.125)	(0.151)
R&D tax credits and policies	0.050*	0.023	0.028	0.042*	0.049*	0.067**	0.054†	−0.102*	−0.106**	0.071†	0.097*	1.366***	0.906***
	(0.023)	(0.020)	(0.020)	(0.019)	(0.039)	(0.026)	(0.028)	(0.041)	(0.039)	(0.038)	(0.043)	(0.203)	(0.267)
R&D X Internationalization of sales	−0.203***	−0.188***	−0.174***	−0.175***	−0.166***	−0.133**	−0.208***	−0.283***	−0.246***	−0.283***	−0.548***	−0.835***	−1.638***
	(0.035)	(0.031)	(0.031)	(0.029)	(0.035)	(0.047)	(0.041)	(0.046)	(0.050)	(0.059)	(0.073)	(0.251)	(0.278)
R&D X External technical knowledge	0.005	−0.000	−0.017†	−0.014	0.006	0.011	0.005	−0.074***	−0.090***	−0.018*	−0.054***	−0.106†	−0.532***
	(0.009)	(0.008)	(0.009)	(0.008)	(0.009)	(0.011)	(0.009)	(0.014)	(0.019)	(0.008)	(0.014)	(0.055)	(0.080)
R&D X Size of R&D portfolio	0.000	0.022***	0.016***	0.015***	0.007	0.007	0.006	0.015*	0.015*	0.003	0.012*	−0.039	−0.003
	(0.002)	(0.002)	(0.001)	(0.001)	(0.004)	(0.005)	(0.004)	(0.006)	(0.008)	(0.005)	(0.005)	(0.029)	(0.035)
Geographic dispersion of R&D portfolio – Squared							−0.829***	−0.793***	−0.785***	−0.455***	−0.342**	−1.630*	−2.798**
							(0.125)	(0.131)	(0.154)	(0.143)	(0.120)	(0.790)	(0.912)
Co−location of R&D portfolio – Squared							−1.305***	−0.716†	−0.992*	−0.917†	0.047	−0.526	−1.397
							(0.367)	(0.424)	(0.450)	(0.477)	(0.465)	(1.662)	(2.361)

(*continued on next page*)

Table 4 (*continued*)

	TFP									Sales		ROA	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13
Size of R&D portfolio – Squared							−0.404***	−0.439***	−0.465***	−0.002***	−0.001***	−0.177***	−0.070
							(0.052)	(0.055)	(0.060)	(0.000)	(0.000)	(0.199)	(0.228)
Internationalization of sales –							0.000	0.000	0.000	0.015	−0.126	0.003	−0.000
Squared							(0.000)	(0.000)	(0.000)	(0.082)	(0.077)	(0.002)	(0.001)
Time dummies	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included
Industry dummies						Included			Included				
Observations	505	505	505	505	505	505	505	390	390	505	390	505	390

Notes: (1) Standard errors are in parentheses, (2) the models use mean-centering. † $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

from both high- and low-technology industries. To examine whether the hypothesized effects hold for high-technology firms, we re-estimated the full model for the sub-sample of high-technology firms only. Although it is based on fewer observations (390), Model 8 confirms all the hypotheses with high levels of significance. These results also hold when we use industry dummy variables in Model 9. Furthermore, although the literature on R&D and spillovers typically focuses on the productivity performance of firms (which was the dependent variable in Models 1–9), one may argue that the role of the geographic dispersion and co-location of R&D portfolios may affect other dimensions of firm performance differently.

Models 10 and 11 examine whether our hypotheses hold for firm sales for the full sample and for high-tech firms only, respectively. The results in both models support the hypotheses and yield a pattern that is almost identical to the results for firm productivity (with the only exception being Hypothesis 2, which yields the correct coefficient but which loses its statistical significance). Models 12 and 13 replicate the results of the full model for firm profitability (ROA), for the full sample and high-tech firms respectively. These results support Hypothesis 1 and Hypothesis 3, but the coefficients of interest are statistically insignificant in Hypothesis 2 and Hypothesis 4. Such change can partly be explained by differences in the determinants of firm profitability and firm productivity. For instance, factors such as transfer pricing and tax rates have a greater influence on profitability.

