Technological radicalness, R&D internationalization, and the moderating effect of intellectual property protection

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ABSTRACT

Drawing on insights from the resource-based view of the firm, this paper examines the link between the radicalness of the firm's technologies and the extent of its exploitation and exploration R&D activities abroad, with an additional focus on the level of the host country's intellectual property (IP) protection as a force moderating this link. It uses information about greenfield foreign direct investment by 185 U.S. publicly-traded manufacturing firms in the period 2003–2013 to demonstrate that technological radicalness is positively associated with the number of exploration and exploitation R&D projects. While the level of IP protection is shown to have a moderating effect, this is nuanced: firms with more radical technologies pursue more exploration R&D projects in countries with stronger IP protection; in turn, the number of exploitation R&D projects is driven by those undertaken in countries with weaker IP protection. The findings have both managerial and policy implications.

KEYWORDS: technological radicalness; R&D internationalization; intellectual property protection; exploration vs. exploitation; manufacturing companies

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1. INTRODUCTION

In 2011, when opening its eighth R&D center in Israel, worth nearly $5 million, Michael Idelchik, Global Research Vice President for Advanced Technologies of U.S.-based General Electric, stated: "*Israel has a rich history of innovation and scientific discovery. [...] With the establishment of the new R&D center, we will be in a better position to build a close relationship with the Israeli technology community and identify new technologies that could become part of our portfolio*".[2] Technologies have indeed long been considered as an important force driving firms' internationalization (see Cantwell, 1989; Dunning, 2013; Narula, 2003). Firms that operate across national borders – so-called multinational enterprises (MNEs) – invest a great deal in technological development in order not only to participate in the global generation of technologies and to source technological knowledge that is locally available (i.e., *exploration* R&D), as in the above example, but also to leverage their technologies internationally by, for instance, providing technological support to other value chain activities through the adaptation of innovations to the preferences of the local market (i.e., *exploitation* R&D; see Archibugi and Pietrobelli, 2003; Gerybadze and Reger, 1999; Lampert and Kim, 2019; Sanna-Randaccio and Veugelers, 2007; Vrontis and Christofi, 2019).

While technologies constitute the basis for firms' competitiveness, they are rarely homogeneous and tend to differ across a spectrum of characteristics, such as radicalness – or the extent to which new technologies differ from existing technologies, with more radical technologies being expected to make a greater contribution to enhancing the firms' competitive position (Ardito *et al.*, 2020; Shane, 2001; Sheng *et al.*, 2013). However, the use of radical technologies in R&D activities – be those exploration or exploitation – spread across geographical locations is associated with significant risks: for example, firms that possess radical technologies face a higher risk of technology leakages and spillovers to rivals, not least

[2] Source: https://www.israelnationalnews.com/News/News.aspx/144948.

because of R&D internationalization, which, in turn, can undermine their competitive position and performance (Alcácer and Chung, 2007; Alcácer and Zhao, 2012; Belderbos and Somers, 2015; Belderbos *et al.*, 2008). Schotter and Teagarden (2014) estimate that, in 2013, business losses, including those due to technology misappropriation, of U.S.-headquartered firms in China (a country that is often considered to offer weak IP protection; see Zhao, 2006) reached about USD 300bn. To protect their technologies and ensure that their competitiveness is maintained, MNEs internalize their operations via R&D foreign direct investment (FDI) – this mechanism enables tighter control over technology transfer and limits the dissipation of technological knowledge. They may also draw on the host country's IP protection and other institutional arrangements to profit from their technologies (Teece, 1986; Zhao *et al.*, 2020).

Although a number of studies have explored the link between technologies and internationalization in general (e.g., Cantwell, 1989; Cantwell and Piscitello, 2000; Narula, 2003; Tseng *et al.*, 2007; Dunning, 2013), and looked at various institutional arrangements underpinning technology transfer (e.g., Oxley, 1999; Maskus, 2000; Glass and Saggi, 2002; Branstetter *et al.*, 2006; Zhao, 2006; Kim *et al.*, 2012; Brander *et al.*, 2017; Peng *et al.*, 2017), there is little insight into how the characteristics of technologies, including their radicalness, are linked to R&D internationalization. Only a handful of works have examined this issue directly (e.g., Ardito *et al.*, 2020; Belderbos *et al.*, 2013; Kriz and Welch, 2018). Recognizing that, we attempt to fill this gap. Drawing on insights from the resource-based view of the firm, we study whether the radicalness of the technologies possessed by an MNE has an association with the firm's decision to pursue exploration and exploitation R&D projects abroad; moreover, we also evaluate the impact of the host country's level of IP protection on this association.

In order to do so, we examine the greenfield FDI projects of 185 U.S. publicly-traded manufacturing firms in the period 2003-2013, with a focus on the firms' engagement in cross-border exploration and exploitation R&D activities.[3] According to our empirical results, the radicalness of MNEs' technologies is positively associated with the number of both exploration and exploitation R&D projects in foreign countries. These findings are consistent with the idea that, since more radical technologies tend to provide greater market opportunities and reflect firms' absorptive capacity, MNEs are able to decentralize their R&D function so that it not only supports their expansion into foreign markets, but also helps them to tap into the host country's technological pool and, thus, participate in the global generation of technologies. However, we find that there is a differential effect of the strength of IP protection that host countries offer – greater technological radicalness is associated with more exploration R&D projects in countries that have stronger IP protection and more exploitation R&D projects in countries with weaker IP protection. These findings reveal a boundary condition of country-level IP protection: that is, technological leaders seem to be strategic in how they approach the decentralization of their R&D function and give priority to countries with stronger IP protection only when engaging in global technology generation.[4]

As such, our study contributes to the literature in three principal ways. First, it adds to the research on the resource-based view of MNEs in general (e.g., Barney *et al.*, 2001; Peng, 2001; Tseng *et al.*, 2007) and on the effect of technologies on R&D internationalization in particular (e.g., Ardito *et al.*, 2020; Belderbos *et al.*, 2013; Kriz and Welch, 2018) by pointing to the need to account for technological characteristics, such as radicalness, when assessing this effect, with MNEs that have more radical technologies engaging in more cross-border R&D activities. Second, it adds to the literature on the role that IP protection in the host country plays in cross-border technology transfer (e.g., Belderbos *et al.*, 2013; Branstetter *et al.*, 2006; Kim *et al.*, 2012; Papageorgiadis *et al.*, 2019; Pathak *et al.*, 2013; Zhao, 2006) by identifying an

[3] Although in this study, we draw on greenfield FDI to capture the two forms (i.e., exploration and exploitation) of firms' R&D internationalization, it needs to be mentioned that MNEs can choose other market entry modes, such as joint ventures and M&A (see Raff *et al.*, 2009), but these are beyond the scope of this study.

[4] It should be noted that countries with stronger IP protection may also have stronger technological expertise, so MNEs may be more likely to engage in exploration R&D projects there (see Thakur-Wernz *et al.*, 2019).

important boundary condition: that is, once technological radicalness and the motives for R&D internationalization are accounted for, the strength of country-level IP protection tends to foster only exploration R&D projects. And third, our results inform the debate over the effect of FDI on the productivity and innovativeness of local firms (see Chung *et al.*, 2003; Haskel *et al.*, 2007; García *et al.*, 2013; Jin *et al.*, 2019) by suggesting that technological radicalness and the effect it has across different stages of a value chain (specifically here the exploration and exploitation stages) can partially explain technology transfer patterns. Therefore, policy-makers in host countries could maximize technology transfer to local firms by better aligning the stages of the value chain they target with the level of IP protection afforded.

2. THEORY AND HYPOTHESES

2.1. The role of technologies in the internationalization process: A resource-based view

One of the basic findings in the business and management literature is that, even within narrowly defined markets, there are significant and persistent differences in firms' internationalization behavior, with various theories having been advanced to explain them (see Paul and Feliciano-Cestero, 2021). For instance, the resource-based view of the firm states that these differences are linked to the different resource endowments possessed by firms (Wernerfelt, 1984; Barney, 1991; Peng, 2001; Peteraf, 1993). Within this theoretical perspective, the firm's resource endowments – or simply resources – are defined as tangible and intangible (e.g., brands, technologies, or skilled personnel) assets that are semi-permanently tied to the firm and that can be utilized to conceive or implement the firm's strategies and lead to competitive advantage. However, to do so, the resources should be valuable, rare, and not easily imitated or substituted (Barney, 1991). As far as internationalization behavior is concerned, the resource-based view clarifies "the nature of resources required to overcome the liability of foreignness"; suggests that the firm's resources are likely to determine its mode of foreign entry, usually in conjunction with its capabilities in deploying resources in external markets; and emphasizes the importance of organizational learning and knowledge transfer within the context of subsidiary capability building and cross-border strategic alliances (Cantwell and Piscitello, 2000; Barney *et al.*, 2001:629; Peng, 2001).

Technologies in particular represent a valuable resource for MNEs. There are three main reasons for firms to deploy technologies internationally (Archibugi and Pietrobelli, 2003): firms may seek to utilize a nationally produced technology in foreign markets, including through the foreign manufacturing of innovative products; they may choose to participate in the global generation of technologies by, for example, setting up international but intra-firm R&D labs or technical centers; and, finally, firms may be involved in global technological collaborations with the aim of creating new technologies and products. International technology deployment can be either through internal transfer, when firms exploit technologies within their boundaries (including knowledge integration activities), or through external transfer, when firms exploit technologies across their boundaries (including sourcing; Andersson *et al.*, 2016). Regardless of the reason for internationalization, existing studies show that leveraging technologies outside the home market increases firms' chances of survival, improves their competitive position, and provides long-term growth opportunities (see Cantwell, 1989; Cantwell and Piscitello, 2000; Narula, 2003; Tseng *et al.*, 2007; Dunning, 2013).

While the importance of technologies for the internationalization process has been acknowledged in the academic literature, the emphasis is primarily on technologies per se, without much insight into the characteristics of the particular technologies developed and owned by MNEs (see Ardito *et al.*, 2020). For example, it has been shown that technologies vary in terms of their *radicalness*, which can be broadly defined as the extent to which a new technology is different from existing technologies (Shane, 2001; Sheng *et al.*, 2013). However, there is a dearth of evidence on whether the radicalness of technologies possessed by firms influences their internationalization behavior. There is, though, a growing body of research suggesting that firms – especially large companies with their rigid management systems, as well as preference for lower risks and immediate reward – often struggle with commercializing such technologies and need to design and implement supporting mechanisms, including across borders, in order to enable technology diffusion (McDermott and O'Connor, 2002; O'Connor and DeMartino, 2006; O'Connor and Rice, 2001).

