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International R&D and MNCs' innovation performance: An integrated approach

René Belderbos[a,b,c,*], Bart Leten[a,d], Shinya Suzuki[e]

[a] KU Leuven (Naamsestraat 69), 3000 Leuven, Belgium
[b] Maastricht University (Tongersestraat 53), 6211 LM Maastricht, the Netherlands
[c] UNU-MERIT (Boschstraat 24), 6211 AX Maastricht, the Netherlands
[d] Hasselt University (Agoralaan Gebouw D), 3590 Diepenbeek, Belgium
[e] Musashi University, 1-26-1 Toyotama-kami, Tokyo, Japan

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ABSTRACT

We propose an integrated framework establishing the environmental and organizational contingencies under which the international dispersion of R&D activities benefits innovation performance in multinational firms. We suggest that R&D dispersion is more likely to enhance innovation performance – the smaller economies of scale and scope in R&D, the greater the technological strength of R&D locations and the stronger intra-firm knowledge integration. Employing a panel dataset of 175 R&D intensive US, EU, and Japanese firms, our findings provide support for this framework and suggest that these contingencies need to be taken into account simultaneously. Technology diversification strengthens rather than weakens the relationship between international R&D and performance, which we attribute to the positive influence of recombining knowledge sourced across diverse locations.

1. Introduction

R&D has for long been the least internationalized business function in multinational corporations (MNCs) (e.g., Papanastassiou et al., 2019; Blomkvist et al., 2017). Firms centralize R&D activities at home to reap economies of scale and to facilitate the transfer and integration of tacit and sticky technological knowledge between headquarters, R&D laboratories, and core manufacturing plants (Pearce, 1989; Patel and Pavitt, 1991; Di Minin and Bianchi, 2011; Ivarsson et al., 2017; Castellani and Lavoratori, 2020). Various changes in the technological, international, and business environment have taken place, such as increased global competition, shorter product life cycles, the increased worldwide spread of technological capabilities, and the availability of scientists and engineers outside industrialized countries. In response, firms have increasingly internationalized their R&D activities (e.g., Belderbos et al., 2017; Castellani et al., 2017). Foreign R&D by MNCs has been organized to respond to increased product market competition, to access foreign pools of research talent, to reduce R&D costs, and to speed up the process of technology development. The literature has considered two main motives for firms to conduct R&D activities outside their home countries (e.g., Kuemmerle, 1997; von Zedtwitz and Gassmann, 2002; Ambos, 2005). First, MNCs have set up foreign R&D activities to tailor home-developed products to local market conditions, and to provide technical support to foreign manufacturing operations ("home-base exploiting R&D"). A second motive is to harness geographically distributed technological expertise abroad and to develop new technologies for world markets ("home-base

* Corresponding author at: KU Leuven (Naamsestraat 69), 3000 Leuven, Belgium.
E-mail addresses: rene.belderbos@kuleuven.be (R. Belderbos), bart.leten@kuleuven.be (B. Leten), s.suzuki1@cc.musashi.ac.jp (S. Suzuki).

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augmenting R&D"). The latter motivation has been termed "knowledge sourcing" and appears to have gained in importance in recent years (e.g., Driffield et al., 2016; Asakawa et al., 2017).

The conditions under which international R&D actually benefits the multinational firm has also received attention. Examining the impact of R&D internationalization on firm performance is not trivial because it is expected that this internationalization is associated with both benefits and costs. Benefits include sourcing foreign technological expertise and information on local demand (e.g., Cantwell and Mudambi, 2005). Internationalization costs include increased coordination and integration complexities, possible redundancies in R&D mandates, efforts of the various laboratories, and potentially reduced scale and scope economies (e.g., Gupta and Govindarajan, 2000; Belderbos et al., 2013; Rabbiosi, 2011). Prior studies on the performance effects of international R&D have shown mixed evidence, with studies reporting positive (Iwasa and Odagiri, 2004; Penner-Hahn and Shaver, 2005; Todo and Shimizutani, 2008; Griffith et al., 2006; Belderbos et al., 2015; Kafouros et al., 2012; Ferraris et al., 2021), negative (Singh, 2008), U-shaped (Hsu et al., 2015) and inverted-U-shaped effects (Hurtado-Torres et al., 2018; Lahiri, 2010). MNCs may find it difficult to establish optimal R&D structures because of disputes over local R&D mandates with subsidiary management and historical legacies when foreign expansion has involved M&A activity (Mudambi and Navarra, 2004; von Zedtwitz et al., 2004). The literature has also pointed to the existence of contingencies under which R&D internationalization is more likely to enhance innovation performance. These include intra-organizational knowledge management and cross-border knowledge exchange (Ferraris et al., 2021; Lahiri, 2010; Belderbos et al., 2008), firms' R&D strengths abroad allowing for knowledge sourcing (Griffith et al., 2006; Belderbos et al., 2015; Todo and Shimizutani, 2008), their level of R&D investment abroad (Kafouros et al., 2012), their international experience (Hsu et al., 2015), international collaboration in their R&D activities (Hurtado-Torres et al., 2018) and their ability to exploit foreign technologies (Penner-Hahn and Shaver, 2005; Tojeiro-Rivero, 2022).

The above studies on the performance effects of R&D internationalization have each taken a partial approach, focusing on one specific contingency, at most. The fragmented and non-comprehensive approach has led to ambiguity in the findings. In the current study, we contribute to the literature by developing an integrated contingency framework on the performance effects of international R&D, in which both the costs and benefits play an important role. Drawing on the knowledge-based view of the MNC (Grant, 1996; Kogut and Zander, 1993; Almeida et al., 2002), we propose a set of organizational and environmental factors that are expected to shape the advantages and disadvantages of international R&D dispersion. We distinguish between knowledge-sourcing advantages related to the technological strengths of foreign R&D locations and the knowledge-integration capabilities of the MNC, as well as knowledge-dispersion disadvantages due to economies of scale in R&D and economies of scope in diversified technology portfolios. By studying the moderating effect of multiple environmental and organizational contingencies, the aim of this study is to develop a comprehensive understanding of the conditions under which R&D internationalization can improve the innovation performance of MNCs.

We test our hypotheses on panel data on the R&D and patent activities of 175 European, Japanese, and US firms that are among the top R&D spenders in five technology-intensive industries. We measure firms' innovation performance by citation-weighted patent counts. Consequently, our innovation measure focuses (by nature of patent requirements) on novel technology and (by nature of the forward citations) on technology with future impact, but it does not take into account innovations (e.g., organizational innovations) that have no technological novelty. Our patent-based measure technically represents inventions, but we adhere to established practice in academic research in using the term "innovation performance" to describe patent outcomes (e.g., Phene et al., 2006; Lahiri, 2010; Geerts et al., 2018; Boone et al., 2019) – particularly, if such patents are used in follow-up research and applications (citation-weighted patents). We examine international dispersion of R&D across 40 major developed and developing countries worldwide. Our empirical analyses control for both region-specific year effects and firm-level fixed effects.

