

## Entry and Technological Performance in New Technology Domains: Technological Opportunities, Technology Competition and Technological Relatedness

**Bart Leten, Rene Belderbos and Bart Van Looy**

*KU Leuven, Vlerick Business School; KU Leuven, UNU-MERIT, Maastricht University; KU Leuven*

**ABSTRACT** Entry and success in new technology domains (NTDs) is essential for firms' long-term performance. We argue that firms' choices to enter NTDs and their subsequent performance in these domains are not only governed by firm-level factors but also by environmental characteristics. Entry is encouraged by the richness of opportunities for technology development, while technology competition by incumbent firms discourages entry and render entries that do take place less successful. Firms are expected to be positioned heterogeneously to recognize and capitalize on technological opportunities, depending on the presence of a related technology base. We find qualified support for these conjectures in a longitudinal analysis of entry and technological performance in NTDs by 176 R&D intensive firms. While opportunity rich technology environments attract entries by firms even if these NTDs are distal from firms' existing technologies, firms require related technological expertise in order to exploit technological opportunities post-entry.

**Keywords:** competition, entry, innovation, relatedness, technological opportunities, technology search

### INTRODUCTION

In 'Schumpeterian' industries, characterized by fast changes in products, technologies, customers and competitors, firms cannot rely exclusively on the strength of their existing core technological competences (Prahalad and Hamel, 1990). Firms have to continuously explore and exploit new and promising technologies at a faster pace and lower cost than their competitors to remain viable and successful in the longer term (Belderbos et al., 2010; Danneels and Sethi, 2011; Levinthal and March, 1993; Markides and

*Address for reprints:* Bart Leten, Faculty of Business and Economics, Department of Managerial Economics, Strategy and Innovation, KU Leuven, Belgium; Naamsestraat 69, B-3000 Leuven, Belgium (bart.leten@kuleuven.be).

Williamson, 1994; Simsek, 2009; Teece et al., 1997; Uotila et al., 2009). Building up capabilities in new technology domains (NTDs) enables firms to avoid lock-in dynamics in times of competence-destroying technological change (Cooper and Schendel, 1976; Tripsas, 1997; Tushman and Anderson, 1986) and provides them with a wider repertoire of problem-definition and problem-solving capabilities instrumental for R&D activities (Ahuja and Lampert, 2001; Hargadon and Sutton, 1997). Building up competences in NTDs is challenging as it involves considerable investments with long horizons under uncertainty (March, 1991; Mitchell and Singh, 1992). Failed attempts can disturb overall firm functioning and survival (Agarwal and Helfat, 2009; Mitchell and Singh, 1993). Hence, it is important to study the conditions under which firms can increase their chances of successfully entering NTDs.

Prior studies on the antecedents of the successful exploration of NTDs have focused on the organizational antecedents of technology exploration, such as autonomous decision-making in organizational units (Jansen et al., 2006; McGrath, 2001; O'Reilly and Tushman, 2008; Tushman and O'Reilly, 1996) and the presence of existing technology resources providing synergetic potential in the new domain (Breschi et al., 2003; Leten et al., 2007; Nesta and Saviotti, 2005; Van Looy et al., 2005). In the current study, we argue that this view of entry into NTDs is incomplete. In addition to organizational factors, the technology environment that firms face has crucial characteristics influencing not only if but also in what direction firms will be able to successfully explore NTDs. The role of organizational antecedents, in particular firms' existing technology resources and synergetic potential, can also differ substantially across heterogeneous technology environments. Considering simultaneously organizational characteristics and the technology environment is therefore essential to understand NTD entry and success.

We suggest that two characteristics of the technology environment have a salient influence on the direction and success of entry into NTDs. First, exploring NTDs will deliver more value if these NTDs hold the promise to spawn commercialization potential in the future. Such technology domains are considered to be rich in technological opportunities, defined in our study as the set of possibilities for exploitable technological advance in a technology domain (Klevorick et al., 1995; Levin et al., 1987; Scherer, 1965), and enabled by progress in science. Second, firms do not explore technologies in isolation but are competing with other firms in their attempts to establish a presence in NTDs. Just as the presence of strong competitors in product markets renders successful entry less likely, the presence of strong established competitors in a technology domain may present an important obstacle for newly entering firms to carve out their proprietary share of technology in this domain.