Finally, we investigated the sensitivity of the findings to changes in the depreciation rate of R&D. To do so, we calculated alternative measures for internal R&D and external knowledge using rates of 15 and 25 percent and we re-estimated the model. The choice of depreciation rates did not appear to be important when estimating R&D stocks, and these alternative specifications did not impact the findings. The findings are more sensitive to changes in time lags for external knowledge. The results presented in Table 4 are based on a three-year lag for external technical knowledge. When we experimented with shorter and longer time lags, the analysis yielded results with either lower or less significant coefficients.

6. Discussion and conclusion

6.1. Theoretical contributions and managerial implications

Although the literature acknowledges that the development of a global R&D portfolio comes with a set of benefits and costs, scholarly understanding of why some firms benefit from global R&D while others fail to do so remains incomplete. We contribute to this line of inquiry by showing that variations in the effects of a firm's own R&D investments and in the effects of external technical knowledge on firm performance are explained by the idiosyncratic manner in which a firm's R&D portfolio is structured in terms of geographic dispersion and the co-location of R&D units. Unlike studies that investigate R&D location choices and knowledge spillovers in isolation or for one country, we capture a firm's entire R&D portfolio, most of the world's R&D efforts and how a firm's R&D units collectively influence the performance of the entire firm. A number of theoretical contributions and managerial implications emerge from the analysis.

As our first contribution, we demonstrate that differential effects of R&D activity on firm performance can be explained not only by the globalization of R&D per se but also by differences in the resulting distribution of R&D units (Jiang et al., 2016; Piening et al., 2016). This premise is distinct from prior theoretical approaches. Rather than treating foreign countries in a similar manner by examining the degree of a firm's R&D globalization, our study underscores the importance of carefully considering *how* R&D portfolios are internationalized and how variations in the geographic configuration of such portfolios may result in differences in inter-firm performance. Our analysis therefore extends explanations that focus on the role of location and geography but that ignore interdependencies between R&D locations. It thus furthers understanding of how variations in R&D portfolios may improve or impede the ability of a firm that innovates in multiple countries to create and capture value from its R&D (Zhao, 2006; Alcácer and Zhao, 2012; Kim, 2016).

A second theoretical contribution concerns the geographic dispersion and co-location of global R&D portfolios. The distinction between these two dimensions is theoretically important first because geographic dispersion and co-location influence how much firms benefit from their own R&D investments. In this respect, we find that geographic dispersion enhances the contributions of a firm's R&D to its performance. From a practical point of view, this finding suggests that when managers make location choices that broaden the geographic scope of research portfolios, a firm's R&D activities become more effective in increasing firm performance. Dispersion into multiple countries enables firms to employ star scientists who cannot be found in one market, to leverage expertise that may complement their technical base and in turn to enhance the contributions of R&D to firm performance (Cantwell and Mudambi, 2005; Kafouros et al., 2012). By contrast, the opposite is true for R&D co-location. Its moderating effects are negative, thus limiting the performance-enhancing benefits of R&D. When firms co-locate multiple R&D units in the same country, R&D units erode the marginal contributions of fellow units, thus reducing the likelihood of generating value over and above the overall value generated by each unit of the firm's R&D portfolio (Vassolo et al., 2004).