In context of MNEs' internationalization behavior, the view of technological radicalness (or, more broadly, technological leadership) has been mixed, yet still very limited. For example, firms that develop novel and potentially breakthrough technologies are found to accelerate their internationalization process, largely in order to exploit this unique resource in various foreign markets (Oviatt and McDougall, 2005). At the same time, firms with new-to-the-world technologies face a tension between technological development and international expansion; as a result, they are found to exhibit uneven and discontinuous internationalization patterns (Kriz and Welch, 2018). Historically, many radical technologies emerged within and were initially reserved for the defense sector, but as soon as they became available for civilian applications they contributed to the proliferation of MNEs, as was the case after World War II (Buckley and Casson, 2009).

In the next subsections, we draw on the insights provided by the resource-based view in exploring the links between technological radicalness and R&D internationalization.[5]

2.2. The link between technological radicalness and the internationalization of R&D activities

The literature identifies two sets of forces guiding the MNE's decision to pursue, or not, its R&D activities abroad – *centrifugal* and *centripetal* forces (see Athukorala and Kohpaiboon, 2010; Belderbos *et al.*, 2013; Granstrand *et al.*, 1993; Hirschey and Caves, 1981; Papanastassiou *et al.*, 2020). *Centrifugal forces* encourage this decision. Historically, the major reason for MNEs to

[5] Although the flow of arguments in our theoretical framework starts with the radicalness of technologies and then moves on to discuss its link with R&D internationalization, we should acknowledge that MNEs are likely to learn from their internationalization activities so as to inform technology development and, as such, increase the radicalness of their technologies (see Bahl *et al.*, 2021; Cantwell and Piscitello, 2000; Thakur-Wernz and Samant, 2019).

internationalize their R&D activities has been to support their foreign manufacturing and sales units in adapting their production processes and products to local markets' needs (Håkanson and Nobel, 1993; Hall, 2011; Kumar, 2001). In addition, more recently, the internationalization of R&D activities has also been driven by the attempts of MNEs to gain access to the host country's technological resources and knowledge (Belderbos *et al.*, 2013; Gerybadze and Reger, 1999) in order to enhances their technological capabilities, diversity, strength, and cost efficiency, but the latter is conditional on the R&D costs in the host country being lower than those in the home country (Ambos, 2005; Chung and Yeaple, 2008; Lampert and Kim, 2019; Song and Shin, 2008; Song *et al.*, 2011).

To reveal the link between technological radicalness and R&D internationalization, we consider *centrifugal forces* from the angles of resource exploration and exploitation (Gerybadze and Reger, 1999). More specifically, the *resource exploration* angle is consistent with the idea of MNEs tapping into the host country's pool of technologies. Firms developing more radical technologies are thus expected to have greater absorptive capacity (Cohen and Levinthal, 1990) and, as a result, should be better equipped to participate in the global generation of technologies, including by locating R&D units abroad, than firms with less radical technologies. This is not to say that the latter firms have less motivation to involve themselves in global technology generation – quite the opposite, as it can improve their technological capabilities; rather, they are less likely to do so because of their lack of absorptive capacity (Berry, 2006; Belderbos *et al.*, 2013). However, the internationalization of R&D activities is usually associated with an increase in communication costs (Asakawa, 2001). These costs are likely to be much higher for MNEs with radical technologies because such technologies, due to their distance from the firm's core technological base, require intensive social interactions among engineers and research teams to explore the possibilities for their industrial and commercial use (Singh and Fleming, 2010). When R&D units are dispersed across countries, "knowledge exchange and the application of joint research [... are] hampered due to spatial, cognitive, and cultural distances between members" (Ardito *et al.*, 2020:5).

Given the competing reasons that underpin exploration R&D, we suggest the following (neutral) hypothesis:

Hypothesis 1(a): *There is an association between the radicalness of the technologies owned by the MNE and the number of its exploration R&D projects.*

In turn, the *resource exploitation* angle is generally consistent with the view of R&D internationalization as a process that supports the expansion of MNEs into foreign markets. Since more radical technologies potentially yield more market opportunities, firms are likely to be keen to use these opportunities by trading products with a technology-based competitive advantage across international borders (Archibugi and Pietrobelli, 2003). For this, a profound knowledge of local demand, an ability to customize products to the local market, and access to technical expertise are essential (Granstrand *et al.*, 1993). These can be acquired by locating R&D units in the host country (usually together with other facilities, such as manufacturing and sales) with the aim to transfer the radical technologies developed in the home country to those local R&D units where these technologies are adjusted to meet the local market's needs. This strategy can also help firms to achieve economies of scale and scope in internal labor markets (Alcácer and Delgado, 2016), which is critical for radical technologies due to their cost intensity and their highly uncertain commercialization.

Hence, we conclude that:

Hypothesis 1(b): *There is a positive association between the radicalness of the technologies owned by the MNE and the number of its exploitation R&D projects.*

2.3. The moderating effect of country-level IP protection

Along with centrifugal forces that favor the internationalization of R&D activities, there are also *centripetal forces* that discourage this process. The literature on MNEs' decisions to conduct research abroad emphasizes the need to protect firm-specific technologies as a main force that prevents such firms from locating R&D units in another country (see Belderbos *et al.*, 2013; Granstrand *et al.*, 1993; Kumar, 2001). Clearly, the decentralization of the R&D function significantly increases the likelihood of technology leakages and spillovers to other firms because it becomes much more difficult to exert full control over technology flows when organizations are spatially dispersed (Audretsch and Feldman, 1996; Feinberg *et al.*, 2004; Sanna-Randaccio and Veugelers, 2007; Vrontis and Christofi, 2019). Although firms may enjoy benefits yielded by technology spillovers from their competitors and research institutions located in a host county, the net effect is likely to be negative when the spillover pool is poor (Alcácer and Chung, 2007; Sanna-Randaccio and Veugelers, 2007; Singh, 2007). Another important force impeding MNEs' pursuit of R&D activities abroad is "the significance of scale economies in R&D and the difficulties of reaching 'critical mass' in decentralized laboratories", with the latter including research equipment and scientific expertise (Belderbos *et al.*, 2013; Granstrand *et al.*, 1993:415). Unless some minimum volume of R&D is achieved in the home country, it may not be economically viable to establish new R&D units in foreign countries. Finally, the costs of controlling and coordinating research activities across different locations, and the embeddedness of MNEs in the home-country innovation system can further contribute to the home bias in R&D (Belderbos *et al.*, 2013; Gerybadze and Reger, 1999; Kumar, 2001).

Centripetal forces – and the technology protection argument in particular – can thus be used to expose the role played by IP protection at the country level in moderating the link between technological radicalness and R&D internationalization. According to the resource-based view, for a resource to increase the firm's competitive advantage, it should be difficult to imitate by a third party (Barney, 1991). Since technology is an intangible asset, firms can invoke a variety of formal and informal IP protection methods (Hall *et al.*, 2014) not only to exclude competitors from using this asset but also to capture profits that stem from it, not least because those profits can be reinvested in future technological development. According to the "profiting from innovation" framework (Teece, 1986; 1998), the firm's ability to capture economic returns from its technologies is a function of two factors – the firm's complementary asset position and the IP protection regime in which the firm operates. If the IP protection regime is weak, the firm requires preferential access to co-specialized assets to profit from its technologies; conversely, if the regime is strong, the firm can employ contractual agreements, such as licensing, in order to extract the profit (Pisano, 2006).

Following the insights above, MNEs with more radical technologies should be more susceptible to technology spillovers, be those due to R&D exploration or exploitation activities, than firms with less radical technologies because of the high market potential attached to the former. Therefore, they may exhibit a greater reluctance to establish R&D units abroad. This argument is supported by the observation that technologically advanced firms tend to "move away from clusters to protect their cutting-edge technologies" from being leaked to competitors (Alcácer and Chung, 2007; Alcácer and Zhao, 2012:736; Belderbos *et al.*, 2008). These firms are also found to discourage inward R&D investments in order to reduce technology outflows to collocating firms (Belderbos and Somers, 2015). In addition, the development of radical technologies that have high market potential, unlike minor adaptations, may require the firm's R&D resources – such as scientific personnel and equipment – to be concentrated in one place, which, in turn, would lead to the firm differentiating the nature of and minimizing the scope of its R&D activities abroad (Cantwell and Janne, 1999; Granstrand *et al.*, 1993).

To diminish the risks of technology spillovers, leakages, and misappropriation due to R&D internationalization, MNEs tend to rely on the IP protection system in the host country, which broadly consists of legal instruments and the mechanisms to enforce them. Multiple studies have looked at the effect of IP protection on firms' behavior in external markets (e.g., Oxley, 1999; Maskus, 2000; Glass and Saggi, 2002; Branstetter *et al.*, 2006; Zhao, 2006; Kim *et al.*, 2012; Brander *et al.*, 2017; Peng *et al.*, 2017), and a general conclusion is that the strength of IP protection in the host country is positively associated with the intensity of technology-based activities by foreign firms, unless those firms are able to adopt alternative strategies for protecting their technologies – in this case, they can capture returns from their technologies even in countries with weak IP protection (Grimaldi *et al.*, 2021; Zhao, 2006). Notably, although the geographic heterogeneity of IP protection is mostly driven by uneven economic and social development across the world, some countries may deliberately circumvent or, at least, limit the enforcement of such protection in order to thrive "on international technology acquisition by any means possible" (Petricevic and Teece, 2019:1489).

So, we propose:

Hypothesis 2(a): *There is a positive moderating effect of stronger IP protection on the link between technological radicalness and the number of the firm's exploration R&D projects.*

Hypothesis 2(b): *There is a positive moderating effect of stronger IP protection on the link between technological radicalness and the number of the firm's exploitation R&D projects.*

In Figure 1, we outline the conceptual framework for our study. This framework summarizes the research hypotheses, and points to the theoretical perspectives used to devise those hypotheses.