We develop hypotheses on the role of technological opportunities and technology competition in firms' entry into NTDs and their subsequent performance in these domains, drawing on, and integrating, insights stemming from the resource-based view of the firm and the industrial organization literature on R&D incentives and technological entry barriers (e.g., Henderson and Mitchell, 1997). We test these hypotheses in a longitudinal analysis (1996–2002) of entry and technological performance in a broad range of NTDs by 176 R&D-intensive USA, European and Japanese firms.

We find that technological opportunities in a technology domain attract entry in a rather indiscriminate manner, while the relationship between technological opportunities and post-entry performance is strongly moderated by firms' related existing technological expertise. The presence of strong technology positions held by incumbent firms in a technology domain both discourages entry and renders less successful those entries that do take place.

Our study makes several contributions to the literature. First, we respond to prior calls for more attention for the role of inter-firm dynamics in innovation studies by examining the role of technology competition in NTD entry (Katila and Chen, 2008; Katila et al., 2008; McGahan and Silverman, 2006). We demonstrate that building up a technological foothold is more difficult in concentrated NTDs in which incumbent firms can leverage their portfolios of technology assets to create entry barriers and obstacles to entrants' post-entry growth in a domain. Second, we contribute to the literature on (technology) exploration by demonstrating the crucial influence of environmental characteristics in determining the direction and success of search and by highlighting that organizational factors and the (technological) environment can strengthen or weaken each other's influences. Our findings thus suggest complementarities between perspectives that stress the environment as a key determinant of performance and resource-oriented theories that emphasize internal firm resources. Third, our findings contribute to the recent debate on whether distal or proximate search provides most advantages to firms (Gavetti, 2012; Winter, 2012). Our results can be interpreted as indicating that, while R&D intensive firms' responsiveness to technological opportunities is not constrained by prior technological expertise, technological success is most assured in case of proximate technology search. Finally, we inform the literature on technological opportunities (Klevorick et al., 1995; Shane, 2001; Teece et al., 1997) by demonstrating that the recognition of relevant technological opportunities is less constrained than effectively seizing these opportunities (e.g., Benner and Tripsas, 2012; Shane and Venkataraman, 2000; Zahra, 2008).

## **THEORY AND HYPOTHESES**

A generally accepted foundation for theorizing on the nature of entry activities in NTDs and firms' technological capabilities is the resource-based view of the firm. Early writings in this strand of literature (Barney, 1991; Penrose, 1959; Peteraf, 1993; Wernerfelt, 1984) emphasized that firms could achieve a competitive advantage by building up portfolios of valuable assets. Technology assets are considered as valuable as they are rare, imperfectly tradable, and hard to imitate due to their (partly) tacit nature and protection by intellectual property rights (Granstrand, 1998; Grant, 1996; Spender, 1996; Teece, 1980). More recent contributions stress that in rapidly changing and unpredictable environments a competitive advantage is only sustainable to the extent that firms continuously renew their assets and technological skills (Eisenhardt and Martin, 2000; Helfat et al., 2007; Markides and Williamson, 1994; Teece, 2007; Teece et al., 1997). Crucial in this process are the abilities to sense and seize emerging technological opportunities in the environment.

The specific role of the (technology) environment and the nature of opportunities has received less attention in resource-based theory and applications. The concept of opportunities instead has been a focus of attention in two other streams of literature: the entrepreneurship literature and the industrial organization literature. Within the entrepreneurship literature, opportunities are considered as constitutive for the phenomenon of entrepreneurship (e.g., Alvarez and Barney, 2013; Kirzner, 1973). New and potentially profitable ventures find their origin at the nexus of individual capabilities and opportunities (Shane and Venkataraman, 2000).<sup>[1]</sup>

In the industrial organization literature, the notion of opportunities has been developed in the specific context of R&D investments of firms and has an explicit focus on technologies. Technological opportunities are defined as comprising the set of possibilities for (exploitable) technological advance in a technology domain and, as such, provide an indication of the 'richness' of a technology domain (Scherer, 1965). Given the state of demand and the existing state of technology, new knowledge replenishes the set of technological opportunities and provides new possibilities to exploit in the future (Klevorick et al., 1995). Technological opportunities are considered as an observable characteristic of a technology domain that may change over time (e.g., as a function of technology life cycles). This conceptualization is in line with the notion of 'external enablers', advanced by Davidsson (2015) as part of an enriched re-conceptualization of entrepreneurial opportunities. External enablers are conceived as changes – e.g., in the state of scientific knowledge, regulation, demographics – that might trigger entrepreneurial initiative, i.e., the formation of new venture ideas (Davidsson, 2015).