Third, our study furthers understanding of how firms can configure their R&D portfolios to benefit from external knowledge, thus contributing to research on knowledge spillovers (Audretsch and Feldman, 1996; Adams and Jaffe, 1996; Liu et al., 2009). Prior research suggests that global R&D portfolios may help firms overcome geographical constraints and access distant knowledge (Kogut and Zander, 1993). However, empirical knowledge of whether and under what conditions knowledge accumulated by a firm's R&D portfolio can in practice be combined and improve the performance of the entire firm remains limited. Our empirical evidence indicates that globally dispersed knowledge pools have significant power in explaining inter-firm performance asymmetries, pointing to the value of integrating such effects into theoretical and empirical models. Although we agree with the established view concerning the benefits of stimuli located in host countries (Berry, 2014; Lahiri, 2010), we show how certain geographic configurations of R&D portfolios may limit or improve a firms' ability to improve its performance by exploiting external globally dispersed knowledge. In this respect, our study contributes to knowledge-based conceptualizations (Kogut and Zander, 1993; Katila and Ahuja, 2002) by showing how a firm's ability to exploit such knowledge is shaped by the geographic dispersion and co-location of its R&D portfolio.

The results reveal that a higher level of geographic dispersion is unlikely to help a firm exploit external knowledge in a way that enhances its firm performance. These results, however, should be interpreted with care. They are specific to a firm's entire R&D portfolio and do not necessarily contradict prior studies that suggest that geographic dispersion increases the number of countries where spillovers can be accessed and may enable each firm subsidiary to benefit from a different knowledge pool. Our results also indicate that establishing multiple R&D units within a country positively moderates the effectiveness of external knowledge in enhancing firm performance. Hence, from a practical point of view, concentrating R&D operations in strong knowledge markets in which a firm already operates is likely to serve as a particularly fruitful means of benefiting from external knowledge. However, R&D managers should implement such strategies with care because despite the benefits of co-location, it can also increase chances of knowledge leakage, imitation and competition between fellow R&D units. In suggesting that firms with higher levels of co-location are better able to exploit external knowledge, this finding runs contrary to results on the effects of R&D, which indicate that geographic dispersion (rather than co-location) increases the value of a firm's own R&D activities.

As this study helps explain why some firms benefit from external technical knowledge while others do not, it complements organizational learning perspectives. Studies on organizational learning focus on how widely firms search for new knowledge across technological space (Katila and Ahuja, 2002). We explain how firms benefit from knowledge across geographic space and how such decisions impact performance. Our results support the premise that depending on a firm's location choices, R&D units collectively access and benefit from a unique set of location-bound knowledge. However, they also reveal that the geographic structure of a firm's R&D portfolio acts as a conditioning mechanism in the relationship between external knowledge and performance. These results have implications for how firms manage R&D. Conducting overseas R&D without optimizing dispersion and co-location impacts how much a firm benefits from external knowledge and from its own R&D, and this leads to different performance outcomes. The results also imply that firms should configure their R&D portfolios differently depending on their strategic aims (e.g., firms focused on enhancing performance by accumulating knowledge from a market may benefit from establishing multiple units in this market). As this analysis underscores the importance of considering both firm-specific idiosyncrasies and exogenously determined knowledge resources, a careful evaluation of these joint moderating effects should be a central facet of a firm's strategy.

6.2. Limitations and future research

First, a common concern in the R&D literature relates to the fact that certain R&D decisions may be endogenous to firm performance. In our models, endogeneity may arise when, for instance, productive firms increase the dispersion and co-location of their R&D portfolios. Although the descriptive statistics in Table 3 indicate that firm productivity is weakly correlated with R&D dispersion and co-location (the correlation coefficients are 0.00 and at 0.03 respectively), the results should be interpreted with care. Second, while we examined the locations of R&D units, data constraints prevented us from examining the type of each R&D unit (e.g., home-base exploiting or competence creating). As objectives and capabilities vary across R&D units (Cantwell and Mudambi, 2005), future studies may complement the present study either by investigating how the type of R&D unit involved influences knowledge exploitation and the effects of R&D on firm performance, or by considering the role of subsidiaries with different functions (e.g. manufacturing units). Third, certain configurations of R&D portfolios that are beneficial for firm productivity and profitability might be detrimental for patent output (and vice versa). Our study could be extended by identifying how geographic dispersion and co-location in R&D portfolios affects patent output and citations or other forms of firm innovativeness (e.g., new product development). Finally, one of the key arguments of this study is that firms benefit from advantages that their globally dispersed R&D units can access. Although such benefits depend on organizational routines and mechanisms that help firms transfer and share resources and advantages across R&D units, data constraints did not allow us to examine these firm capabilities. Future studies aimed at capturing such effects would advance theories on the relationship between global R&D and firm performance.