Our empirical results suggest that the relationship between international dispersion of R&D and innovation performance crucially depends on organizational and environmental contingencies. MNCs benefit to a much greater extent from an internationally dispersed R&D base when they locate their activities in countries with a strong technology base. Moreover, the benefits of international R&D are enhanced if the MNC has effective cross-border knowledge integration practices in place, requiring efforts to source, transfer, and utilize knowledge sourced abroad across all units of the MNC. Firms benefit less from R&D internationalization if scale economies are important in the MNC's technology portfolio. Against our expectations, MNCs with a diverse technology portfolio benefit more rather than less from R&D dispersion. We discuss our findings and implications in the final section of the paper.

2. Theory and hypotheses

The knowledge-based view of the MNC regards knowledge as the most strategically important of a firm's resources. The main premise of this view (Grant, 1996: Kogut and Zander, 1993; Almeida et al., 2002; Foss et al., 2013) is that firms' competitiveness and survival rests, to an important extent, on their capacity to create, recombine, source, and integrate knowledge. Firms that internationalize their R&D activities are motivated by the wish to obtain sophisticated specialized knowledge from international sources (e.g., Meyer-Krahmer and Reger, 1999; Dunning and Narula, 1995). Firms probe beyond the frontiers of their local networks because searching for information in well-known domains (local search) significantly lowers their chances of finding new information. Thus, firms need to explore new sources of knowledge by establishing linkages outside their traditional geographic regions, increasing the breadth of search, and improving the effectiveness of technological capability development (Lahiri, 2010). Creating linkages to various locations increases the breadth of search and potentially allows for knowledge recombination and cross-fertilization (Leiponen and Helfat, 2011; Nieto and Rodriguez, 2011).

Research has emphasized the importance of the firm's capability to learn from foreign activities and to build up experience from the transfer of tacit knowledge available in different geographic locations (Grant, 1996; Kogut and Zander, 1993; Martin and Salomon, 2003; Foss et al., 2013). International experience is a prime source of organizational learning in multinational firms, and geographically diversified operations generate valuable learning opportunities (Barkema and Vermeulen, 1998; Hsu et al., 2015) from the knowledge bases and innovation systems in different locations (Zahra et al., 2000; Belderbos et al., 2018; Cano-Kollmann et al., 2016). These innovation systems may have particular strengths that are not present – or not to the same extent – in the home country (Phene et al., 2006), providing the firm with opportunities for complementary technology development. Moreover, ties to geographically dispersed sources may fulfill a "radar" function, supplying a firm with information on a wide range of relevant technological developments.

A local R&D presence is often required to access tacit knowledge components that are specific to the location and which are unlikely to diffuse easily outside the location (Jaffe et al., 1993; Alcacer and Chung, 2007; Leten et al., 2014). Prior literature has shown that MNCs have increasingly internationalized their R&D activities and created geographically dispersed knowledge hubs with specialized expertise (Penner-Hahn and Shaver, 2005; Kogut and Zander, 1992). These knowledge hubs allow embedded participation in local R&D networks and facilitate access to tacit and specialized local knowledge (Frost, 2001; Lahiri, 2010; Phene and Almeida, 2008). However, despite this trend of R&D internationalization, a major portion of corporate R&D is still conducted in the home countries of the multinational firms and only a few corporations internationalize their R&D activities in a major way (OECD, 2007; Zanfei, 2000; Di Minin and Bianchi, 2011; Belderbos et al., 2013; Blomkvist et al., 2010; Moncada-Paternò-Castello et al., 2011).

The ambiguous evidence on R&D internationalization is related to the potential disadvantages of dispersing R&D facilities and knowledge creation over multiple foreign locations. For instance, an MNC may be less able to reap economies of scale and scope when R&D activities are spread over many locations (e.g., Argyres et al., 2020; Belderbos et al., 2013). Moreover, there are pertinent managerial challenges to the model of global R&D organization, which places high demands on the international coordination abilities of the MNC. Coordination of the MNC's R&D facilities – with its headquarters, business units, and marketing and manufacturing operations – is increasingly challenging and costly when R&D operations are dispersed over diverse locations. This R&D organization requires intensive communication between researchers across units to achieve effective knowledge transfer because the knowledge to be transferred contains tacit elements (Gupta and Govindarajan, 2000; Meyer and Mizushima, 1989; Nobel and Birkinshaw, 1998; Almeida and Phene, 2004). Effective communication necessitates face-to-face interaction, and so proximity and centralization are key. In the case of R&D dispersion, firms are obliged to engage in costly international R&D management practices, such as international personnel mobility and co-practice, so as to facilitate effective cross-border knowledge flows (Belderbos et al., 2013; Frost and Zou, 2005; Singh, 2008; Lahiri, 2010). Even when an international R&D organization is in place, the required transfer and integration of knowledge across units does not always happen (Gupta and Govindarajan, 2000; Kogut and Zander, 1993; Fang et al., 2013). In practice, foreign affiliates often have to fight to win "legitimacy" and recognition of their capabilities in the broader R&D network of the MNC (Keupp et al., 2011; Mudambi and Navarra, 2004).

The studies reviewed above make it clear that the relationship between international R&D dispersion and firm innovation performance is complex and crucially depends on a number of contingencies. In this paper, we therefore propose an integrated framework that takes into account a range of organizational and environmental contingencies that are likely to affect the advantages and disadvantages of international R&D dispersion. Drawing on the knowledge-based view of the MNC (Grant, 1996; Kogut and Zander, 1993; Almeida et al., 2002), we distinguish between knowledge-sourcing advantages related to the technological strengths of foreign R&D locations and the knowledge-integration capabilities of the MNC, as well as the knowledge-dispersion disadvantages from economies of scale in R&D and economies of scope in diversified technology portfolios. Fig. 1 illustrates our conceptual framework.

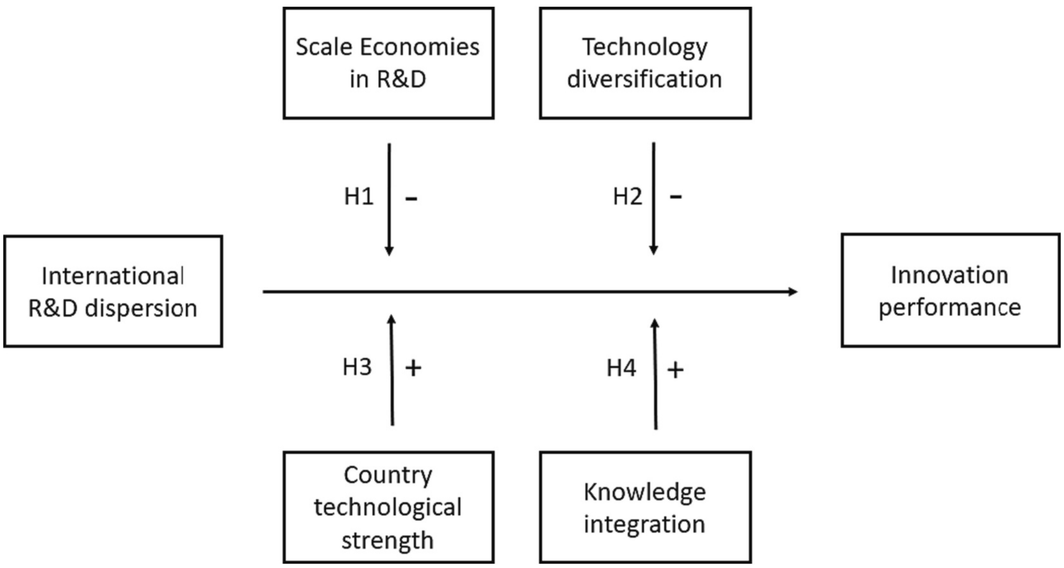

Fig. 1. Conceptual framework.