===== Figure 1 is about here =====

3. DATA AND METHODS

3.1. Data sources

Our empirical analysis relies on detailed information about the greenfield FDI projects of 185 U.S. publicly-traded manufacturing firms in the period between 2003 and 2013. To construct the sample, we integrated several sources of information. We started with the *S&P Compustat North America* database, in which we identified manufacturing firms (SIC codes 2000–3999) and extracted financial statistics for each of them. We then used the *Financial Times fDi Markets* database to collect information about the firms' greenfield FDI projects, including the type of each project as well as its source and destination countries. Finally, to obtain U.S. patent counts and quality indicators, we utilized the *OECD Patent Quality Indicators* database. To link these databases, we drew on firm names: we first identified the most distinctive part of the firm's name and then searched each database for potential matches. Overall, we found 4,311 greenfield FDI projects (including 698 R&D, design, development, and testing projects; 1,764 manufacturing projects; and 1,849 other projects, such as sales, marketing, and support; technical support centers; education and training; and business services), and 161,123 patents registered by the sampled firms over the period of observation. Our unit of analysis is the firm-year. A summary of study variables and data sources is provided in Table A1 in Appendix A.

3.2. Study variables

Dependent variables. To capture the firm's cross-border exploration and exploitation activities, we draw on the project classification in the fDi Markets database (the "Industry activity" field). The number of exploration R&D projects is calculated by first counting design, development, testing, and R&D projects started by the firm in the given country in the given year if the firm started *no* other greenfield FDI project types in that country in that year, and then aggregating those projects the firm level. In turn, the number of exploitation R&D projects is calculated by counting design, development, testing, and R&D projects started by the firm in the given country in the given year if the firm *did* also start other greenfield FDI project types (e.g., manufacturing; sales, marketing, and support; logistics, distribution and transportation; etc.) in that country in that year; the number of those projects is aggregated at the firm level as well. The main reason to justify the combination of different types of greenfield FDI projects is that MNEs sometimes choose to establish an R&D unit in parallel or integrate it with other activities of their value chain to better utilize the host country's innovation potential and to benefit from the cost advantages stemming from such integration (see Alcácer and Delgado, 2016; Von Zedtwitz *et al.*, 2004).

Moreover, within each category, we distinguish between projects carried out in countries with weaker IP protection and those carried out in countries with stronger IP protection. To draw this distinction, we use the results of a survey conducted by the World Economic Forum and published in the annual *Global Competitiveness Report*. The survey assesses, *inter alia*, the strength of IP protection in different countries by asking respondents the following question: "In your country, to what extent is intellectual property protected?" The responses are scaled from 1 (not at all) to 7 (to a great extent). We classify the countries with a score of 5 or above as having stronger IP protection and the rest as having weaker IP protection (see Table A2). This approach has been adopted by prior studies to capture IP protection at the country level (e.g., Belderbos *et al.*, 2013).

Explanatory variable. We capture the radicalness of new technologies owned by the firm using the patent radicalness index derived by Squicciarini *et al.* (2013). It is based on the definition of patent radicalness proposed by Shane (2001:210): "the radicalness of the patent [...] is a time-invariant count of the number of [... technology] classes in which previous patents cited by the given patent are found, but the patent itself is not classified." The radicalness of a patent therefore reflects the degree to which it differs from the patents it draws on. The score on the patent radicalness index R_p for Patent p can be calculated as (Squicciarini *et al.*, 2013:53):

$$R_p = \sum_{j}^{n_p} \frac{CT_j}{n_p} \; so\ that\ IPC_{pj} \neq IPC_p \,, \tag{1}$$

where CT_j is the number o IPC 4-digit classes (IPC_{pj}) of Patent j cited in Patent p that are different from Patent p's IPC 4-digit classes (IPC_p); n is the number of IPC classes in the backward citations counted at the most disaggregated level available (up to the fifth hierarchical level). With R_p taking a score of 0 to 1, we define those patents that have higher scores of this index as more radical. We consider only the patents registered by U.S. firms at the U.S. Patent and Trademark Office (USPTO), thus approximating the firm's inventive activities in the home country. In order to aggregate the index at the firm level, we calculate its average value across all patents granted to the firm in the given year. Finally, we assume that the association between technological radicalness and the numbers of exploration and exploitation R&D projects is contemporaneous, largely on the basis that both planning and establishment of cross-border R&D projects are lengthy processes that require some degree of coordination.

The use of patent data to capture firms' inventive activities, including their qualitative characteristics, has been popular in academic research (e.g., Ardito *et al.*, 2020; Belderbos *et al.*, 2013; Griliches, 1998; Grupp and Schmoch, 1999; Shan and Song, 1997). However, patent data does have its limitations (see Hall *et al.*, 2001): for example, not all technological inventions are patentable due to the novelty criterion for patent registration. Firms may also choose not to invoke patent protection for some of their inventions and, instead, rely on other mechanisms (such as secrecy) to appropriate returns. Nevertheless, in the context of this study, patent data allows us not only to determine the number of new technologies possessed by firms, but also to assess their radicalness.

Control variables. Following previous studies, we control for a number of firm-specific factors. We include firm size, operationalized as the logarithm of the total number of employees, to control for the firm's resourcefulness (Calof, 1993; 1994). To control for the firm's experience and accumulation of knowledge, we include firm age: it is calculated by subtracting the year to which the firm traces its origin from the current year (Autio *et al.*, 2000). We also capture potential nonlinear effects associated with firm age by adding its squared term (Belderbos *et al.*, 2013). Given that firm sales are found to be associated with R&D activities, including those undertaken internationally (Belderbos, 2001), we control for this association with the year-to-year growth of sales and with the intensity of sales, calculated as the ratio of total sales to total assets. We use capital intensity to control for the attributes related to the firm's production technologies, with the view that firms pursing cross-border projects tend to rely on capital-intensive production technologies (Liu and Chen, 2003; Ramstetter, 1999). It is measured as the ratio of the total net value of the firm's property, plant, and equipment to the total number of its employees. We also control for the level of resources allocated to inventive activities in general. To do so, we calculate R&D intensity as the ratio of R&D spending to total assets. For the small number of firms for which R&D spending values are missing, we either extrapolate to fill in the gaps or set those missing values to zero – an approach widely adopted in the literature (see Hall and Ziedonis, 2001; Hirschey *et al.*, 2012). Finally, we control for the firm's investment opportunities, profitability, and slack resources with, respectively, Tobin's q (the ratio of total assets plus outstanding common shares multiplied by the close price of a share minus the total value of common equity to total assets); return on assets (the ratio of income before extraordinary items to total assets); and book leverage (the ratio of long-term debt plus current liabilities to total assets).

3.3. Econometric analysis

Our empirical analysis consists in modeling the expected number of exploration and exploitation R&D projects of Firm *i* in Year *t* (y_{it}) conditional on the average radicalness of Firm *i*'s patents registered in Year *t* (x_{it}). In order to do so, we use the following formula:

$$E[y_{it}|x_{it},\overline{z_{it-1}}] = exp\big(\alpha \times x_{it} + \bar{\beta} \times \overline{z_{it-1}} + \gamma_i + \tau_t\big)\,, \qquad (2)$$

where $\overline{z_{it-1}}$ is a vector of firm-specific control variables (i.e., company size, company age, sales growth, sales intensity, capital intensity, R&D intensity, Tobin's q, return on assets, and book leverage); γ_i is firm-specific effects; and τ_t is year-specific effects. As our dependent variables take non-negative integer values, we assume them to be Poisson distributed; hence, the above model is specified in the log-linear form (Wooldridge, 2010). In this specification, we lag all the control variables by one period to minimize simultaneity bias. We correct for heteroskedasticity and autocorrelation by clustering standard errors at the firm and the industry levels.

An additional comment should be made here regarding how we introduce firm-specific effects in our model. Unlike the fixed-effects Poisson model that assumes independent variables to be strictly exogenous (in other words, to be uncorrelated with shocks to dependent variables), we relax the strict exogeneity assumption because it is likely to be violated if, for example, an unobserved shock to the firm's cross-border projects causes the firm to change its current and future technology-generation behavior. One can do so by relying on pre-sample information about the firm's cross-border projects, which enters the model directly, thereby accounting for initial conditions (Blundell *et al.*, 1999). As we have no information about the exploration and exploitation R&D projects that each sampled firm had started before 2003, we instead use the five-year pre-sample mean of income from the firm's foreign operations (before taxes), obtained from the Compustat database, to construct the proxy of firm-specific effects (γ_i).

4. EMPIRICAL RESULTS

Descriptive statistics and the correlation matrix for all study variables are presented in Tables 1 and 2, respectively. It can be seen that the average firm our sample initiates 0.243 exploration R&D projects and 0.100 exploitation R&D projects per year. While the split of exploration R&D projects between countries with weaker and stronger IP protection is similar (54% and 46%, respectively), a clear majority of exploitation R&D projects (67%) are based in countries with weaker IP protection. The radicalness of new technologies possessed by sampled firms is scored 0.362, which is lower than the mid-point for this indicator (0.500). Finally, our analysis of correlation coefficients raises no multicollinearity concerns.

===== Tables 1 and 2 are about here =====

The results of regression analysis for exploration R&D projects are presented in Table 3. Given the non-linear nature of our model, a one-unit change in the explanatory variable should be interpreted in terms of the expected log count of the dependent variable. To ease the interpretation of coefficients, in what follows we refer to expected counts rather than expected log counts – expected counts can be calculated by exponentiating the coefficients reported in the table.[6] We begin the analysis of our empirical results with a general observation that the radicalness of new technologies possessed by the firm has a *positive* association with the number of its exploration R&D projects (Hypothesis 1(a) is supported). More specifically, a one-unit increase in technological radicalness (effectively, this reflects switching from no to maximum technological radicalness because the indicator is bounded between 0 and 1) is associated with an increase in the number of exploration R&D projects by a factor of 2.472 ($p < 0.012$), when other variables are held constant. Figure 2(a) offers a more detailed account of how the number of exploration R&D projects changes with technological radicalness.