Acknowledgements

We would like to thank three anonymous reviewers and the editor for their valuable commnents and help in improving the study. Chengqi Wang is grateful for the financial support from the National Natural Science Foundation of China (No. 71563058).

References

Adams, J.D., Jaffe, A.B., 1996. Bounding the effects of R&D: an investigation using matched establishment-firm data. RAND J. Econ. 27 (4), 700–721.

Alcácer, J., Zhao, M., 2012. Local R&D strategies and multilocation firms: the role of internal linkages. Manage. Sci. 58 (4), 734–753.
Allen, L., Pantzalis, C., 1996. Valuation of the operating flexibility of multinational corporations. J. Int. Bus. Stud. 27 (4), 633–653.
Almeida, P., Kogut, B., 1999. Localization of knowledge and the mobility of engineers in regional networks. Manage. Sci. 45 (7), 905–917.
Anand, J., Capron, L., Mitchell, W., 2005. Using acquisitions to access multinational diversity: thinking beyond the domestic versus cross-border M&A comparison. Ind. Corp. Change 14 (2), 191–224.
Andersson, U., Dasí, À., Mudambi, R., Pedersen, T., 2016. Technology, innovation and knowledge: the importance of ideas and international connectivity. J. World Bus. 51, 153–162.
Argyres, N.S., Silverman, B.S., 2004. R&D, organization structure, and the development of corporate technological knowledge. Strateg. Manage. J. 25 (8–9), 929–958.
Audretsch, D.B., Feldman, M.P., 1996. R&D spillovers and the geography of innovation and production. Am. Econ. Rev. 86 (3), 630–640.
Barkema, H.G., Vermeulen, F., 1998. International expansion through start-up or acquisition: a learning perspective. Acad. Manage. J. 41, 7–26.
Beaudry, C., Schiffauerova, A., 2009. Who's right, Marshall or Jacobs?: The localization versus urbanization debate. Res. Policy 38, 318–337.
Belderbos, R., Zou, J., 2009. Real options and foreign affiliate divestments: a portfolio perspective. J. Int. Bus. Stud. 40, 600–620.
Berry, H., 2014. Global integration and innovation: multicountry knowledge generation within MNCs. Strateg. Manage. J. 35 (6), 869–890.
Birkinshaw, J., Lingblad, M., 2005. Intrafirm competition and charter evolution in the multibusiness firm. Org. Sci. 16 (6), 674–686.
Brown, J.R., Martinsson, G., Petersen, B.C., 2017. What promotes R&D? Comparative evidence from around the world. Res. Policy 46 (2), 447–462.
Buckley, A., 1996. International Capital Budgeting. Prentice-Hall, NJ.
Cantwell, J., Mudambi, R., 2005. MNE competence-creating subsidiary mandates. Strateg. Manage. J. 26, 1109–1128.
Cantwell, J., Narula, R., 2001. The eclectic paradigm in the global economy. Int. J. Econ. Bus. 8 (2), 155–172.
Cantwell, J., Piscitello, L., 2000. Accumulating technological competence: its changing impact on corporate diversification and internationalization. Ind. Corp. Change 9 (1), 21–51.
Cassiman, B., Veugelers, R., 2006. In search of complementarity in innovation strategy: internal R&D and external knowledge acquisition. Manage. Sci. 52 (1), 68–82.
Cheng, Z., Nault, B.R., 2007. Industry level supplier-driven IT spillovers. Manage. Sci. 53 (8), 1199–1216.
Chung, W., Alcácer, J., 2002. Knowledge seeking and location choice of Foreign Direct Investment in the United States. Manage. Sci. 48 (12), 1534–1554.
Chung, W., Yeaple, S., 2008. International knowledge sourcing: evidence from U.S: firms expanding abroad. Strateg. Manage. J. 29, 1207–1224.
Coe, D., Helpman, E., 1995. International R&D spillovers. Eur. Econ. Rev. 39, 859–887.
Delios, A., Beamish, P., 1999. Geographic scope product diversification, and the corporate performance of Japanese firms. Strateg. Manage. J. 20 (8), 711–727.
Dosi, G., Marengo, L., Pasquali, C., 2006. How much should society fuel the greed of innovators? On the relations between appropriability, opportunities and rates of innovation. Res. Policy 35, 1110–1121.
Dutta, S., Narasimhan, O., Rajiv, S., 2005. Conceptualizing and measuring capabilities: methodology and empirical application. Strateg. Manage. J. 26, 277–285.