2.1. Knowledge creation and economies of scale in R&D

A central tenet of the knowledge-based view is that knowledge creation is a cumulative process in which firms embark on path-dependent knowledge-creation trajectories that build on prior accumulated capabilities and expertise (Stuart and Podolny, 1996; Leten et al., 2016; Regner and Zander, 2014). A key implication is that centralizing firms' knowledge-creation activities – rather than dispersing them globally across different units – may bring benefits in terms of knowledge creation, especially in technology domains that are characterized by large economies of scale in knowledge creation. Economies of scale play an important role in determining the productivity of firms' knowledge-creation activities. R&D activities are characterized by substantial scale economies (Kuemmerle, 1998; Ambos, 2005; Perrino and Tipping, 1991). A main source of scale economies is the indivisible nature of R&D inputs. It is more efficient for a firm to fully utilize indivisible assets, such as research equipment, research teams, and talented personnel, at a large central laboratory rather than at widely dispersed small-scale R&D sites (Pearce, 1999; Herschey and Caves, 1981; Hewitt, 1980). By centralizing research teams in a large laboratory, firms can stimulate interaction and knowledge spillovers between research teams and improve the effectiveness of R&D (Kuemmerle, 1998). When scale economies in their R&D activities are large, firms need to organize these activities in sufficiently large laboratories to achieve the minimum efficient scale (Perrino and Tipping, 1991). Empirical evidence on the organization of R&D has suggested that firms can benefit from conducting R&D in fewer locations, with a consequent reduction in transaction costs (Argyres and Silverman, 2004; Argyres et al., 2020). Centralization of R&D allows the MNC to spread the high cost of specialized equipment and human capital and to reach the critical mass needed to efficiently utilize these resources (Poppo, 2003).

The extent to which R&D is characterized by economies of scale differs across technology domains and industries. In his study of pharmaceutical and electronics firms, Kuemmerle (1998) found that the optimal laboratory size is larger for electronics than for pharmaceutical firms. He attributed this finding to differences in the nature of R&D in these industries. While pharmaceutical R&D focuses on the discovery and testing of single molecules, R&D in the electronics industry is geared to the creation of complex products that consist of numerous components. The complexity of electronic products calls for a greater critical mass of researchers at one location. Furthermore, Ambos (2005) observed that the (optimal) size of R&D laboratories differs across industries, with R&D-intensive industries (semiconductors, electronics, pharma, and automobiles) operating much larger R&D laboratories than less R&D-intensive industries (chemicals and machinery). This implies that firms that are active in scale-intensive technology domains benefit most from centralization of R&D activities and are more likely to experience negative repercussions from spreading their activities over various foreign locations. It will be less effective for these firms to expand their R&D to new laboratories without fully utilising the assets and personnel of existing R&D sites (Pearce, 1999; Herschey and Caves, 1981; Hewitt, 1980; Perrino and Tipping, 1991). This leads to the following hypothesis:

Hypothesis 1. The association between international R&D dispersion and innovation performance is negatively moderated by the extent to which scale economies are present in the MNC's technology portfolio.

2.2. Knowledge recombination and economies of scope in R&D

Knowledge recombination is considered another important process in the knowledge-based view (Grant, 1996; Kogut and Zander, 1992). By recombining knowledge elements in novel ways – either created internally or sourced externally – firms can innovate (Fleming, 2001; Hargadon and Sutton, 1997) and build up a competitive advantage (Grant, 1996). The process of knowledge recombination requires knowledge diversity and achieving economies of scope in R&D from knowledge cross-fertilization and resource sharing in different technological fields (Henderson and Cockburn, 1996; Leten et al., 2007; Belderbos et al., 2013). Cross-fertilization takes place more easily when knowledge-creation activities in different technology fields are centralized (Argyres, 1996; Argyres and Silverman, 2004; Argyres et al., 2020; Geerts et al., 2018). A case in point is Bell laboratories, where diverse research activities were placed in the same building, employing open door policies and creating serendipitous interaction and cross fertilization of ideas (Gertner, 2012). In contrast, coordination and integration of R&D activities become increasingly difficult and costly when they are conducted in different locations. R&D is an activity that requires a high level of communication between the parties involved, and efficient communication often necessitates face-to-face interaction (e.g., Nobel and Birkinshaw, 1998; Rabbiosi, 2011).

Technologically diversified firms are well positioned to benefit from scope economies in R&D. There are various sources of scope economies, such as the joint use of specialized equipment, the establishment of common technology platforms, and interdisciplinary interaction leading to synergies in technology development (Belderbos et al., 2013). Firms that have built up cumulative capabilities in a range of technology domains are uniquely positioned to benefit from knowledge recombination by achieving knowledge spillovers across domains and developing innovations that combine different domains (Henderson and Cockburn, 1996; Argyres and Silverman, 2004; Leten et al., 2007; Suzuki and Kodama, 2004; Nesta and Saviotti, 2005). Innovations that combine different technology domains in novel ways are more likely to become technological breakthroughs (Verhoeven et al., 2016; Pezzoni et al., 2022). However, given the importance of personal knowledge exchange, achieving knowledge exchange at low coordination costs is best achieved by collocating R&D activities in diverse technology domains in a limited number of (central) R&D facilities (Argyres, 1996; Argyres et al., 2020; Kuemmerle, 1998). Centralization of R&D activities, rather than international dispersion, provides the flexibility to respond to the specific needs of R&D more easily and efficiently. This is achieved by leveraging the central unit's diverse cumulative pool of knowledge, technological know-how, and infrastructure (Argyres and Silverman, 2004). This increases the recombination potential of R&D in diverse technology domains and facilitates the transition of new ideas into the later stages of development and commercialization (Kogut and Zander, 1993; Argyres et al., 2020).

In conclusion, firms with a diversified technology portfolio and the potential to realize economies of scope are most likely to benefit from centralization of their R&D activities and experience disadvantages from dispersing R&D. This leads to the following hypothesis:

Hypothesis 2. The association between international R&D dispersion and innovation performance is negatively moderated by the level of technological diversification of the MNC's technology portfolio.