===== Table 3 is about here =====

To test Hypothesis 2(a), which states that the link between technological radicalness and the number of exploration R&D projects is moderated by the strength of IP protection in the host country, we have conducted subsample analysis; its results are also presented in Table 3. Consistent with the hypothesis, the perception of how well IP is protected in the host country has an impact on the firm's cross-border exploration behavior (Hypothesis 2(a) is supported): in particular, firms increase the number of exploration R&D projects in countries where IP protection is stronger so long as the radicalness of their new technologies increases. According to our results, the full-unit increase in technological radicalness is associated with a 2.754-fold increase in the number of exploration R&D projects in such countries ($p < 0.005$). At the same time, we have found no statistically significant association between the radicalness of the firm's new technologies and the number of its exploration R&D projects in countries with weaker IP protection. Figure 2(b) depicts the number of exploration R&D projects in countries where IP protection is stronger at different levels of technological radicalness.

===== Figures 2(a) and 2(b) are about here =====

[6] To exponentiate the coefficients reported in our tables, one needs to use the following approach (taking as an example the coefficient for technological radicalness from Model 2 of Table 3): e^0.905 = 2.472.

Turning to the firm's cross-border exploitation projects (see Table 4), our results show that, for the whole sample, the full-unit increase in technological radicalness is associated with an increase in the number of exploitation R&D projects by a factor of 5.496 ($p < 0.022$), thus supporting Hypothesis 1(b). The differentiation effect of host country IP protection for this type of project comes from the fact that the results are primarily driven by exploitation R&D projects in countries that have weaker IP protection (Hypothesis 2(b) is supported): the full-unit increase in technological radicalness is associated with an increase in the number of exploitation R&D projects in such countries by a factor of 7.221 ($p < 0.005$). Indeed, the association between technological radicalness and the number of exploitation R&D projects when countries with stronger IP protection are considered is statistically insignificant. In Figures 3(a) and 3(b), we demonstrate the marginal effects of technological radicalness on the number of exploitation R&D projects for all countries and for countries with weaker IP protection, respectively.

===== Table 4, Figures 3(a) and 3(b) are about here =====

Finally, some insight can be obtained from the analysis of control variables. Particularly, larger firms tend to start more cross-border R&D projects, regardless of the type of those projects or the strength of IP protection in the host country. The association between firm age and the number of cross-border R&D projects is generally U-shaped (i.e., initially declining as firms mature and then increasing after a certain point), except for exploitation R&D projects in countries with stronger IP protection, where the relationship takes an *inverted* U-shape. Firms that rely on capital-intensive production technologies pursue more exploitation R&D projects (mostly due to projects in countries with stronger IP protection), whereas firms with a higher intensity of R&D spending are more active with exploration R&D projects. Finally, firms with more debt are found to have fewer exploration R&D projects, no matter what the level of IP protection is, and fewer exploitation R&D projects in countries with weaker IP protection.

4.1. Robustness checks and model extensions

To ensure that our findings are robust to the choice of modeling methods and variable specifications, we have conducted a number of robustness checks that interested readers can find in Appendix A, with only a brief discussion provided here. First, we have verified whether the findings are affected by our assumption about the Poisson distribution of the dependent variables. We have experimented with a negative binomial model (see Gardner *et al.*, 1995; Greene, 1994) because it relaxes the assumption of the Poisson model that the mean and the variance are the same. We have also used a Tobit model to fit the data, thus assuming that there is left-censoring in our data generation process that produces non-negative numbers (see Amemiya, 1984; Tobin, 1958). According to the results of this robustness check (see Tables A3 and A4), we can still observe a positive association between technological radicalness and the numbers of exploration and exploitation R&D projects, as well as the moderating effect of IP protection – all effects are consistent with our baseline results.

Our next robustness check is related to the cut-off point (a score of 5 on the IP protection index) we have chosen to separate countries with stronger IP protection from those with weaker IP protection. To find out if our results are sensitive to this choice, we also use 4 and 6 as cut-off points. The results of this analysis are reported in Tables A5 and A6; they show a high degree of consistency with our baseline results. Moreover, recognizing that there are other indexes that aim to capture the strength of IP protection in different countries (e.g., Papageorgiadis and Sofka, 2020; Park, 2008), we have assessed the degree of similarity between the index that we have adopted from the Global Competitiveness Report and those indexes. We have not been able to use alternative indexes in our empirical analysis because of significant discrepancies in time and/or country coverage. Nevertheless, we are able to show that the baseline results are unlikely to be affected by the choice of the IP protection index because those indexes are highly correlated: for example, the correlation coefficient between scores on our index and those on the index devised by Papageorgiadis and Sofka (2020) ranges from 0.94 to 0.97 over time.

We have further experimented with alternative lag structures for our explanatory variables. In Tables A7 and A8, we show the results of analyses that lag the explanatory variable by different periods (one, two, and three years). Interestingly, when exploration R&D projects are considered, those located in countries with stronger IP protection are associated with the contemporaneous portfolio of radical technologies, while technological radicalness in previous periods (at least up to three years) seems to drive exploration R&D projects in countries where IP protection is weaker. Our findings for exploitation R&D projects are less clear-cut. For example, unlike the results for the three-year lag, which are consistent with our baseline results, lagging the explanatory variable by one year yields no effects across the whole sample or either subsample. In turn, lagging technological radicalness by two years points to its negative association with the number of exploitation R&D projects in countries with stronger IP protection and confirms our baseline results for such projects in countries where IP protection is weaker.

Finally, a potential limitation of using the counts of exploration and exploitation R&D projects to capture firms' cross-border behavior is that the firms may invest larger sums in only a handful of projects, or smaller sums in many projects. If either is indeed a common strategy among firms in our sample then the results we have observed so far need qualification. To eliminate this concern, we have re-estimated our baseline models using the monetary values of projects (in millions of U.S. dollars), obtained from the fDi Markets database, as an alternative to project counts as the dependent variables. We have not log-transformed those new dependent variables because there is no merit in doing so, considering that they are highly skewed to the right, non-negative, and have an excess of zeroes. As an alternative solution, we have followed past studies (see Wooldridge, 2010) and fitted the data using a Poisson model. The results of this analysis are presented in Table A9 and show a high degree of consistency with our baseline results: that is, there is a positive association between technological radicalness and the values of exploration and exploitation R&D projects. However, the differentiating effect of the strength of IP protection in this case consists in greater technological radicalness being associated with much larger cross-border exploration and exploitation R&D projects (in terms of their monetary value) in countries where IP protection is stronger than in countries where it is weaker.

5. DISCUSSION AND CONCLUSION

In this paper, we have relied on insights from the resource-based view of the firm to study the link between the radicalness of MNEs' technologies and the internationalization of their R&D activities. We have also examined the moderating effect that country-level IP protection has on this link. Our empirical analysis indicates that technological radicalness is positively associated with the number of both exploration and exploitation R&D projects started by firms abroad, thus suggesting that technological leaders rely on such investment not only to support other value chain activities (e.g., manufacturing and/or sales) by adapting production processes and final products to the needs of the local market, but also to gain access to the host country's technological resources and knowledge. Further, we have revealed that the strength of IP protection in the host country positively affects the link between technological radicalness and R&D internationalization. However, this effect is nuanced: that is, greater technological radicalness is found to be associated with more exploration R&D projects in host countries with stronger IP protection; in contrast, firms with more radical technologies tend to have more exploitation R&D projects in countries where IP protection is weaker. Such a differential effect of the strength of country-level IP protection likely reflects the fact that, given the recognized risks of technology leakages and spillovers that come with the decentralization of the R&D function (especially when it is able to generate radical technologies), MNEs allocate their cross-border R&D projects such that those associated with greater technology sharing and exposure (i.e., *exploration*) are located in countries offering stronger IP protection. In turn, they choose to locate supporting R&D projects with a lower risk of technology spillovers (i.e., *exploitation*) in countries that offer other location-specific advantages than stronger IP protection.

5.1. Implications for practice and policy

Our findings have several implications for practice and policy. First, they emphasize the importance of accounting for technological characteristics, such radicalness, when assessing the internationalization of R&D activities by MNEs. Unlike Belderbos *et al.* (2013), who reveal that technological leadership is a key determinant of R&D home-country bias, we demonstrate that the extent to which firms' new technologies differ from their existing technologies (or what we call "*technological radicalness*") guides the decision to invest in R&D projects abroad, with MNEs developing more radical technologies being inclined to expand such investment. This applies not only to exploration R&D projects, whose key goal is to source new technologies from the host country's pool of technological knowledge, but also to exploitation R&D projects – those that help with customizing technologies to the needs of the local market and support other value chain activities (e.g., manufacturing, sales, and after-sales services; see Ambos, 2005; Kuemmerle, 1997; Von Zedtwitz and Gassmann, 2002). Additionally, we qualify Belderbos *et al.*'s (2013) finding that stronger levels of IP protection in the host country can help to correct for the R&D location bias, in that we identify a crucial boundary condition: that is, stronger country-level IP protection fosters only exploration R&D projects, while MNEs pursue more exploitation R&D projects in countries where IP protection is weaker, possibly owing to a lower risk of technology spillovers and leakages associated with such projects together with location-specific advantages (other than stronger IP protection) that those countries can offer to MNEs.

Therefore, our findings point to the need for managers to engage in an analysis of the characteristics (e.g., radicalness) of their technological portfolios when selecting the mode of R&D internationalization – exploration versus exploitation – to align it with the strength of IP protection in the host country. Despite the benefits associated with pursuing either exploration or exploitation R&D projects abroad, MNEs' managers should be aware that pursuing both simultaneously can also create tensions because it requires the creation of an ambidextrous organization (Andriopoulos and Lewis, 2009). Instead, they need to strike a balance between the two in order to achieve success (He and Wong, 2004).

In relation to exploitation R&D projects, we show that when countries with stronger IP protection are considered, technological radicalness has no statistically significant association with the number of such projects. This appears to be in line with predictions of the profiting from innovation framework (see Teece, 1986; 1998): more specifically, tight appropriability regimes make the imitation of technological assets difficult, the competition from imitators limited, and the enforcement of patents relatively easy. MNEs' managers thus can leverage their technologies in the production of innovative goods across the entire spectrum of technological radicalness and with a range of mechanisms. Given the lower risk of technology spillovers, they can rely not only on exploitation R&D activities (to keep control over their technologies) but also on technology transfer based on contractual arrangements with firms from such countries.