Edmondson, A.C., Bohmer, R.M., Pisano, G.P., 2001. Disrupted routines: team learning and new technology implementation in hospitals. Adm. Sci. Q. 46, 685–716.
Feinberg, S.E., Majumdar, S.K., 2001. Technology spillovers from foreign direct investment in the Indian pharmaceutical industry. J. Int. Bus. Stud. 32 (3), 421–437.
Frost, T.S., 2001. The geographic sources of foreign subsidiaries' innovations. Strateg. Manage. J. 22 (2), 101–123.
Goerzen, A., Beamish, P.W., 2003. Geographic scope and multinational enterprise performance. Strateg. Manage. J. 24 (13), 1289–1306.
Goto, A., Suzuki, K., 1989. R&D capital: rate of return on R&D investment and spillover of R&D on Japanese manufacturing industries. Rev. Econ. Stat. 71 (4), 555–564.
Greenhalgh, C., Rogers, M., 2007. The value of intellectual property rights to firms and society. Oxf. Rev. Econ. Policy 23 (4), 541–567.
Griliches, Z., 1979. Issues in assessing the contribution of research and development to productivity growth. Bell Jo. Econ. 10, 92–116.
Griliches, Z., 1989. Patents: recent trends and puzzles. Brookings Papers Microeconomics. pp. 291–319.
Griliches, Z., 1992. The search for R&D spillovers. Scand. J. Econ. 94, 29–47.
Hall, B., Mairesse, J., 1995. Exploring the relationship between R&D and productivity in French manufacturing firms. J. Econ. 65, 263–293.
Hall, B.H., Jaffe, A.B., Trajtenberg, M., 2005. Market value and patent citations. RAND J. Econ. 36 (1), 16–38.
Hansen, M.T., Lovas, B., 2004. How do multinational companies leverage technological competencies? Moving from single to interdependent explanations. Strateg. Manage. J. 25 (8–9), 801–822 Special Issue.
Hitt, M., Hoskisson, R., Kim, H., 1997. International diversification: effects on innovation and firm performance in product-diversified firms. Acad. Manage. J. 40 (4), 767–798.
Hitt, M.A., Tihanyi, L., Miller, T., Connelly, B., 2006. International diversification: antecedents, outcomes, and moderators. J. Manage. 32 (6), 831–867.
Iwasa, T., Odagiri, H., 2004. Overseas R&D, knowledge sourcing: and patenting: an empirical study of Japanese R&D investment in the US. Res. Policy 33, 807–828.
Jaffe, A.B., Trajtenberg, M., Henderson, R., 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. Q. J. Econ. 108 (3), 577–598.
Jiang, G.F., Holburn, G.L., Beamish, P.W., 2016. The spatial structure of foreign subsidiaries and firm expansion strategy. J. World Bus. 51, 438–450.
Kafouros, M.I., Buckley, P.J., 2008. Under what conditions do firms benefit from the research efforts of other organizations? Res. Policy 37 (2), 225–239.
Kafouros, M.I., Buckley, P.J., Clegg, J., 2012. The effects of global knowledge reservoirs on the productivity of multinational enterprises: the role of international depth and breadth. Res. Policy 41, 848–861.
Katila, R., Ahuja, G., 2002. Something old, something new: a longitudinal study of search behaviour and new product introduction. Acad. Manage. J. 45 (6), 1183–1194.
Kim, H., Hoskisson, R.E., Lee, S.-H., 2015. Why strategic factor markets matter: new multinationals' geographic diversification and firm profitability. Strateg. Manage. J. 36 (4), 518–536.
Kim, M., 2016. Geographic scope, isolating mechanisms and value appropriation. Strateg. Manage. J. 37 (4), 695–713.
Klevorick, A.K., Levin, R.C., Nelson, R.R., Winter, S.G., 1995. On the sources and significance of interindustry differences in technological opportunities. Res. Policy 24 (2), 185–205.
Kogut, B., Zander, U., 1993. Knowledge of the firm and the evolutionary theory of the multinational corporation. J. Int. Bus. Stud. 24, 625–645.
Kotabe, M., Srinivasan, S.S., Aulakh, P.S., 2002. Multinationality and firm performance: the moderating role of R&D and marketing capabilities? J. Int. Bus. Stud. 33 (1), 79–97.
Kotabe, M., Dunlap-Hinkler, D., Parente, R., Mishra, H.A., 2007. Determinants of cross-national knowledge transfer and its effect on firm innovation. J. Int. Bus. Stud. 38, 259–282.
Kumar, N., 2001. Determinants of location of overseas R&D activity of multinational enterprises: the case of US and Japanese corporations. Res. Policy 30 (1), 159–174.