2.3. Knowledge sourcing and technological strengths abroad

An important attention point in the knowledge-based view concerns access to external knowledge (Foss et al., 2013; Kogut and Zander, 1993). MNCs seek to locate firm activities in order to maximize knowledge from external sources. By placing activities in locations that abound with knowledge, firms can create a competitive advantage by combining firm-specific knowledge advantages with location-specific advantages (Narula and Verbeke, 2015). The benefits of international R&D and knowledge sourcing in foreign locations will depend on the host country environment and, in particular, the technological strengths of the host countries where firms conduct their R&D activities. Knowledge-sourcing advantages of local R&D are most likely in countries with technological advantages in domains that are relevant to the firm (e.g., Ambos and Ambos, 2011; Chung and Alcácer, 2002; Kuemmerle, 1999). Countries follow distinct knowledge development trajectories and specialize in specific technologies (Cantwell, 1989). This specialization is the result of a number of influences, such as differences between countries in resource endowments, culture, institutional factors, demand and supply conditions, and the scientific and regulatory environment (Phene et al., 2006). Prior research has shown that MNCs are influenced by countries' technological specialization and strength when making location choices for foreign R&D activities (Patel and Vega, 1999; Belderbos et al., 2017) and that local knowledge sourcing by foreign affiliates is a function of the strength of technological capabilities in the host country (Scott-Kennel and Giroud, 2015; Song et al., 2011; Song and Shin, 2008). In locations with substantial R&D capabilities and a large stock of relevant knowledge in technical disciplines, firms have greater opportunities to source relevant external technological knowledge, to find valuable partner firms or organisations to conduct joint R&D activities, and to hire talented and experienced scientists and engineers for their R&D laboratories (Almeida and Phene, 2004; Iwasa and Odagiri, 2004; Griffith et al., 2006; Belderbos et al., 2015; Lewin et al., 2009). This leads to the following hypothesis:

Hypothesis 3. The association between international R&D dispersion and innovation performance is positively moderated by the technological strength of the host countries in which the MNC conducts R&D activities.

2.4. Intra-firm knowledge integration

In the knowledge-based view, MNCs are considered superior organizational vehicles to transfer and integrate knowledge across geographic borders (Kogut and Zander, 1993; Almeida et al., 2002). This is especially the case when knowledge is tacit in nature and difficult to codify. Effective transfer of locally sourced knowledge within the MNC network is an important condition to reap the full benefits from dispersed R&D activities. When knowledge that is sourced and developed locally across different R&D locations is transferred within the MNC and recombined with the existing knowledge base, there is potential for innovation (Belderbos et al., 2015; Penner-Hahn and Shaver, 2005; Faems et al., 2020). The ability of the MNC to effectively transfer and integrate knowledge across borders can be seen as an essential capability from which it can derive competitive advantage (Kogut and Zander, 1992, 1993). International management studies have identified that knowledge integration of globally dispersed R&D activities by the MNC is a key success factor in international R&D (Singh, 2008).

The organizational setting of the MNC stimulates intra-firm knowledge transfers and integration because subsidiaries share common organizational goals, a common organizational culture, and similar working practices (Gomes-Casseres et al., 2006). Nevertheless, knowledge transfers between different R&D sites across borders may be hindered by obstacles such as geographic, cultural, and temporal distances (Ambos and Ambos, 2009; Sosa et al., 2002; Allen, 1977). Firms may undertake various activities to overcome these barriers to communication and to improve the efficiency of the intra-firm international knowledge transfer network. MNCs can implement coordination mechanisms, such as knowledge management systems, liaison personnel, information meetings, rotating firm personnel and joint R&D activities to stimulate knowledge exchange across subsidiaries (Ambos and Ambos, 2009; Gupta and Govindarajan, 2000; Singh, 2008; Frost and Zou, 2005). Moreover, MNCs can adopt human resource practices, such as financial compensations and promotions, to stimulate international knowledge transfers (Andersson et al., 2015; Song, 2014). Those MNCs that have succeeded in arranging effective cross-border intra-firm knowledge transfers are more likely to benefit from international knowledge sourcing and knowledge recombination derived from dispersed R&D activities. We hypothesize:

Hypothesis 4. The association between international R&D dispersion and innovation performance is positively moderated by intra-MNC knowledge integration.

3. Data and methods

To investigate the innovation performance and R&D internationalization of firms, we utilize a panel dataset from the R&D and patent activities of the 175 largest (international) R&D spending European, US, and Japanese firms in five different industries: pharmaceuticals and biotechnology, IT hardware, electronics and electrical machinery, chemicals, and non-electrical machinery. The sample firms are selected as top R&D spenders in their sectors and countries based on the 2004 EU Industrial R&D Investment

Scoreboard. Patent datasets of firms are constructed at the consolidated level – that is, all patents of the parent firm and its consolidated (majority-owned) subsidiaries are considered. The consolidation was conducted on a yearly basis to take into account frequent changes in the group structure of the sample firms due to acquisitions, mergers, green-field investments, and spin-offs. Patent data are taken from the European Patent Office (EPO). The sample firms filed for approximately 30 % of all patent applications at the EPO. A significant share of these patents (25.3 %) originated from foreign R&D activities. The advantage of the panel dataset is the broad sample of firms across different technology-intensive industries and home countries, allowing us to test for the consequences of differences in scale and scope economies, host country technology advantages, and intra-MNC knowledge integration on the relationship between R&D international dispersion and firms' innovation performance. A disadvantage of the panel dataset is that the period for which we have full information is restricted to 1996–2002, and we have no means of updating it. We discuss this limitation in the concluding section of the paper. Overall, we have 1118 observations from 175 firms.[1]

Patent data have the advantage of being easy to access and of containing detailed information on the technological content, owners, and inventors of patented inventions. At the same time, they have shortcomings. For instance, not all inventions are patented, and patent propensities vary across industries and firms (Basberg, 1987; Griliches, 1990). However, this concern may be mitigated by the fact that patent propensities in the industries we examined are relatively high (Arundel and Kabla, 1998). Given the novelty element that patents require, patent-based indicators of foreign R&D are perhaps more likely to represent foreign research activities than foreign development activities directed at local adaptation. In the context of our research on foreign R&D, a disadvantage is that patents are a form of "intermediate output" of the R&D process rather than an input measure. Patent counts differ not only because of differences in the scale of R&D operations but also because of differences in R&D productivity. Despite these drawbacks, patents are extensively used as indicators of the location of inventive activities (Patel and Vega, 1999; Guellec and Van Pottelsberghe, 2001; Le Bas and Sierra, 2002; Cantwell and Piscitello, 2005; Branstetter and Kwon, 2004; Allred and Park, 2007; Belderbos et al., 2013). The reason for their widespread use is that systematic data (certainly at the firm level) on R&D expenditures by location are not collected or are not generally available for analysis.

Address information of patent inventors are used to determine the country of origin of patented inventions and to calculate the indicator of the level of international R&D dispersion of firms (Belderbos et al., 2013; Lahiri, 2010; Singh, 2008). Inventor addresses give a much more accurate indication of patents' geographic origins than company addresses because firms tend to register the headquarter address with the patent office instead of the address of the subsidiary or unit where the invention originated (Deyle and Grupp, 2005; Khan and Dernis, 2006). If a patent lists several inventors based in more than one country, we assigned the patent to each country in part, based on a fractional count logic. We examined the international dispersion of R&D activities across 40 countries, including all major developed countries globally and the larger and more R&D-intensive developing and emerging economies in South-East Asia, Latin America, and South Africa. The 40 countries were selected on the basis of having a minimum level of technological activity (50 patents) over the period 1995–2002, so that we could realistically observe R&D activities based on patent data in individual countries.