In turn, the results observed for exploitation R&D projects in countries with weaker IP protection are likely to reflect the fact that some value chain activities, such as manufacturing, have been shifting to lower-cost locations (see Aron and Singh, 2005; Kazmer, 2014), and these usually have weaker IP protection. Along with technological radicalness being an important predictor of the number of exploitation R&D projects pursued there, their association is found to be positive. Based on this finding, we argue that, if they are unwilling to ignore the location-specific advantages offered by such countries, MNEs' managers can think of minimizing the risk of technology spillovers caused by R&D internationalization with the use of alternative mechanisms of IP protection. One such mechanism is relying on the modularity of the focal technical system, whereby firms "divide complex technical systems into components (modules) that can be designed independently but function together as a whole" (Zhao, 2006; Baldwin and Henkel, 2015:1640–1641). Overall, we can conclude that for certain types of cross-border investment projects (e.g., exploitation R&D), the weakness of IP protection in the host country does not constitute a barrier for commercializing radical technologies abroad as there are firm-level strategies available to MNEs' managers that can mitigate or even circumvent this.

Finally, our results also inform the policy-related debate on whether inward FDI fosters the productivity and innovativeness of local firms (see Chung *et al.*, 2003; Haskel *et al.*, 2007; García *et al.*, 2013; Jin *et al.*, 2019). Host countries often face a tradeoff: on the one hand, they seek to attract MNEs, whose superior technologies should provide an opportunity for local firms to learn and develop their technological bases; on the other hand, this comes at the expense of increased competition (Jin *et al.*, 2019). There is no consensus on what the net total effect of FDI is likely to be on local firms or on what factors might enhance or mitigate this effect, but we argue that adopting the technological radicalness perspective offers valuable insights into why technological leaders may facilitate technology transfer – and, thus, provide more learning opportunities to local firms – as well as into which stages of the value chain should be targeted to increase the chance of radical technologies flowing to the host country, depending on that country's level of IP protection (see Brandl *et al.*, 2019; Thakur-Wernz and Wernz, 2022).

5.2. Study limitations and directions for future research

As with any research, our work has limitations, but these offer opportunities for future studies. First, when examining the association between the radicalness of new technologies possessed by firms and the numbers of their exploration and exploitation R&D projects abroad, we do not trace the actual link between a specific technology and a specific cross-border project or projects in which this technology is used. We are therefore unable to account for any time-cost tradeoffs, although Teece (1977:836) notes that "when the transferred technology involves a change in the state of the art [as is likely to be the case with more radical technologies], the extra costs of speeding a project would seem to be considerable" (see also Kriz and Welch, 2018). As such, it would be interesting to study the extent to which the speed of technology transfer depends on the radicalness of the underlying technologies, and whether this would refine our findings.

Another limitation of this research is that all countries in our analysis are grouped according to the perceived level of IP protection, and this does not allow us to control for other country-specific factors that might be important for R&D internationalization (e.g., institutional context; see Alcácer and Chung, 2007; Cantwell, 2009; Cantwell *et al.*, 2010). Future studies may address this issue by investigating if country-level IP protection should be combined with other institutional arrangements to induce changes in the firm's cross-border behavior when it comes to exploration and exploitation R&D projects that draw on more radical technologies.

Further, our empirical framework does not address the causality between technological radicalness and the internationalization of R&D activities. As previous studies have suggested, the firm's technological knowledge can increase through internationalization (see Cantwell and Piscitello, 2000). Hence, R&D internationalization per se is likely to have a positive impact on the firm's future technologies. We are thus unable to employ techniques such as instrumental variables analysis because it is difficult to find an instrument that does not violate the exclusion restriction. Future studies may establish the direction of the relationships under consideration.

Finally, in this study, we concentrate on large companies, while small and medium-sized firms may face different environmental – both external and internal – constraints and, as such, come up with very different responses to the challenges of R&D internationalization, including those that involve leveraging technological resources (see Calof, 1993; Calof, 1994; Zahra, 2005). Future studies may look at such firms to gain more insights into the association between technological radicalness and the internationalization of R&D activities.

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Table 1. Descriptive statistics

No.	Variable	Mean	Standard deviation	Min	Max
1	Exploration R&D projects: All countries	0.243	0.809	0.000	11.000
2	Exploration R&D projects: Countries with *weaker* IP protection	0.132	0.514	0.000	7.000
3	Exploration R&D projects: Countries with *stronger* IP protection	0.111	0.463	0.000	6.000
4	Exploitation R&D projects: All countries	0.100	0.560	0.000	10.000
5	Exploitation R&D projects: Countries with *weaker* IP protection	0.067	0.411	0.000	7.000
6	Exploitation R&D projects: Countries with *stronger* IP protection	0.033	0.252	0.000	5.000
7	Technological radicalness	0.362	0.231	0.000	1.000
8	Company size*	9.316	1.430	5.298	12.765
9	Company age	38.935	17.417	4.000	63.000
10	Sales growth	0.058	0.188	-0.817	2.346
11	Sales intensity	1.001	0.438	0.119	3.437
12	Capital intensity	0.097	0.195	0.006	6.724
13	R&D intensity	0.041	0.044	0.000	0.252
14	Tobin's q	1.874	0.911	0.533	9.664
15	Return on assets	0.055	0.088	-0.853	0.953
16	Book leverage	0.222	0.152	0.000	1.395

The table presents the means and standard deviations for the study variables. The asterisk (*) denotes the natural logarithm of a variable.

Table 2. The correlation matrix

No.	Variable	1	2	3	4	5	6	7	8	9	10	11	12
1	Exploration R&D projects: All countries	1.000											
2	Exploitation R&D projects: All countries	**0.454**	1.000										
3	Technological radicalness	**0.072**	**0.052**	1.000									
4	Company size*	**0.307**	**0.264**	0.029	1.000								
5	Company age	**0.124**	**0.140**	**0.100**	**0.505**	1.000							
6	Sales growth	-0.014	-0.006	-0.004	-0.043	**-0.130**	1.000						
7	Sales intensity	**-0.131**	**-0.086**	**-0.073**	**0.081**	0.036	**0.050**	1.000					
8	Capital intensity	0.005	0.018	**0.084**	-0.019	**0.059**	**-0.077**	0.007	1.000				
9	R&D intensity	**0.090**	-0.014	**0.216**	**-0.304**	**-0.334**	0.041	**-0.223**	**-0.110**	1.000			
10	Tobin's q	0.039	-0.028	**0.060**	0.024	**-0.128**	**0.150**	0.004	**-0.074**	**0.199**	1.000		
11	Return on assets	**0.048**	0.009	0.025	**0.152**	**0.083**	**0.256**	**0.139**	-0.006	**-0.049**	**0.478**	1.000	
12	Book leverage	-0.027	**0.054**	**-0.056**	**0.146**	**0.120**	**-0.054**	**-0.065**	0.038	**-0.284**	**-0.122**	**-0.156**	1.000

The table presents Pearson's pairwise correlations for the study variables. The asterisk (*) denotes the natural logarithm of a variable. Pearson's correlation coefficients in bold are those that are significant at the 5% level or better.

Table 3. Regression analysis: Exploration R&D projects

Dependent variable: The number of exploration R&D projects $_{i,t}$	Controls only	All countries	Countries' level of IP protection: weaker	Countries' level of IP protection: stronger
	Model 1	*Model 2*	*Model 3*	*Model 4*
Technological radicalness $_{i,t}$		**0.905**** *(0.360)*	0.917 *(0.626)*	**1.013***** *(0.361)*
Company size $_{i,t-1}$	**0.689***** *(0.079)*	**0.692***** *(0.076)*	**0.636***** *(0.070)*	**0.787***** *(0.135)*
Company age $_{i,t-1}$	**-0.099***** *(0.024)*	**-0.091***** *(0.025)*	**-0.091***** *(0.019)*	**-0.085**** *(0.039)*
Company age^2 $_{i,t-1}$	**0.0014***** *(0.0003)*	**0.0012***** *(0.0003)*	**0.0013***** *(0.0002)*	**0.0011**** *(0.0005)*
Sales growth $_{i,t-1}$	0.174 *(0.308)*	0.168 *(0.315)*	**0.374*** *(0.216)*	-0.163 *(0.569)*
Sales intensity $_{i,t-1}$	-0.493 *(0.463)*	-0.529 *(0.459)*	-0.568 *(0.472)*	-0.434 *(0.531)*
Capital intensity $_{i,t-1}$	3.003 *(2.034)*	2.683 *(1.955)*	2.885 *(2.526)*	2.569 *(1.693)*
R&D intensity $_{i,t-1}$	**5.840***** *(1.301)*	**5.708***** *(1.060)*	**5.745***** *(1.393)*	**5.289***** *(1.474)*
Tobin's q $_{i,t-1}$	0.120 *(0.101)*	0.0871 *(0.112)*	0.144 *(0.118)*	0.0236 *(0.109)*
Return on assets $_{i,t-1}$	-1.053 *(0.688)*	-1.072 *(0.661)*	**-1.908***** *(0.656)*	-0.0664 *(0.819)*
Book leverage $_{i,t-1}$	**-2.190***** *(0.515)*	**-2.314***** *(0.471)*	**-1.395***** *(0.472)*	**-3.668***** *(0.521)*
Firm fixed effects	**0.00015***** *(0.00005)*	**0.00016***** *(0.00004)*	**0.00009*** *(0.00005)*	**0.00025***** *(0.00006)*
Industry fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Log pseudolikelihood	-887.150	-883.594	-607.306	-494.617
Number of observations	1,850	1,850	1,850	1,850

* 10% significance; ** 5% significance; *** 1% significance

Standard errors (in parentheses) are clustered at the firm and the industry level. Firm fixed effects are calculated as the five-year pre-sample mean of the income from the firm's foreign operations (before taxes). Industry fixed effects are based on the Standard Industrial Classification (SIC).