Lahiri, N., 2010. Geographic distribution of R&D activity: how does it affect innovation quality? Acad. Manage. J. 53 (5), 1194–1209.
Laursen, K., Salter, A., 2006. Open for innovation: the role of openness in explaining innovative performance among UK manufacturing firms. Strateg. Manage. J. 27 (2), 131–150.
Liu, X., Wang, C., Wei, Y., 2009. Do local manufacturing firms benefit from transactional linkages with multinational enterprises in China. J. Int. Bus. Stud. 40 (7), 1113–1130.
Love, J.H., Roper, S., Vahter, P., 2014. Learning from openness: the dynamics of breadth in external innovation linkages. Strateg. Manage. J. 35, 1703–1716.
Lu, J.W., Beamish, P.W., 2001. The internationalization and performance of SMEs. Strateg. Manage. J. 22, 565–575.
Lu, J.W., Beamish, P.W., 2004. International diversification and firm performance: the S-curve hypothesis. Acad. Manage. J. 47 (4), 598–609.
Makadok, R., Barney, J.B., 2001. Strategic factor market intelligence: an application of information economics to strategy formulation and competitor intelligence. Manage. Sci. 47 (12), 1621–1638.
McFetridge, D.G., Warda, J.P., 1983. Canadian R & D Incentives: Their Adequacy and Impact (No. 70). Canadian Tax Foundation, Toronto.
Metcalfe, J.S., 1994. The economics of evolution and the economics of technology policy. Econ. J. 104, 931–944.
Meyer, K.E., Wright, M., Pruthi, S., 2009. Managing knowledge in foreign entry strategies: a resource-based analysis. Strateg. Manage. J. 30, 557–574.
Miller, J.D., Fern, M.J., Cardinal, L.B., 2007. The use of knowledge for technological innovation within diversified firms. Acad. Manage. J. 50, 308–326.
Nobel, R., Birkinshaw, J., 1998. Innovation in multinational corporations: control and communication patterns in international R&D operations. Strateg. Manage. J. 19, 479–496.
Ocasio, W., 1997. Towards an attention-based view of the firm. Strateg. Manage. J. 18, 187–206 Summer Special Issue.
Penner-Hahn, J., Shaver, J.M., 2005. Does international research and development increase patent output? An analysis of Japanese pharmaceutical firms. Strateg. Manage. J. 26, 121–140.
Phene, A., Almeida, P., 2008. Innovation in multinational subsidiaries: the role of knowledge assimilation and subsidiary capabilities. J. Int. Bus. Stud. 39, 901–919.
Piening, E.P., Salge, T.O., Schäfer, S., 2016. Innovating across boundaries: a portfolio perspective on innovation partnerships of multinational corporations. J. World Bus. 51, 474–485.
Reuer, J.R., Leiblein, M.J., 2000. Downside risk implications of multinationality and international joint ventures. Acad. Manage. J. 43 (2), 203–214.
Rosenkopf, L., Almeida, P., 2003. Overcoming local search through alliances and mobility. Manage. Sci. 49, 751–766.
Shimizutani, S., Todo, Y., 2008. What determines overseas R&D activities? The case of Japanese multinational firms. Res. Policy 37 (3), 530–544.
Singh, J., 2007. Asymmetry of knowledge spillovers between MNCs and host country firms. J. Int. Bus. Stud. 38, 764–786.
Tallman, S., Li, J., 1996. Effects of international diversity and product diversity on the performance of multinational firms. Acad. Manage. J. 39 (1), 179–196.
Tallman, S., Phene, A., 2007. Leveraging knowledge across geographic boundaries. Org. Sci. 18 (2), 252–260.
Tang, C.Y., Tikoo, S., 1999. Operational flexibility and market valuation of earnings. Strateg. Manage. J. 20 (8), 749–761.
Teece, D.J., 1986. Profiting from technological innovation. Res. Policy 15, 285–306.
Thomson, R., 2009. Tax Policy and the Globalisation of R&D. Melbourne Institute of Applied Economic and Social Research.
Tsai, W., 2001. Knowledge transfer in intraorganizational networks: effects of network position and absorptive capacity on business unit innovation and performance. Acad. Manage. J. 44 (5), 996–1004.
Union Bank of Switzerland, 2006. Prices and Earnings: A Comparison of Purchasing Power Around the Globe. Union Bank of Switzerland, Zurich.
Union Bank of Switzerland, 2009. Prices and Earnings: A Comparison of Purchasing Power Around the Globe. Union Bank of Switzerland, Zurich.