3.1. Dependent variable and methodology

To measure the innovation performance of the sample firms in a particular year, we count the number of patent applications by a sample firm in the year, weighted by the number of forward patent citations that are received by the patents over a fixed time window of 4 years.[2] The "weighting" by forward citations allows us to control for variation in the technological and economical importance of patented inventions (Harhoff et al., 1999; Hall et al., 2005; Lahiri, 2010). Empirical evidence has shown significant correlation between forward citations of a patent and the value of the underlying invention (e.g., Chiou et al., 2016).

Since the dependent variable only takes non-negative integer values, a negative binomial count data model is estimated to relate the dependent variable to the explanatory variables. We employ this model rather than a Poisson model because the negative binomial model accommodates the existence of overdispersion in the distribution of the dependent variable. A *t*-test examining the assumption of the Poisson model that the variance of the dependent variable equals its mean (Cameron and Trivedi, 2005) rejected the null hypothesis of no overdispersion at the 1 % level and, hence, rejected the assumptions of the Poisson model.

To control for the impact of unobserved firm-specific characteristics that may correlate with and bias the effect of explanatory variables, firm fixed effects panel data analyses are performed. We include a full set of firm dummies to model these as affecting the conditional mean rather than the conditional fixed effects that enter the variance term in the conventional negative binomial fixed effects model (Allison and Waterman, 2002).[3] We conducted a Hausman test to determine whether a fixed effect model was preferable to a random effects model. The test rejected the random effects model at the 1 % level and, therefore, we adopted the fixed effect specification. Our analyses use robust standard errors that correct for heteroskedasticity.

We performed unit root tests to ensure that our data are stationary (Hsiao et al., 2012; Roberts and Whited, 2013). A Fisher type (Phillips-Perron) unit root test rejected the null hypothesis that the panel contains unit roots, with an inverse Chi-square test statistic of 528.71 ($P < 0.0001$). Lagged versions of the test gave similar results. In order to reduce potential cross-sectional dependence among firms based in the same region (e.g., Pesaran, 2015), we have augmented our models with region-specific time effects, interacting year

[1] The dataset is not fully balanced because some firms did not exist in all years (e.g., AstraZeneca was only created in 1999 as a result of a merger between Astra AB and Zeneca Group PLC), and there are a number of instances of missing data on R&D expenditures.

[2] We obtain similar results when citation-weighted granted patents are used as the dependent variable.

[3] We note that any industry fixed effects are fully subsumed in the firm fixed effects.

dummies with dummies for Japan, the US, and Europe. We applied Pesaran's CD test for weak cross-sectional independence, as the LM test has been shown to over-reject in nonlinear models with small T (Hsiao et al., 2012). The CD test is applicable to unbalanced panel data with a short time dimension. Recent work by Juodis and Reese (2022), however, shows that the CD test diverges if it is applied to residuals of panel models with periodic-specific coefficients, as is the case in our models. Hence, we apply the CDW version of the test with observations weighed by Rademacher weights, which take on the values of 1 or − 1 with equal probability. Juodis and Reese (2022) claim that the test can also be utilized in nonlinear models, such as count data. We use repeated draws of the Rademacher weights to ensure robustness. Using the XTCD2 command from Juodis and Reese (2022) with 50 replications, the test statistic is 0.283 ($p = 0.777$), suggesting that the null hypothesis of weak cross-sectional dependence cannot be rejected. To examine the moderating effects of the environmental and organizational factors on the relationship between international R&D dispersion and innovation performance, we include interaction effects between international R&D dispersion and the moderating variables.

3.2. Focal explanatory variables

The variable of interest is the level of *international dispersion* of the MNC's *R&D* activities. Following prior work by Singh (2008) and Lahiri (2010), this variable is measured as the inverse of the Herfindahl index of the geographic distribution of firms' inventive activities over countries.[4] Formally, this is calculated as: *International R&D Dispersion* $= 1 / \Sigma_i (n_i/n)^2$, where n is the total number of patents in a firm's five-year prior patent portfolio, and n_i refers to the subset of firm patents that have been invented in country i. This index takes larger values when firms' R&D activities are spread more equally over a larger number of countries.

The importance of *scale economies in* the *R&D* activities of a firm (Hypothesis 1) is measured as the weighted average level of scale economies characterizing the technologies that are present in the firm's five-year prior patent portfolio. The level of scale economies in a technology field is measured by the observed share of large R&D laboratories in a technology field, based on the premise that scale-intensive R&D activities are undertaken in large laboratories.[5] Data on scale economies of technologies are available for six technology domains (Ambos, 2005). We distinguish these technology domains in the firms' patent portfolios by classifying patents into these six groups (chemistry, pharmaceuticals, machinery, electronics, semiconductors, and telecommunications) using the ISI-INPI-OST technology classification (OECD, 1994) and the technology classification in Schmoch et al. (2003). For these six domains, data on the laboratory size is available from surveys conducted by Ambos (2005). Prior studies suggest that a laboratory size of 50–100 employees is a minimum for effective R&D, although there are differences across disciplines in optimal laboratory size (Perrino and Tipping, 1991). Kuemmerle (1998) suggests that the optimal size of R&D laboratories abroad ranges from 167 to 256 employees. We follow Belderbos et al. (2013) in taking a threshold of 200 employees to define a large R&D laboratory, with the share of large laboratories acting as our indicator of scale economies. The share of large R&D laboratories in the laboratory size data of Ambos (2005) is highest in the semiconductor field (50 %) and lowest in the chemical industry (6 %). At the firm level, the economies of scale in the R&D variable is the weighted average of the share of large laboratories variable, with the share of the firm's five-year prior patent portfolio in each of the six technology domains taken as weights.[6]

The level of *technology diversification* of a firm's technology portfolio as an indicator of potential economies of scope (Hypothesis 2) is measured as the spread of patents in the firm's five-year prior patent portfolio over technology fields. Here, we can distinguish the 30 more detailed technology fields of the ISI-INPI-OST technology classification (OECD, 1994). The technology diversification variable is calculated as the inverse of the Herfindahl index of concentration of the firm's five-year prior patent portfolio in the 30 technology classes. The variable takes larger values when the technology portfolio of a firm is more diversified.

The *technological strength of host countries* (Hypothesis 3) is constructed as the average relevant technological strength across host countries in which a firm conducts R&D activities, weighted by the share of the R&D (inventive) activities of the firm in each host country. The host country's relevant technological strength is measured by the world share of patents invented in the host country in the relevant technology fields to the firm's main industry. The relevance of the technology fields of host country patents to the firm's industry is determined by the concordance table linking technology classes to the industries provided in Schmoch et al. (2003).

The effectiveness of the firm's intra-firm international *knowledge integration* network (Hypothesis 4) is measured by a firm's patent self-citations, following the prior work of Frost and Zou (2005) and Singh (2008). The variable is constructed as the average frequency by which the patents in a firm's five-year prior patent portfolio that are invented abroad cite its patents invented at home and vice versa. The number of self-citations is scaled by the number of the firm's patent applications invented in both home and host countries.