In the present study on entry and success in NTDs, we focus on technological opportunities and the importance of science as the external enabler of such opportunities. Unfolding technological opportunities will affect entry and investment decisions of firms as they influence the incentives to invest in R&D (Belderbos et al., 2009; Jaffe, 1986; Levin and Reiss, 1984). While technological opportunities have been recognized as drivers of cross-industry variation in R&D intensity (Levin et al., 1985; Scherer, 1965), the impact of technological opportunities on the direction and success of firms' technology exploration efforts has not been examined.

A second environmental characteristic affecting entry into NTDs relates to the degree of (expected) competition from incumbent rival firms. The industrial organization literature has a rich tradition in examining the role of entry barriers raised by incumbent firms to thwart (market) entry and maintain market power (Bain, 1956; Sutton, 1998). Models of R&D rivalry have suggested that firms can use technology development – in particular, patent strategies – strategically to raise entry barriers and to discourage entry by potential entrants (Belderbos and Somers, 2015; Gilbert, 2005; Gilbert and Newbery, 1982; Reinganum, 1983). Such entry deterring strategies can improve the profitability of the incumbent firms (Ceccagnoli, 2009). The strength, incentives and behaviour of incumbent firms are therefore important factors to take into account by firms contemplating entry into specific NTDs.

In the remainder of this section, we develop hypotheses on the influence of these two environmental characteristics of technology domains – technological opportunities and technology competition- on the likelihood that firms enter into NTDs and their subsequent technological performance in these NTDs. We draw on both the industrial

organization literature and the resource-based theory of the firm to formulate our hypotheses.

### **Entry into New Technology Domains**

Firms scan their environments to identify newly emerging technological opportunities, in particular technological developments with market potential (Breschi et al., 2000; Teece, 2007). In technology-based industries, the discovery and exploitation of technological opportunities and emerging trajectories can be considered a 'dynamic' capability underlying sustainable competitive advantage (Gavetti, 2012; Katila and Mang, 2003; Teece, 2007; Zahra, 2008). High levels of technological opportunities exist in a technology domain to the extent that there is a continuous supply of new technological possibilities that can be exploited by firms to satisfy existing or latent market demands (Scherer, 1965). In some technology domains, technological opportunities may become depleted over time as cumulative resources are devoted to R&D and projects are completed, whilst in other technology domains technological opportunities are continuously re-created by scientific and technological discoveries (Breschi et al., 2000; Rosenberg, 1974; Zahra, 2008).

One important source of technological opportunities is scientific research (Klevorick et al., 1995; Levin et al., 1985). There are two important ways through which science generates opportunities for technological advance. First, it expands the pool of theory, data, technique and problem-solving capability that can be employed in industrial R&D. Second, scientific insights can directly open up new technological possibilities, proposing solutions to older practical problems, pointing to new avenues to pursue and occasionally even providing prototypes for elaboration and refinement (Fleming and Sorenson, 2004; Klevorick et al., 1995; Rosenberg, 1990). For example, successful scientific research on genes and DNA opened up a wide range of opportunities to develop new therapies and treatments, new seed varieties and new medical devices (Klevorick et al., 1995). Likewise, recent scientific insights in health and disease prevention, informed and spurred the growth of functional foods. Such scientific research creating technological opportunities leaves traces in subsequent technology development activities by firms in the form of references to scientific publications on patent documents (Arts et al., 2013; Schmoch, 2007; Van Looy et al., 2003, 2006).

Firms learn about technological opportunities in various ways: by reading (scientific) journals, examining patent data and the (scientific) references therein, attending industry events and workshops at universities, interacting with scientists and firms, and by conducting own R&D (Allen, 1977; Patel and Pavitt, 1997). They can also derive clues on technological opportunities through inferential learning by monitoring technology decisions and patenting behaviour of other firms (Bandura, 1986; Breschi et al., 2000; Huber, 1991; Katila and Chen, 2008). As technological opportunities become more visible, firms build up knowledge on the distribution of returns to R&D in particular technology domains. Klevorick et al. (1995) analogizes R&D to drawing balls from an urn, in which technological opportunities describe the distribution of values of the balls in the urn. When technological opportunities are high, the distribution of draws (i.e., R&D projects) has a higher mean and R&D is more likely to result in valuable inventions.