Table 4. Regression analysis: Exploitation R&D projects

Dependent variables: The number of exploitation R&D projects $_{i,t}$	Controls only	All countries	Countries' level of IP protection: weaker	Countries' level of IP protection: stronger
	Model 5	*Model 6*	*Model 7*	*Model 8*
Technological radicalness $_{i,t}$		**1.704**** *(0.746)*	**1.977***** *(0.699)*	1.507 *(1.011)*
Company size $_{i,t-1}$	**0.929***** *(0.112)*	**0.934***** *(0.115)*	**0.891***** *(0.070)*	**1.063***** *(0.267)*
Company age $_{i,t-1}$	**-0.083***** *(0.030)*	**-0.060**** *(0.026)*	**-0.135***** *(0.026)*	**0.143**** *(0.060)*
Company age^2 $_{i,t-1}$	**0.0013***** *(0.0005)*	**0.0009**** *(0.0004)*	**0.0019***** *(0.0004)*	**-0.0018***** *(0.0007)*
Sales growth $_{i,t-1}$	-0.425 *(0.616)*	-0.383 *(0.611)*	-0.450 *(1.083)*	-0.202 *(0.673)*
Sales intensity $_{i,t-1}$	0.0968 *(0.332)*	-0.0183 *(0.328)*	-0.404 *(0.294)*	0.293 *(0.710)*
Capital intensity $_{i,t-1}$	**5.031***** *(1.275)*	**4.136***** *(1.203)*	**2.687** *(1.981)*	**6.350***** *(1.704)*
R&D intensity $_{i,t-1}$	2.022 *(7.130)*	2.673 *(6.490)*	0.009 *(8.757)*	**6.556*** *(3.965)*
Tobin's q $_{i,t-1}$	-0.171 *(0.145)*	**-0.286*** *(0.153)*	-0.239 *(0.223)*	**-0.397***** *(0.107)*
Return on assets $_{i,t-1}$	-0.183 *(2.161)*	-0.315 *(2.236)*	0.542 *(2.220)*	-1.633 *(2.027)*
Book leverage $_{i,t-1}$	-1.074 *(1.244)*	-1.388 *(1.154)*	**-2.344**** *(1.018)*	0.089 *(1.473)*
Firm fixed effects	**0.00018**** *(0.00009)*	**0.00020***** *(0.00007)*	**0.00017*** *(0.00009)*	**0.00025**** *(0.00011)*
Industry fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Log pseudolikelihood	-381.002	-377.605	-301.434	-150.984
Number of observations	1,850	1,850	1,850	1,850

* 10% significance; ** 5% significance; *** 1% significance

Standard errors (in parentheses) are clustered at the firm and the industry level. Firm fixed effects are calculated as the five-year pre-sample mean of the income from the firm's foreign operations (before taxes). Industry fixed effects are based on the Standard Industrial Classification (SIC).

Figure 1. The conceptual framework

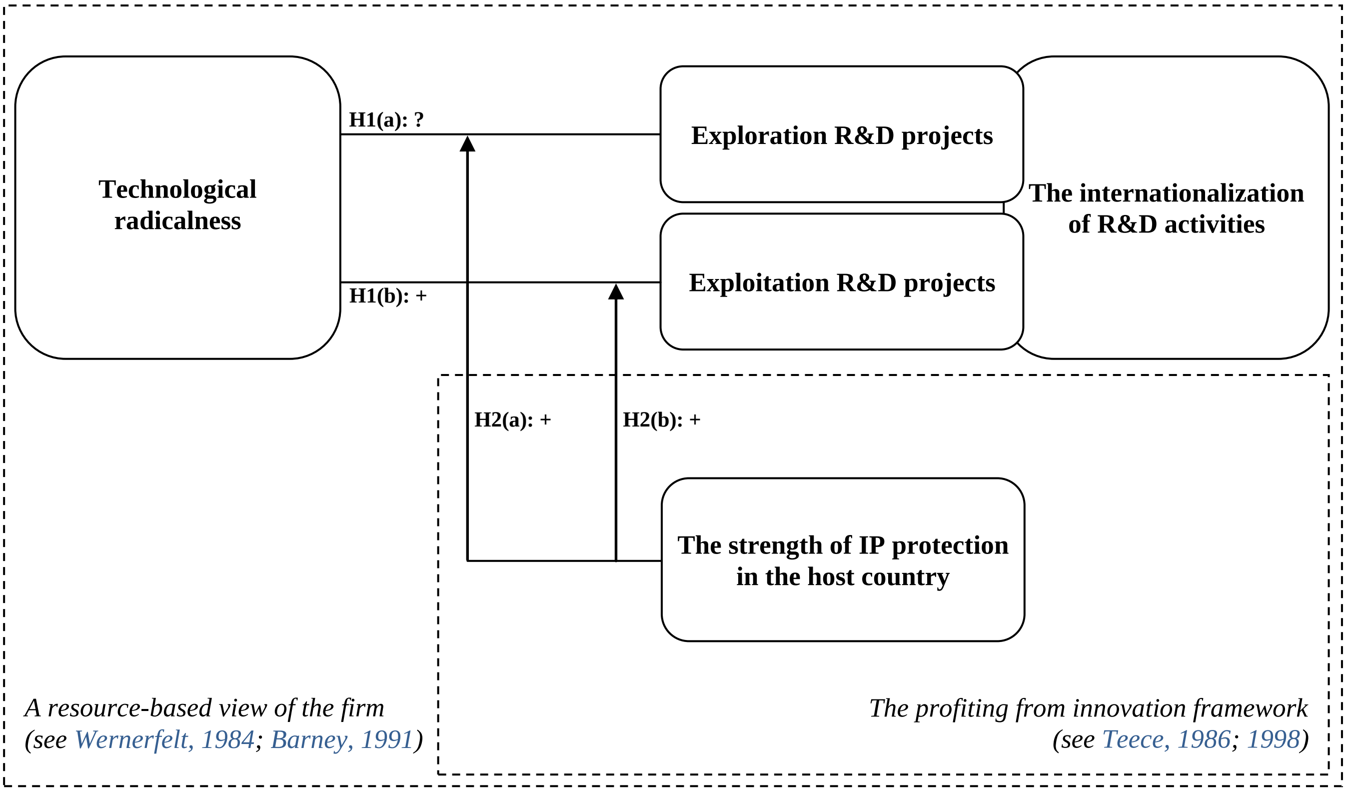
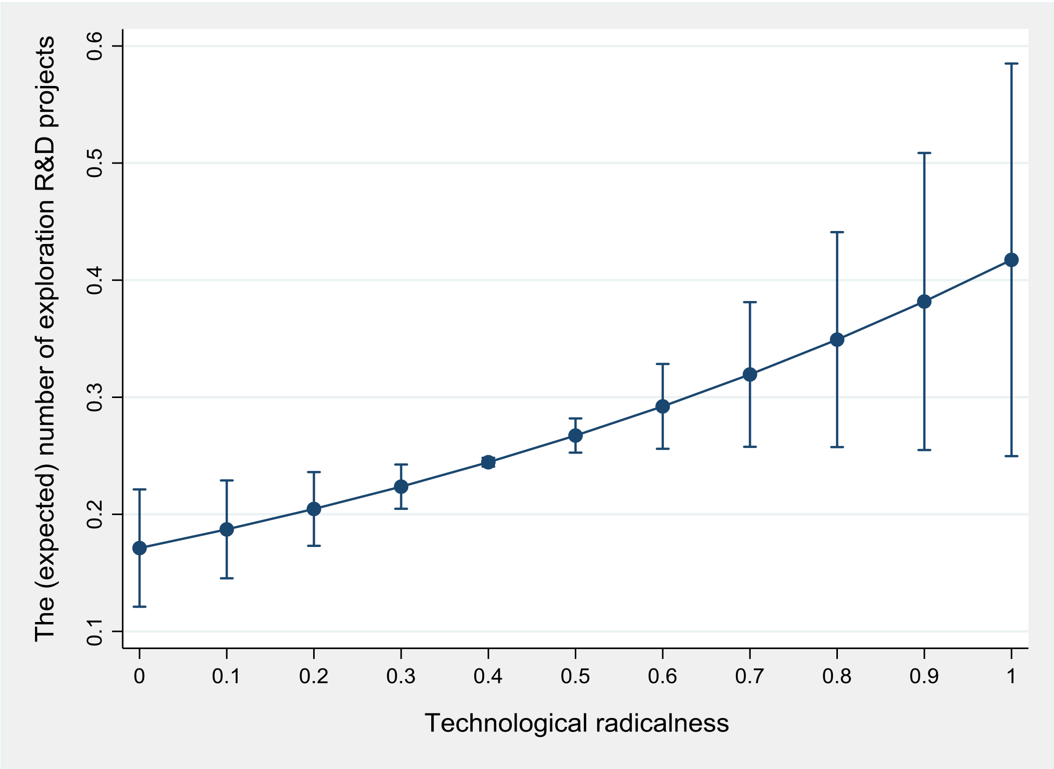


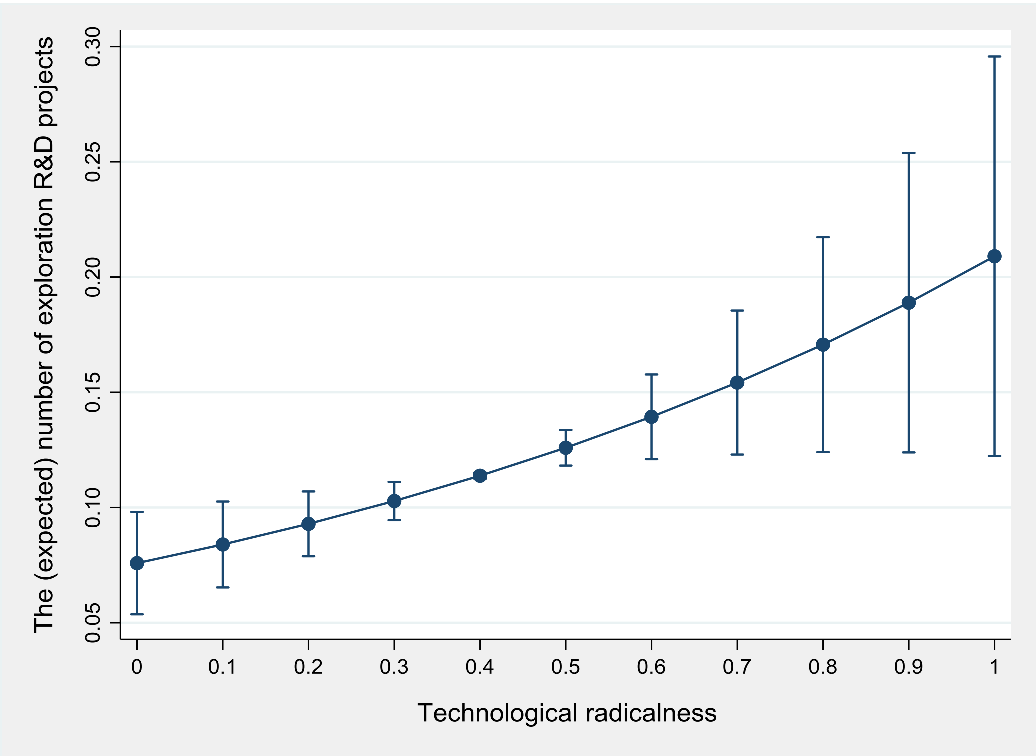
Figure 2. Marginal effects of technological radicalness on exploration R&D projects

a) all countries (based on Model 2)



Note: all marginal effects are significant at the 1% level or better.