All explanatory variables are lagged by one year to allow for a proper time ordering. All the continuous explanatory variables that constitute the interaction terms are mean centered.

[4] This measurement appears little affected by the way we calculate it. A measure based on triadic patents (patents filed in Europe, the U.S., and Japan) is >90 % correlated with our EPO-based variable.

[5] We note that our focus, both theoretically and empirically, is on research units, or combined research and development units, rather than on units deploying mere development activities (e.g., integrated manufacturing and development units). Patent-based measures of scale and scope economies of R&D units are less reflective of development activities, which are often less likely to produce patentable inventions.

[6] We note there is considerable variation in the level of scale economies even between firms that have their main activity in the same industry, due to firms' heterogeneous technology portfolios. For instance, the highest value of the scale economies variable for firms with their main activity in the chemical industry is 25 % while the lowest value is 6 %. For firms in the semiconductor industry, this range is 25 %–50 %.

3.3. Control variables

We control for time-variant firm characteristics that might affect innovation performance, beyond the main effects of the focal variables. We control for *firm size* by including the value of the firm's sales (in logarithmic transformation). Moreover, we control for a firm's *research and development (R&D) intensity* (R&D over sales) because innovation performance is influenced by the amount of money invested in R&D (Pakes and Griliches, 1984). Sales and R&D expenditures are measured in constant U.S. dollars (millions), and both are collected from corporate annual reports, Worldscope and Compustat. We also include an indicator of a firm's patenting propensity and existing technology base, measured by a firm's five-year prior patent stock.

Summary statistics and correlations of the variables are provided in Table 1. These statistics are based on the original values of the variables before mean centering for easier interpretation, while the mean-centered values actually used in the analysis are included in the correlations. The average level of international R&D dispersion is 1.80, meaning that the average firm has foreign R&D activities of equal size in slightly fewer than two countries. The correlation table indicates no multicollinearity concerns. The average variance inflation factor (VIF) of the control variables is 1.71, well below the recommended cut-off values of 5 or 10.

4. Results

Table 2 reports results of the fixed effects panel negative binomial regression analyses relating MNCs' innovation performance to the international dispersion of R&D under different environmental and organizational contingencies. Model 1 includes only the control variables and the main effects of the hypothesis-testing variables and serves as a reference case for the other models. In Model 2, the international dispersion of firms' R&D is added. Subsequently, each moderator variable testing one of the four hypotheses is included separately in models 3 to 6. Finally, all moderator variables are included jointly in model 7.

In model 1, technology diversification, country technological strength, and R&D intensity show significant and positive coefficients. This indicates that R&D-intensive firms that operate with a diversified technology portfolio and a strong technology base in their host countries have a better innovation performance. The firm-level patent stock controlling for patent propensity does not have a significant association with innovation performance, perhaps because the industries in our sample are all relatively patent intensive. Nor is firm innovation performance systematically associated with firm size.

In model 2, the focal international R&D dispersion variable has a positive coefficient but is insignificant, suggesting an overall insignificant association between R&D internationalization and innovation performance without taking into account contingencies. In models 3 to 6, we find a significant negative moderating coefficient for scale economies in R&D in support of Hypothesis 1. Yet, the coefficient on the moderation by technology diversification is positive rather than negative, rejecting Hypothesis 2. The coefficient on the moderation effect of host country technology strength is positive and (weakly) significant (10 % level), providing qualified support for Hypothesis 3. The moderation by knowledge integration is positive and significant, in support of Hypothesis 4. In model 7, when the hypothesis testing variables are simultaneously included, we obtain full statistical support (1 % level) for Hypothesis 3 on the positive moderation effect of host country technology strength. This, and the significant likelihood ratio test statistic, show the importance of taking an integrated approach and estimating a fully developed contingency model of the performance effects of R&D internationalization.

The magnitude of the influence of the moderator variables on the relationship between international R&D dispersion and firms' innovation performance is shown in Table 3. The numbers represent the proportional change in innovation performance due to a standard deviation increase in international R&D dispersion for various levels of the moderator variables. The calculations are based on the coefficients of model 7, and all other variables are kept at the sample mean except for the focal moderating variable. The implied association between international R&D dispersion and innovation performance depends substantially on the environmental and organizational contingencies. An increase in international R&D dispersion by one standard deviation increases the innovation performance of firms with weak scale economies in their technology base by 32.9 %, whereas the performance of firms with strong scale economies in their technology portfolio is decreased by 10.8 %. Similar but smaller differences are found for the other moderator variables. An increase in international R&D dispersion increases the performance of firms with low and high diversified technology portfolios by 1.5 % and 20.6 %, respectively. If firms operate R&D units in host countries lacking technological advantages, international R&D dispersion is negatively associated with innovation performance (−4.5 %), whereas this association is strongly positive

Table 1
Descriptive statistics and correlations.

		Mean	Std. Dev.	1	2	3	4	5	6	7	8
1	Innovation Performance	125.32	237.13								
2	International R&D Dispersion	1.80	0.93	−0.03							
3	Scale Economies in R&D	23.84	10.08	**0.14**	**−0.22**						
4	Technology Diversification	5.06	2.68	**0.10**	**−0.08**	**−0.37**					
5	Country Technological Strength	0.19	0.09	0.04	**−0.44**	**0.23**	0.02				
6	Knowledge Integration	0.02	0.03	0.05	**0.22**	0.00	−0.04	**−0.06**			
7	Sales	15.35	1.37	**0.52**	−0.01	**−0.12**	**0.39**	**0.15**	0.03		
8	R&D Intensity	0.09	0.25	−0.02	**−0.07**	**0.26**	**−0.14**	**0.17**	−0.01	**−0.36**	
9	Firm Patent Stock	0.56	1.01	**0.77**	0.00	**0.09**	**0.20**	0.03	0.03	**0.57**	−0.03

Notes: significant correlations (5 % level) in bold.