Hence, firms are likely to (re)allocate R&D resources to technology search and development into opportunity-rich technology domains.

In sum, technological opportunities are to an important extent driven by advances in scientific research, they become visible to firms in various ways (including reference patterns on patent data), and provide powerful incentives to firms to enter a NTD. This suggests the following hypothesis:

*Hypothesis 1:* The greater the technological opportunities in a new technology domain, the greater the likelihood that a firm enters into this technology domain.

Despite (widely) available means and ways to identify technological opportunities, firms are likely to be positioned heterogeneously to identify, accurately evaluate, and act upon technological opportunities in particular technology domains. We argue that the likelihood that firms recognize and act upon technological opportunities is greater if firms possess knowledge and experience in related technology domains.

New R&D projects are proposed by individuals and teams ingrained with technological knowledge, capabilities and heuristics reflecting their past experiences and technological specializations (Allen and Marquis, 1964; Dosi, 1982). Problem-definition processes are influenced by prior R&D experiences of individuals and teams. (Fleck, 1935; Kuhn, 1962; Lave, 1988). Results of past technology activities are taken as natural starting points for proposing and initiating new technological activities (Stuart and Podolny, 1996). Domains with rich technological opportunities may not be identified as such or may not be among the set of technologies considered for new search if they are situated far beyond the technology repertoire that is already present within the firm.

Prior experience of individuals and firms also affects internal selection processes (Nelson and Winter, 1982). Firms' R&D funds are allocated across R&D projects by management teams that have limited information-gathering, attention and information-processing abilities (Cyert and March, 1963; Ocasio, 1997; Simon, 1955, 1979). Under these conditions of bounded rationality, managers cannot attend equally to all available technological opportunities (Ocasio, 1997) and the direction of R&D allocations and technological search is influenced by accumulated set of beliefs on the best performing business models, future opportunities, and critical resources (Christensen, 1997; Prahalad and Bettis, 1986; Teece, 2007; Tripsas and Gavetti, 2000). Relatively stable beliefs and technological search routines simplify decision-making and filter how individuals and firms assess new technological opportunities (Barreto, 2012; Bercovitz et al., 1996; Grégoire et al., 2010; Gruber et al., 2012, 2013; Tripsas, 2009). Routines and beliefs tend to limit the search space of firms to opportunities located in the vicinity of existing (technological) resources (Benner and Tripsas, 2012; Christensen, 1997; Coen and Maritan, 2011; Tripsas and Gavetti, 2000). Bounded search reduces the probability that firms adequately assess the importance of technological opportunities situated beyond the scope of prior conducted technology activities.

The above arguments suggest that firms' technology exploration behaviour is constrained by cognitive limitations and experience of individuals and the organizations that they employ (Gruber et al., 2012, 2013; Nelson and Winter, 1982; Tripsas and Gavetti, 2000). These limitations hinder the identification and enactment of opportunities that are distal to the firms' existing technology resources. Technological

opportunities are more likely to lead to efforts to enter NTDs, the NTDs are proximate and related to the portfolio of technology resources of the firm. This leads to the following hypothesis:

*Hypothesis 2:* The technological relatedness between a new technology domain and a firm's existing technology base positively moderates the effect of technological opportunities on the likelihood that a firm enters into this technology domain.

Entry into NTDs is not only governed by differences in technological opportunities and firms' existing technological resources but is also influenced by the behaviour of rival firms – in particular, by incumbent firms with existing technology positions. Firms that have carved out strong technology positions enabling them to exploit their technology leadership have strong incentives to protect their positions (Gambardella et al., 2007; Gilbert and Newbery, 1982). A strong position within a technology domain can establish an at least temporary quasi-monopoly, allowing firms to extract higher rents from exploiting their technology, in particular when they possess significant complementary downstream assets (Arora and Fosfuri, 2003; Gambardella et al., 2007).