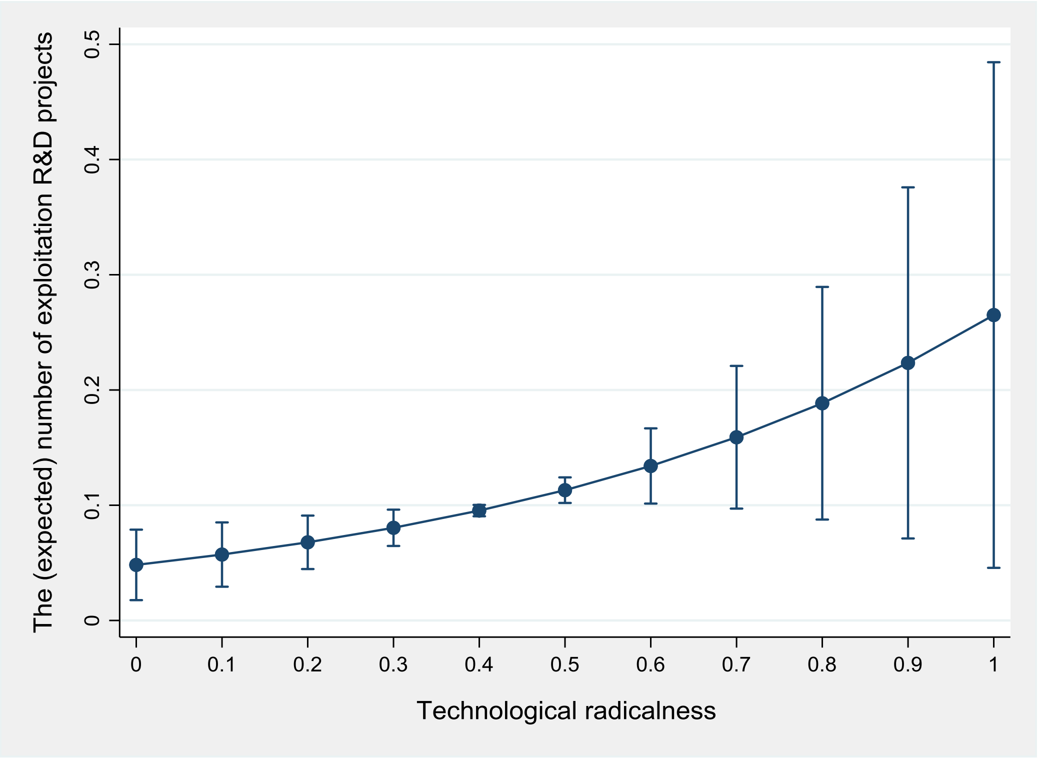
b) countries with *stronger* IP protection (based on Model 4)



Note: all marginal effects are significant at the 1% level or better.

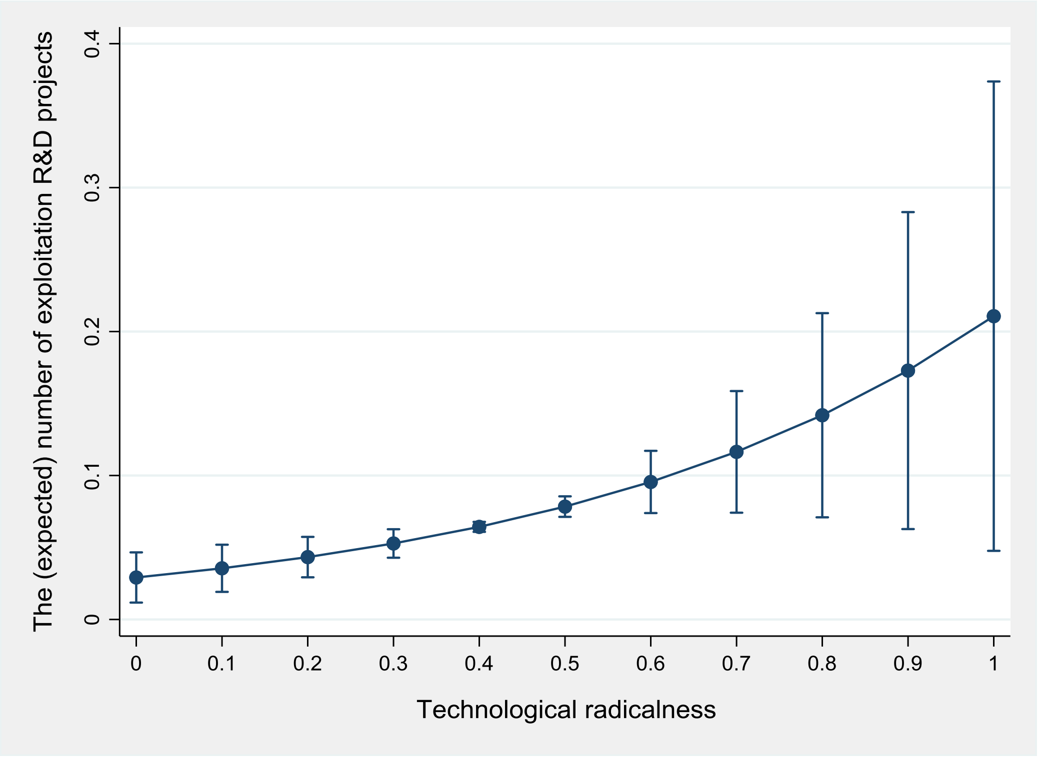
Figure 3. Marginal effects of technological radicalness on exploitation R&D projects

a) all countries (based on Model 6)



Note: all marginal effects are significant at the 5% level or better.

b) countries with *weaker* IP protection (based on Model 7)



Note: all marginal effects are significant at the 5% level or better.

APPENDIX A. SUPPLEMENTARY INFORMATION AND THE RESULTS OF ROBUSTNESS CHECKS

Table A1. Study variables and data sources

Name	Description	Source
Dependent variables		
Exploration R&D projects*	The number of R&D, design, development, and testing projects started by the firm in the given country in the given year if the firm started *no* other greenfield FDI types in that country in that year.	The Financial Times fDi Markets database
Exploitation R&D projects*	The number of R&D, design, development, and testing projects started by the firm in the given country in the given year if the firm also started other greenfield FDI types in that country in that year.	
Explanatory variables		
Technological radicalness	The score on the patent radicalness index R_p for Patent p is calculated using the following formula: $R_p = \sum_{j}^{n_p} \frac{CT_j}{n_p}$ $so\ that\ IPC_{pj} \neq IPC_p$, where CT_j is the number of IPC 4-digit classes (IPC_{pj}) of Patent j cited in Patent p that are different from Patent p's IPC 4-digit classes (IPC_p); n is the number of IPC classes in the backward citations counted at the most disaggregated level available (up to the fifth hierarchical level).	The OECD Patent Quality Indicators database
Control variables		
Company size	The logarithm of the total number of employees.	The S&P Compustat North America database
Company age	The difference between the current year and the year to which the firm traces its origin.	
Sales growth	Total sales in Year *t* minus total sales in Year *t-1* divided by total sales in Year *t-1*.	
Sales intensity	The ratio of total sales to total assets.	
Capital intensity	The ratio of the total net value of the firm's property, plant, and equipment to the total number of its employees.	
R&D intensity	The ratio of R&D spending to total assets.	
Tobin's q	The ratio of total assets plus outstanding common shares multiplied by the close price of a share minus the total value of common equity to total assets.	
Return on assets	The ratio of income before extraordinary items to total assets.	
Book leverage	The ratio of long-term debt plus current liabilities to total assets.	

* We draw on a yearly survey published in the World Economic Forum's *Global Competitiveness Report* in order to decompose this variable further. More specifically, we regard cross-border projects as being set in countries with *weaker/ stronger* IP protection if the respondents to the survey, when answering the question: "In your country, to what extent is intellectual property protected?", chose 1–4 for weaker/5–7 for stronger IP protection.

Table A2. The classification of countries by the level of IP protection

Countries with stronger IP protection (in at least one year during the period 2003–2013)			**Countries with weaker IP protection** (in each year during the period 2003–2013)			
No.	**Country**	**Number of periods***	**No.**	**Country**	**No.**	**Country**
1	Australia	11	1	Afghanistan	36	Lithuania
2	Austria	11	2	Algeria	37	FYR Macedonia
3	Belgium	11	3	Angola	38	Malta
4	Canada	11	4	Argentina	39	Mexico
5	Denmark	11	5	Aruba	40	Moldova
6	Finland	11	6	Azerbaijan	41	Mongolia
7	France	11	7	Bangladesh	42	Morocco
8	Germany	11	8	Brazil	43	Mozambique
9	Hong Kong	11	9	Bulgaria	44	Myanmar
10	Luxembourg	11	10	Cambodia	45	Nigeria
11	Netherlands	11	11	Chile	46	Pakistan
12	New Zealand	11	12	China	47	Panama
13	Norway	11	13	Colombia	48	Papua New Guinea
14	Singapore	11	14	Costa Rica	49	Paraguay
15	Sweden	11	15	Czech Republic	50	Peru
16	Switzerland	11	16	Egypt	51	Philippines
17	United Kingdom	11	17	El Salvador	52	Poland
18	Ireland	10	18	Estonia	53	Romania
19	Japan	10	19	Ghana	54	Russia
20	Iceland	9	20	Greece	55	Serbia
21	South Africa	9	21	Guatemala	56	Slovakia
22	Qatar	6	22	Guinea	57	Somalia
23	United Arab Emirates	6	23	Honduras	58	Spain
24	Israel	5	24	Hungary	59	Suriname
25	Malaysia	5	25	India	60	Tajikistan
26	Bahrain	4	26	Indonesia	61	Tanzania
27	Taiwan	4	27	Iraq	62	Thailand
28	Saudi Arabia	3	28	Italy	63	Tunisia
29	Portugal	1	29	Jamaica	64	Turkey
30	South Korea	1	30	Jordan	65	Ukraine
			31	Kazakhstan	66	Uruguay
			32	Kenya	67	Venezuela
			33	Kuwait	68	Vietnam
			34	Laos		
			35	Latvia		

* The number of years (out of 11) when the IP protection index is equal to or greater than 5.