Table 2
The relationship between the international dispersion of R&D Activities and firms' innovation performance.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
International R&D Dispersion		0.0640	0.0040	0.0796	0.1484*	0.0591	0.1188
		(0.0624)	(0.0640)	(0.0612)	(0.0825)	(0.0628)	(0.0765)
R&D Disp. * Scale Economies in R&D			−0.0202***				−0.0232***
			(0.0057)				(0.0059)
R&D Disp. * Technology Diversification				0.0613***			0.0381**
				(0.0154)			(0.0152)
R&D Disp. * Country Technological Strength					1.3481*		1.9586***
					(0.7830)		(0.7250)
R&D Disp. * Knowledge Integration						1.3933**	2.1354***
						(0.6494)	(0.7222)
Scale Economies in R&D	0.0104	0.0109	0.0116	0.0142	0.0100	0.0091	0.0095
	(0.0137)	(0.0136)	(0.0140)	(0.0140)	(0.0133)	(0.0136)	(0.0138)
Technology Diversification	0.0534*	0.0502*	0.0393	0.0409	0.0497*	0.0498*	0.0310
	(0.0297)	(0.0300)	(0.0292)	(0.0293)	(0.0293)	(0.0300)	(0.0284)
Country Technological Strength	2.4935**	2.8159**	2.6615**	2.7853**	3.4532***	2.6747**	3.3230***
	(1.2513)	(1.2696)	(1.2464)	(1.2300)	(1.2339)	(1.2683)	(1.1870)
Knowledge Integration	0.4238	0.2487	0.6199	0.1573	0.0653	−0.2151	−0.3453
	(0.9267)	(0.9532)	(1.0021)	(0.9299)	(0.9521)	(1.0189)	(1.0636)
Sales	0.0385	0.0386	0.0491	0.0344	0.0384	0.0516	0.0661
	(0.0939)	(0.0942)	(0.0929)	(0.0933)	(0.0938)	(0.0944)	(0.0928)
R&D Intensity	0.3274***	0.3272***	0.3582***	0.3427***	0.3163**	0.3253***	0.3534***
	(0.1244)	(0.1243)	(0.1309)	(0.1274)	(0.1243)	(0.1213)	(0.1288)
Firm Patent Stock	−0.0194	−0.0164	−0.0158	−0.0109	−0.0186	−0.0101	−0.0058
	(0.0366)	(0.0372)	(0.0365)	(0.0367)	(0.0365)	(0.0375)	(0.0352)
Region-Year Dummies	Included	Included	Included	Included	Included	Included	Included
Firm Fixed Effects	Included	Included	Included	Included	Included	Included	Included
Constant	−0.2106	−0.1974	−0.4994	−0.2431	−0.1205	−0.4084	−0.7614
	(1.4888)	(1.4921)	(1.4649)	(1.4729)	(1.4867)	(1.4966)	(1.4570)
Observations	1118	1118	1118	1118	1118	1118	1118
Firms	175	175	175	175	175	175	175
Log Likelihood	−4748.89	−4748.31	−4741.24	−4740.72	−4746.61	−4746.64	−4730.24
LR Test against Model 2			14.14***	15.19***	3.41*	3.35*	36.14***
Pseudo R2	0.2468	0.2468	0.2480	0.2481	0.2471	0.2471	0.2497

Notes: Results negative binomial models with firm fixed effects. Robust standard errors in parentheses. * = $p < 0.1$, ** = $p < 0.05$, *** = $p < 0.01$.

Table 3
Proportional increase in firms' innovation performance due to an increase in international R&D dispersion for different levels of moderator variables.

Moderating Variable:	Low	High
Scale Economies in R&D	32.9 %	−10.8 %
Technology Diversification	1.5 %	20.6 %
Host Country Technological Strength	−4.5 %	26.7 %
Knowledge Integration	4.1 %	18.0 %

Notes: increases due to a standard deviation increase in R&D dispersion. Low (high) values of moderators represent a standard deviation below (above) the mean value.

(26.7 %) for R&D in top locations. The respective associations between innovation performance and international R&D dispersion are 4.1 % and 18.0 % for MNCS with low and high knowledge integration.

Supplementary Analyses.

We conducted a number of supplementary analyses to examine the robustness of our findings. First, we explored whether the inclusion of quadratic effects of international R&D dispersion would be consequential, but we saw no evidence of a curvilinear relationship. Second, we conducted an analysis with a simple patent count rather than the citation-weighted count as dependent variable and found qualitatively similar results. Third, we examined whether European firms experience different R&D benefits than US and Japanese firms. Although our models already accommodate the idiosyncratic behaviour of European firms by incorporating firm fixed effects and a set of year dummies that are region specific, European firms have the opportunity to invest in R&D abroad in nearby countries, whereas this is less the case for US firms and Japanese MNCs. On the one hand, this may mean that dispersed R&D units are more easily coordinated, increasing the advantages of international R&D but, on the other hand, that geographic proximity is associated with reduced underlying variety in innovation approaches, which may limit potential innovation benefits. The net differences may be ambiguous because MNCs differ in the degree to which they focus on Europe in their R&D internationalization. In analysing this further, we observe that the average share of foreign R&D conducted in Europe is actually quite similar for European and non-European firms, given that Europe is a prime foreign R&D location for US and Japanese firms. Moreover, there is substantial variation in the importance of Europe as a destination for foreign R&D within each group. These observations may suggest that distinguishing firms solely by their home country is not likely to lead to different findings related to their proximity to European countries. Indeed, when we allow the focal variables to have different coefficients for European firms, no significant differences are observed apart from a marginally significant smaller moderation effect of technological diversification. Perhaps this finding is in line with the lack of variety explanation.

5. Discussion and conclusion

In this paper, we examined the relationship between the international dispersion of R&D activities and MNC innovation performance in a sample of 175 R&D and patent-intensive European, American, and Japanese firms active in five high-tech industries. Inspired by the prior literature on R&D internationalization and the knowledge-based view of the MNC (Kogut and Zander, 1993; Almeida et al., 2002), we proposed an integrated framework of the environmental and organizational contingencies driving this relationship. From this, we developed hypotheses on the knowledge-sourcing advantages of international R&D. These involved the technological strength of host countries where foreign R&D is performed, the positive consequences of the MNC's knowledge-integration capabilities, and the potential knowledge-creation and recombination disadvantages of R&D dispersion related to loss of economies of scale in R&D and economies of scope in diversified technology portfolios.

The empirical results suggest that the relationship between international dispersion of R&D and innovation performance crucially depends on a number of organizational and environmental contingencies. MNCs benefit to a much greater extent from an internationally dispersed R&D base when they locate their activities in countries with a strong technology base in their focal technology domains. Furthermore, the benefits of international R&D are enhanced if the MNC has effective cross-border knowledge-integration practices in place, with efforts made to source, transfer, and utilize knowledge sourced abroad across all units of the MNC. Against our expectations, a firm's technological diversity enhances the positive consequences of R&D dispersion. On the other hand, firms benefit less from R&D internationalization if scale economies are important in the MNC's technology portfolio.

We found no support for our hypothesis that the benefits of international R&D dispersion are lower for firms with a diverse technology portfolio. Our reasoning was that such firms could benefit from economies of scope by jointly pursuing R&D activities in different technology domains in central R&D laboratories at home (Argyres, 1996; Argyres et al., 2020; Belderbos et al., 2013). However, the benefits of international R&D dispersion appear greater for firms with diversified technology portfolios. One possible explanation is that technologically diversified firms require a variety of good locations for their technology development, given the technological specialization of countries and their local innovation clusters (Cantwell, 1989; Phene et al., 2006). Indeed, they may require wider technology search across locations to maintain their technological diversity (Berry, 2014). Furthermore, technologically diversified firms may be better positioned to benefit from locally sourced knowledge in foreign R&D subsidiaries because of the greater potential offered by their diversified technology portfolio to recombine new and existing knowledge into new innovations. Greater technological diversity increases the likelihood that newly sourced knowledge will relate to some of the firm's existing knowledge, given its extensive range of recombination possibilities (Lahiri, 2010). Moreover, this will increase the likelihood that firms can create novel combinations of knowledge elements with the potential to become technological breakthroughs (Verhoeven et al., 2016).