Incumbent firms can use different strategies to raise entry barriers and to reduce the attractiveness of entry into a technology domain. A primary strategy to raise such entry barriers is patent pre-emption (Cohen et al., 2002; Gambardella et al., 2007; Gilbert and Newbery, 1982; Granstrand, 1999; Grimpe and Hussinger, 2014). Patent pre-emption occurs when incumbents expand their patent portfolio scope by applying for patents on variants of existing technologies (e.g., Ceccagnoli, 2009; Cohen et al., 2002; Gilbert and Newbery, 1982; Schneider, 2008). Firms expand their patent portfolios strategically in order to reduce the options for rival and entrant firms to patent technology variants. Patent pre-emption entails the creation of 'patent fences' (Granstrand, 1999; Reitzig, 2004; Schneider, 2008) or 'patent walls' (Blind et al., 2006): i.e., broad groups of similar patents in a technology domain owned by a single firm. These patent fences reduce the 'space' in a domain for patent applications by new entrants. They hamper new entrants in technology development and successful patent applications by forcing the entrants to 'invent around' a portfolio of existing patents.

Patent pre-emption strategies are most often employed by large firms with strong patent portfolios (Blind et al., 2006; Cohen et al., 2002) and are found to have effective entry deterring effects in industries in which incumbents employ them to safeguard existing leadership positions (Ceccagnoli, 2009; Cockburn and MacGarvie, 2006). Hence, the greater the level of concentrated technology ownership in the hands of a limited number of incumbent firms in a technology domain, the more likely that these incumbent firms use their patent portfolios strategically to discourage entry. Potential entrants into a NTD characterized by concentrated patent ownership will have to face such entry barriers and will generally expect competition from incumbents aiming to protect their established position. This will discourage entry into these technology domains. We hypothesize:

*Hypothesis 3:* The higher the level of (expected) technology competition from incumbents in a new technology domain, the lower the likelihood that a firm enters into this domain.

## Technological Performance in New Technology Domains

Firms are positioned heterogeneously to benefit from emerging technological opportunities. We argue that the ability of firms to seize technological opportunities in NTDs depends on the relatedness between NTDs and firms' existing technology base. When firms recognize technological opportunities in more distal domains, such opportunities are most likely to be approached from the cognitive mind-sets and organizational routines that build on the current expertise and technology base (Bercovitz et al., 1996; Christensen, 1997). As existing routines and mind-sets may be less effective in distal domains, entry into distal NTDs is less likely to be successful. The pursuit of distal technological opportunities may also conflict with elements of a firm's identity (Benner and Tripsas, 2012; Tripsas, 2009) and create resistance from internal and external stakeholders (Gavetti, 2012).

The pursuit of distal technologies will render it less likely that a firm benefits from economies of scope and knowledge sharing in technology search and knowledge creation, as existing and distal new domains might have little synergetic potential (Henderson and Cockburn, 1996). Knowledge creation is a cumulative, path-dependent process, influenced by capabilities already present at the individual and organizational level (Cohen and Levinthal, 1990; Dosi, 1982; Teece et al., 1997; Van de Ven et al., 1989). Individuals learn through a process in which new understandings build on established concepts and ideas (Vygotsky, 1978). The ability to learn therefore increases when new technology domains are close to what is already known (Bierly et al., 2009; Cassiman and Veugelers, 2006; Cohen and Levinthal, 1990). An organization's ability to learn in turn depends on the ability of its individual members to learn, since organizational learning involves the joint contribution of individual members to define and solve problems (e.g., Helfat, 1994).

Hence, although technological opportunities imply the promise of increased technological performance, firms that have fewer possibilities to leverage existing technological knowledge into NTDs will be less well positioned to exploit technological opportunities in NTDs. These considerations lead to the following hypothesis:

*Hypothesis 4:* The technological relatedness between a new technology domain and a firm's existing technology base positively moderates the effect of technological opportunities on the firm's technological performance within the new technology domain.

The ability of firms to successfully build up a technology position in NTDs also depends on the strategic behaviour of the incumbent firms in the technology domain subsequent to entry. Firms that have overcome initial entry hurdles and that have developed potentially promising technologies in a NTD can still face important challenges stemming from incumbent firm behaviour. If only a few incumbents hold the 'secrets' of a particular technology, they have strong incentives to thwart efforts of new entrants to carve out a stronger patent position in the technology domain. Important means at their disposal in response to entry are restrictive licensing strategies and stepping up patent fencing efforts (Gambardella et al., 2007; Gilbert and Newbery, 1982).