Table A3. Alternative estimation methods: Exploration R&D projects

Dependent variable: The number of exploration R&D projects $_{i, t}$	**Negative binomial**			**Tobit**		
	All	*Weaker IP*	*Stronger IP*	*All*	*Weaker IP*	*Stronger IP*
	Model A3.1	Model A3.2	Model A3.3	Model A3.4	Model A3.5	Model A3.6
Technological radicalness $_{i, t}$	**0.571***	0.679	**0.823****	0.403	0.492	**0.722***
	(0.310)	*(0.591)*	*(0.352)*	*(0.369)*	*(0.614)*	*(0.375)*
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudolikelihood	-844.452	-587.178	-485.437	-939.121	-668.791	-541.593
Number of observations	1,850	1,850	1,850	1,850	1,850	1,850

* 10% significance; ** 5% significance; *** 1% significance.

Standard errors (in parentheses) are clustered at the firm and the industry level. Firm fixed effects are calculated as the five-year pre-sample mean of the income from the firm's foreign operations (before taxes). Industry fixed effects are based on the Standard Industrial Classification (SIC).

Table A4. Alternative estimation methods: Exploitation R&D projects

Dependent variable: The number of exploitation R&D projects $_{i, t}$	**Negative binomial**			**Tobit**		
	All	*Weaker IP*	*Stronger IP*	*All*	*Weaker IP*	*Stronger IP*
	Model A4.1	Model A4.2	Model A4.3	Model A4.4	Model A4.5	Model A4.6
Technological radicalness $_{i, t}$	**1.320****	**1.700****	1.253	**1.494****	**2.015*****	0.605
	(0.651)	*(0.696)*	*(1.104)*	*(0.606)*	*(0.605)*	*(1.008)*
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudolikelihood	-367.108	-289.626	-151.514	-416.449	-325.519	-173.935
Number of observations	1,850	1,850	1,850	1,850	1,850	1,850

* 10% significance; ** 5% significance; *** 1% significance.

Standard errors (in parentheses) are clustered at the firm and the industry level. Firm fixed effects are calculated as the five-year pre-sample mean of the income from the firm's foreign operations (before taxes). Industry fixed effects are based on the Standard Industrial Classification (SIC).

Table A5. Alternative cut-off points for the WEF index: Exploration R&D projects

Dependent variable: The number of exploration R&D projects $_{i,t}$	**WEF index ≥ 4**		**WEF index ≥ 5**		**WEF index ≥ 6**	
	Weaker IP	*Stronger IP*	*Weaker IP*	*Stronger IP*	*Weaker IP*	*Stronger IP*
	Model A5.1	Model A5.2	Model A5.3	Model A5.4	Model A5.5	Model A5.6
Technological radicalness $_{i,t}$	0.795 *(0.710)*	**1.006***** *(0.265)*	0.917 *(0.626)*	**1.013***** *(0.361)*	**0.786**** *(0.380)*	**2.304**** *(1.031)*
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudolikelihood	-423.687	-544.393	-607.306	-494.617	-708.032	-153.264
Number of observations	1,850	1,850	1,850	1,850	1,850	1,850

* 10% significance; ** 5% significance; *** 1% significance.

Standard errors (in parentheses) are clustered at the firm and the industry level. Firm fixed effects are calculated as the five-year pre-sample mean of the income from the firm's foreign operations (before taxes). Industry fixed effects are based on the Standard Industrial Classification (SIC).

Table A6. Alternative cut-off points for the WEF index: Exploitation R&D projects

Dependent variable: The number of exploitation R&D projects $_{i,t}$	**WEF index ≥ 4**		**WEF index ≥ 5**		**WEF index ≥ 6**	
	Weaker IP	*Stronger IP*	*Weaker IP*	*Stronger IP*	*Weaker IP*	*Stronger IP*
	Model A6.1	Model A6.2	Model A6.3	Model A6.4	Model A6.5	Model A6.6
Technological radicalness $_{i,t}$	**1.642***** *(0.537)*	2.258 *(1.437)*	**1.977***** *(0.699)*	1.507 *(1.011)*	**1.670***** *(0.534)*	**12.74***** *(4.402)*
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudolikelihood	-248.676	-178.167	-301.434	-150.984	-342.017	-14.562
Number of observations	1,850	1,850	1,850	1,850	1,850	1,850

* 10% significance; ** 5% significance; *** 1% significance.

Standard errors (in parentheses) are clustered at the firm and the industry level. Firm fixed effects are calculated as the five-year pre-sample mean of the income from the firm's foreign operations (before taxes). Industry fixed effects are based on the Standard Industrial Classification (SIC).

Table A7. Alternative lag structures for the explanatory variable: Exploration R&D projects

Dependent variable: The number of exploration R&D projects $_{i,t}$	**Contemporaneous**			**Lag T-1**			**Lag T-2**			**Lag T-3**		
	All	*Weaker IP*	*Stronger IP*	*All*	*Weaker IP*	*Stronger IP*	*All*	*Weaker IP*	*Stronger IP*	*All*	*Weaker IP*	*Stronger IP*
	Model A7.1	Model A7.2	Model A7.3	Model A7.4	Model A7.5	Model A7.6	Model A7.7	Model A7.8	Model A7.9	Model A7.10	Model A7.11	Model A7.12
Technological radicalness $_{i,\ t}$	**0.905**** *(0.360)*	0.917 *(0.626)*	**1.013***** *(0.361)*									
Technological radicalness $_{i,\ t-1}$				**0.846***** *(0.316)*	**1.179**** *(0.567)*	0.509 *(0.399)*						
Technological radicalness $_{i,\ t-2}$							**0.982***** *(0.334)*	**1.487***** *(0.550)*	0.433 *(0.316)*			
Technological radicalness $_{i,\ t-3}$										**0.896***** *(0.341)*	**1.421***** *(0.448)*	0.370 *(0.413)*
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudolikelihood	-883.594	-607.306	-494.617	-884.174	-606.169	-496.012	-824.193	-559.581	-465.625	-727.687	-486.315	-422.904
Number of observations	1,850	1,850	1,850	1,850	1,850	1,850	1,665	1,665	1,665	1,480	1,480	1,480

* 10% significance; ** 5% significance; *** 1% significance.

Standard errors (in parentheses) are clustered at the firm and the industry level. Firm fixed effects are calculated as the five-year pre-sample mean of the income from the firm's foreign operations (before taxes). Industry fixed effects are based on the Standard Industrial Classification (SIC). Firm controls are lagged by one period in all models.

Table A8. Alternative lag structures for the explanatory variable: Exploitation R&D projects

Dependent variable: The number of exploitation R&D projects $_{i,t}$	**Contemporaneous**			**Lag T-1**			**Lag T-2**			**Lag T-3**		
	All	*Weaker IP*	*Stronger IP*	*All*	*Weaker IP*	*Stronger IP*	*All*	*Weaker IP*	*Stronger IP*	*All*	*Weaker IP*	*Stronger IP*
	Model A8.1	Model A8.2	Model A8.3	Model A8.4	Model A8.5	Model A8.6	Model A8.7	Model A8.8	Model A8.9	Model A8.10	Model A8.11	Model A8.12
Technological radicalness $_{i,t}$	**1.704**** *(0.746)*	**1.977***** *(0.699)*	1.507 *(1.011)*									
Technological radicalness $_{i,t-1}$				0.678 *(0.950)*	1.385 *(0.975)*	-0.661 *(0.817)*						
Technological radicalness $_{i,t-2}$							0.601 *(0.654)*	**1.761***** *(0.573)*	**-1.481***** *(0.513)*			
Technological radicalness $_{i,t-3}$										**1.518**** *(0.608)*	**2.493***** *(0.662)*	0.237 *(0.955)*
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudolikelihood	-377.605	-301.434	-150.984	-380.449	-302.984	-151.648	-355.162	-279.720	-145.681	-314.086	-247.634	-133.201
Number of observations	1,850	1,850	1,850	1,850	1,850	1,850	1,665	1,665	1,665	1,480	1,480	1,480

* 10% significance; ** 5% significance; *** 1% significance.

Standard errors (in parentheses) are clustered at the firm and the industry level. Firm fixed effects are calculated as the five-year pre-sample mean of the income from the firm's foreign operations (before taxes). Industry fixed effects are based on the Standard Industrial Classification (SIC). Firm controls are lagged by one period in all models.

Table A9. An alternative specification of the dependent variables:
The monetary values of exploration and exploitation R&D projects

Dependent variable: The monetary values of exploration and exploitation R&D projects $_{i, t}$	**Exploration R&D projects**			**Exploitation R&D projects**		
	All	*Weaker IP*	*Stronger IP*	*All*	*Weaker IP*	*Stronger IP*
	Model A9.1	Model A9.2	Model A9.3	Model A9.4	Model A9.5	Model A9.6
Technological radicalness $_{i, t}$	**1.712***** *(0.498)*	**0.975**** *(0.431)*	**2.925***** *(0.790)*	**7.681***** *(1.666)*	**2.521***** *(0.845)*	**8.743***** *(2.555)*
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudolikelihood	-21,252.966	-12,321.822	-14,008.935	-17,511.876	-9,875.470	-4,502.492
Number of observations	1,850	1,850	1,850	1,850	1,850	1,850

* 10% significance; ** 5% significance; *** 1% significance.

Standard errors (in parentheses) are clustered at the firm and the industry level. Firm fixed effects are calculated as the five-year pre-sample mean of the income from the firm's foreign operations (before taxes). Industry fixed effects are based on the Standard Industrial Classification (SIC).