Union Bank of Switzerland, 2015. Prices and Earnings: A Comparison of Purchasing Power Around the Globe. Union Bank of Switzerland, Zurich.
Uzzi, B., Gillespie, J.J., 2002. Knowledge spillover in corporate financing networks: embeddedness and the firm's debt performance. Strateg. Manage. J. 23 (7), 595–618.
Vassolo, R.S., Anand, J., Folta, T.B., 2004. Non-additivity in portfolios of exploration activities: a real options-based analysis of equity alliances in biotechnology. Strateg. Manage. J. 25, 1045–1061.
Wan, W., Hoskisson, R.E., 2003. Home country environments, corporate diversification strategies, and firm performance. Acad. Manage. J. 46 (1), 27–45.
Wooldridge, J.M., 2002. Econometric Analysis of Cross Section and Panel Data. MIT Press, Cambridge, MA.
Zahra, S.A., 1996. Governance, ownership, and corporate entrepreneurship: the moderating impact of industry technological opportunities. Acad. Manage. J. 39 (6), 1713–1735.
von Zedtwitz, M., Gassmann, O., 2002. Market versus technology drive in R&D internationalization: four different patterns of managing research and development. Res. Policy 31, 569–588.
Zhao, M., 2006. Conducting R&D in countries with weak intellectual property rights protection. Manage. Sci. 52 (8), 1185–1199.