In the case of defensive licensing, established firms refuse to license existing technologies to new entrants. They choose to forego profits from licensing patented technologies in order to block efforts by new entrants to establish a significant position in the technology domain (Arora and Fosfuri, 2003; Ziedonis, 2004). Defensive licensing can be an effective strategy to protect existing leadership positions of incumbents since innovations are cumulative and build further on prior innovations (Grindley and Teece, 1997; Reitzig, 2004; Scotchmer, 1991; Shapiro, 2000). Restricted access to technologies protected in prior patents can impede effective participation in new technology development by new entrants in the technology domain (Levin et al., 1987; Shapiro, 2000), reducing the likelihood that entrants are able to expand their patent position.

Incumbents can also escalate patent fencing strategies in response to entry into their technology domains (Cohen et al., 2002; Reitzig, 2004). If entrants are unable to 'invent around' the patent fences, they will be forced to search for technical solutions in less attractive areas of a technology domain, characterized by lower probabilities of successful innovation (Granstrand, 1999).

The above arguments suggest that firms entering into NTDs characterized by concentrated technology ownership will face tough 'post entry' conditions and will therefore be less able to develop a significant technological position in the NTD. This implies the following hypothesis:

*Hypothesis 5:* The higher the levels of (expected) technology competition from incumbents in a new technology domain, the lower the technological performance of a firm in the new technology domain

## DATA AND SAMPLE

We collected longitudinal data (1995–2002) on the technological activities of 176 firms operating in R&D intensive industries. The sample firms are Japanese, European and US firms with the largest R&D budgets in five industries: pharmaceuticals and biotechnology, chemicals, IT hardware (computers and communication equipment), electronics and electrical machinery, and non-electrical machinery. The firms are drawn from the '2004 EU industrial R&D investment scoreboard', which provides listings of the 500 most R&D intensive European and the 500 most R&D intensive non-European (mostly US and Japanese) firms.

Table I shows the number of sampled firms in each industry and region of origin. The firms are roughly equally distributed across industries and regions. The USA hosts the largest number of firms in the pharmaceuticals and biotechnology and IT hardware industries. Japan records the largest number of electronics and electrical machinery firms. The sample of European firms is equally distributed over the five sectors. Electronics and IT hardware firms are the largest, employing respectively 60,000 and 48,000 employees, on average. Chemical and non-electrical machinery firms are somewhat smaller and employ on average around 25,000 people. The pharmaceutical and biotechnology firms rank the lowest with an average number of 17,000 employees. Electronics and IT hardware firms have the largest average patent stocks (840 and 560,

Table I. Sample composition

<i>Sector</i>	<i>Region</i>			<i>Total</i>
	<i>Europe</i>	<i>Japan</i>	<i>USA</i>	
Chemicals	11	11	11	33
Electronics and Electrical Machinery	11	14	7	32
Non-Electrical Machinery	13	11	11	35
IT Hardware	13	12	16	41
Pharmaceuticals and Biotech	10	11	14	35
Total	58	59	59	176

respectively), followed by chemicals (461), pharmaceuticals and biotech (250) and non-electrical machinery (160).

We use patent data to construct indicators of firms' entry choices in NTDs and their technological performance in those NTDs. Patent data have the advantage that they are publicly available, cover long time series and contain detailed information on the technological content and ownership of inventions. Patent data also have their shortcomings: patent propensities vary across industries and firms, and patented inventions differ in technical and economic value (Griliches, 1990). The first concern implies limiting analyses to industries with a high propensity to patent, such as our sample industries (Arundel and Kabla, 1998). The second issue can be addressed by weighing patent counts by the number of forward patent citations they receive (Hall et al., 2005; Trajtenberg, 1990). Another potential disadvantage of using patents is that patents are a form of 'intermediate output' of the R&D process rather than the 'final output' such as actual product or process innovations.