The positive consequence of technological diversification for the relationship between innovation performance and international R&D dispersion provides a new insight for the literature on international R&D, which has tended to emphasize the negative consequences – for instance, in terms of foregone scope economies (Belderbos et al., 2021; Lahiri, 2010). The notion that technological diverse firms can effectively combine such diversity with geographically diverse R&D units also offers a new insight for the literature on the knowledge-based view of the MNC (Kogut and Zander, 1993. Almeida et al., 2002; Foss et al., 2013). Geographic diversity and technological diversity can strengthen each other in the efforts by MNCs to source, recombine, and exploit knowledge. While technological and geographical diversification are often regarded as alternative growth strategies for knowledge-intensive firms (Penrose, 1959; Cantwell and Piscitello, 2000), our study shows that these two strategies are complements rather than substitutes.

Scale economies prove to be the most consequential factor of our framework in determining whether or not international R&D improves innovation performance. This factor has not received much explicit attention in prior studies on the performance effects of international R&D. By highlighting the role of scale economies in R&D, our study contributes to the literature on the advantages and disadvantages of centralized R&D structures (Leiponen and Helfat, 2011; Argyres and Silverman, 2004; Argyres et al., 2020; Belderbos et al., 2013). While prior work has referred to centralization advantages, such as reducing internal transaction costs (Argyres and Silverman, 2004) and improving inventor connections (Argyres et al., 2020), we refer to the role of scale economies in the technology domains where firms are active. We demonstrate that scale economies strongly reduce the potential benefits of international R&D dispersion. The dominant approach in the knowledge-based view of the MNC is that all would do well to explore new sources of knowledge outside their existing environments and increase the breadth of search and opportunities for cross-fertilization (Leiponen and Helfat, 2011; Nieto and Rodriguez, 2011; Foss et al., 2013). However, our study emphasizes that the costs of geographic dispersion and wider search must form part of the design consideration of an MNC's global R&D organization, and that such costs differ significantly between technology domains.

Overall, our empirical results demonstrate that the relationship between international R&D dispersion and firm innovation performance is complex. Consequently, reliable inferences can only be derived if all relevant contingencies are taken into account. This supports our suggested approach of developing an integrated model to bring out all contingencies, rather than adopting the partial approaches that have been characteristic of most prior studies. This is an important insight that we contribute to the stream of literature on the performance effects of international R&D (Belderbos et al., 2008; Iwasa and Odagiri, 2004; Penner-Hahn and Shaver, 2005; Todo and Shimizutani, 2008; Griffith et al., 2006; Belderbos et al., 2015; Kafouros et al., 2012; Lahiri, 2010; Tojeiro-Rivero, 2022; Hsu et al., 2015; Hurtado-Torres et al., 2018; Ferraris et al., 2021).

Our study informs managers on the conditions under which firms can benefit from international R&D dispersion, such as locating international R&D in countries with technological advantages in domains that are relevant to the firm, creating an organizational setting in which knowledge transfer and integration is stimulated and supported, and investing in a diverse technology portfolio that facilitates knowledge recombination and innovation. However, creating such conditions requires firms to undertake substantial investment in technology portfolio development, and to screen foreign R&D locations and implement corporate structures that enable knowledge transfers. All this has to be weighted carefully against the benefits of centralizing R&D activities in home countries, such as achieving economies of scale in technology development. An important implication of our study is that the optimal design of a global R&D organization will vary significantly between MNCs, depending on the technology domains in which they are active.

Moreover, our study is relevant to regulators and policy makers dealing with innovation. Our finding that the benefits of international R&D depend on the technological strength of countries where MNCs conduct foreign R&D infers that an innovation policy directed towards attracting foreign direct investments in R&D should focus on creating a strong national innovation system. Developing local technology strengths in specific domains is the most straightforward way to attract and maintain R&D units because it enhances the performance effects of MNCs' R&D and, hence, provides a sustainable advantage for the location. We suggest building a strong specialized local innovation system, which promotes (joint) research and interaction between government, universities, and firms. Here, focusing on a domain of strength may be the best approach (e.g., Lundvall et al., 2002; Jacob et al., 2023). Investment in the education and training of scientists and engineers and building a legislative framework that provides effective protection for intellectual property rights and the provision of financial support (e.g., subsidies and tax credits) to stimulate R&D investments will be instrumental in driving innovation (e.g., Du et al., 2022). Our findings on knowledge integration offer a second actionable suggestion. The knowledge integration of foreign laboratories can be facilitated by investing in improved transport (airport) and telecommunication infrastructure, which recent research has identified as an attractor of foreign R&D investment and has termed "international connectivity" (Castellani et al., 2022; Du et al., 2022).

Our research is subject to a number of limitations, and here we discuss the most salient. First, our research methodology did not allow us to interpret the results as causal relationships. Finding a set of suitable instruments for not only international R&D dispersion but also the particular (organizational) contingencies under which these dispersed R&D activities take place will remain a challenging task for future research. Second, we were restricted in our investigation of the hypothesized relationships to a panel of firms based on data from the early years of the 21st. century. This limitation stemmed from our reliance on secondary data that did not allow for updating. The relationships uncovered may have changed over time, particular from 2020 onwards during and after the Covid-19 pandemic. Social distancing conditions to combat the pandemic will have forced MNCs to join forces on R&D without the face-to-face interactions deemed essential for effective collaboration and intra-MNC knowledge transfers and to be creative using various forms of online communication. This experience can fundamentally change perceptions of the value of proximity and centralization versus the value of dispersion in different regions of technological strength. Collaboration in R&D across units may be perceived as effective at lower cost, using online interaction rather than face-to-face meetings and mobility of personnel. An important question for future research is to what extent this has changed international R&D practice and the strength of contingencies affecting the relationship between innovation performance and R&D dispersion.

Third, we were not able to examine the role of a firm's upper echelons. A well-functioning top management team, which often plays a key role in international R&D strategies and R&D budget allocation, can serve as an important cornerstone of an effective global R&D organization (Mihalache et al., 2012). An effective top management team will likely bring together managers with experience in countries where major R&D activities are in operation (Boone et al., 2019). Fourth, while we found a significant moderating influence of the effects of intra-firm cross-border knowledge integration, it would be interesting to examine the mechanisms through which such integration can best be achieved, distinguishing for instance digital communication versus personal interaction (Rabbiosi, 2011), and central coordination versus local autonomy (Belderbos et al., 2021; Blomkvist et al., 2017; Argyres and Silverman, 2004), or the hiring of migrants bringing diversity and host country knowledge in headquarter operations (Laursen et al., 2020).

Finally, a general challenge for future research is to combine a global perspective on foreign R&D with detailed analysis at the regional level, given that that effective knowledge sourcing requires close geographic proximity (e.g., Jaffe et al., 1993; Belenzon and Schankerman, 2013). Our study used countries as the demarcation of location decisions, which is a natural starting point from a global R&D perspective. Combining this perspective with more fine-grained regional location characteristics is a promising avenue for future research, but it will encounter important hurdles in calculating reliable indicators for regions in a global context.

Data availability

Data will be made available on request.

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