Although patent-based indicators have their limitations, patents are found to correlate strongly with other indicators of technological activity such as expert rankings of companies' technological performance (Narin and Noma 1987) and the number of new product announcements in trade and technical journals (Hagedoorn and Cloudt, 2003; Narin and Noma, 1987). Patent-based indicators are extensively used in research on technological innovation (e.g., Ahuja and Lampert, 2001; Katila and Chen, 2008; Phene et al., 2006; Rosenkopf and Nerkar, 2001), and the literature has qualified patents as appropriate indicators of firms' technological activities.

We used patent filings with the European Patent Office (EPO) as the source of information on entry into NTDs. EPO data was preferred to USPTO data because of the unavailability of information in the USPTO on patent applications. The EPO publishes information on both patent applications and granted patents since its foundation in 1978, but the USPTO only published information on granted patents prior to 2001. Since patent applications provide the broadest available measure of firms' technological search, indicators of firms' technology exploration choices are preferably created from data on patent applications rather than on the subset of granted patents.

An application for a patent in a specific technology domain, which may or may not subsequently be granted, provides a clear indication that a firm is pursuing technology

development in the technology domain. Such technology development should be seen as having a minimum of substance, as the costs associated with drafting and applying for patents is such that insignificant inventions in the technology domain are unlikely to lead to patent filings (Van Pottelsberghe de la Potterie and François, 2009). The patent application is a broader measure than a patent grant, as the former is a closer indicator of technology development efforts, while the latter is closer to an indicator of success: a granted patent establishes an invention that is novel and potentially exploitable.

We constructed patent datasets of firms at the consolidated level, i.e., all patents of the parent firm and its consolidated (majority-owned) subsidiaries were collected. For this purpose, yearly lists of consolidated subsidiaries included in corporate annual reports, 10-K reports filed with the SEC in the USA and, for Japanese firms, information on foreign subsidiaries published by Toyo Keizai in the yearly ‘Directories of Japanese Overseas Investments’, were used. The consolidation was conducted on an annual basis to take into account changes in the group structure of firms over time. Using consolidated patent data is important to get a complete view of firms’ entries in NTDs, since a considerable share of firms’ patented inventions are developed in firms’ subsidiaries.

## MEASURES AND METHODS

We constructed two dependent variables, ‘entry into a NTD’ and ‘technological performance in a NTD’, from technology class information available from patent documents. The EPO classifies all patents in at least one eight-digit technology class, using the International Patent Classification System (IPC). Each of the approximately 64,000 technology classes stands for a particular technical function or application. Technology classes can be aggregated into 118 broader three-digit IPC classes, which we use in our study. An overview of the 118 technology domains is provided in Table II. When a patent contains multiple IPC three-digit technology codes, it is assigned to each of the technology domains.

### Entry into New Technology Domains

We examine entries into *new-to-the-firm* technology domains by the 176 firms during the period 1996–99. A technology domain is defined as *new-to-a-firm* in year  $t$ , if the firm did not patent in that technology domain during the prior five years. The assumption is that, a domain presents a new technology to the firm if the firm has not been active in it for a considerable time. In technology-intensive industries, the rate of technical change is fast. A firm’s technology stock in a technology domain depreciates and becomes obsolete when a firm is inactive in the technology domain for an extended period of time (Ahuja and Lampert, 2001). Prior research in technology-intensive industries has often considered a five-year window as appropriate for assessing the ‘newness’ of technology domains for firms (e.g., Ahuja and Lampert, 2001; Belderbos et al., 2010; Gilsing et al., 2008; Stuart and Podolny, 1996).

Our panel dataset (1996–99) consists of all firm-technology domain combinations that are new to the 176 firms. The firms were active on average in 20 technologies in their 5-year patent portfolios. Hence, close to 100 technology domains are, on average,

Table II. Technological opportunities by technology domain

<i>IPC</i>	<i>Technology Domain</i>	<i>Opportunities</i>	<i>IPC</i>	<i>Technology Domain</i>	<i>Opportunities</i>
A	<b>Human Necessities</b>				
A01	agriculture	2.126	C12	biochemistry	5.062
A21	baking	0.486	C13	sugar	0.768
A22	butchering	0.029	C14	skins, leather	0.130
A23	foods or foodstuffs	0.910	C21	metallurgy of iron	0.192
A24	tobacco	0.080	C22	metallurgy of (non-) ferrous alloys	0.333
A41	wearing apparel	0.015	C23	coating metallic material	0.485
A42	headwear	0.007	C25	electrolytic/electrophoretic processes	0.227
A43	footwear	0.008	C30	crystal growth	1.268
A44	jewellery	0.006	D	<b>Textiles, Paper</b>	
A45	hand or travelling articles	0.006	D01	threads and fibres	0.136
A46	brushware	0.010	D02	yarns	0.025
A47	furniture	0.007	D03	weaving	0.024
A61	medical, veterinary science	1.868	D04	braiding	0.036
A62	life-saving, fire-fighting	0.166	D05	sewing	0.000
A63	sports, games	0.048	D06	treatment of textiles	0.120
B	<b>Performing Operations, Transporting</b>		D07	ropes	0.019
B01	physical/chemical processes in general	0.369	D21	paper-making	0.124
B02	crushing, pulverizing	0.039	E	<b>Fixed Constructions</b>	
B03	separation of solid materials	0.245	E01	construction of roads	0.027
B04	centrifugal apparatus	0.024	E02	hydraulic engineering	0.040
B05	spraying, atomizing	0.105	E03	water supply	0.018
B06	generating/transmitting vibrations	0.226	E04	building	0.026
B07	separating solids from solids	0.071	E05	locks, keys	0.010
B08	cleaning	0.061	E06	doors, windows, shutters	0.017
B09	disposal of solid waste	0.390	E21	earth rock drilling	0.153
B21	mechanical metal-working	0.069	F	<b>Mechanical Engineering, Lightning, Heating</b>	
B22	casting, powder metallurgy	0.164	F01	machines/engines in general	0.055
B23	machine tools	0.074	F02	combustion engines	0.051
B24	grinding, polishing	0.051	F03	machines/engines for liquids	0.221
B25	hand tools	0.112	F04	positive-displacement machines	0.047
B26	hand cutting tools	0.016	F15	fluid-pressure actuators	0.124
B27	working/preserving wood	0.041	F16	engineering elements or units	0.030
			F17	storing/distributing gases/liquids	0.113

Table II. Continued

<i>IPC</i>	<i>Technology Domain</i>	<i>Opportunities</i>	<i>IPC</i>	<i>Technology Domain</i>	<i>Opportunities</i>
B28	working cement	0.044	F21	lighting	0.047
B29	working of plastics	0.080	F22	steam generation	0.100
B30	presses	0.021	F23	combustion apparatus	0.054
B31	making articles of paper	0.015	F24	heating	0.048
B32	layered products	0.073	F25	refrigeration, cooling	0.085
B41	printing	0.054	F26	drying	0.057
B42	book binding	0.034	F27	furnaces	0.083
B43	writing or drawing implements	0.010	F28	heat exchange in general	0.051
B44	decorative arts	0.067	F41	weapons	0.079
B60	vehicles in general	0.038	F42	ammunition	0.039
B61	railways	0.070	G	<b>Physics</b>	
B62	land vehicles	0.024	G01	measuring, testing	1.516
B63	ships	0.080	G02	optics	0.614
B64	aircraft, aviation	0.263	G03	photography	0.185
B65	conveying, packing	0.012	G04	horology	0.104
B66	hoisting, lifting	0.028	G05	controlling, regulating	0.319
B67	opening/closing bottles	0.007	G06	computing	0.800
B68	saddlery, upholstery	0.000	G07	checking-devices	0.117
C	<b>Chemistry, Metallurgy</b>		G08	signalling	0.157
C01	inorganic chemistry	0.569	G09	educating, cryptography	0.199
C02	treatment of water	0.224	G10	musical instruments	0.899
C03	glass	0.316	G11	information storage	0.245
C04	cements, concrete	0.317	G12	instrument details	0.660
C05	fertilizers	0.252	G21	nuclear physics	0.493
C06	explosives, matches	0.337	H	<b>Electricity</b>	
C07	organic chemistry	2.973	H01	electric elements	0.451
C08	organic macromolecular compounds	0.329	H02	generation/distribution electric power	0.177
C09	dyes, paints	0.263	H03	electronic circuitry	0.579
C10	petroleum, gas and coke	0.162	H04	electric communication technique	0.598
C11	animal/vegetable oils	0.367	H05	electric techniques (others)	0.199

*Notes:* The reported numbers for the technological opportunities measure are the average number of citations to scientific literature per EPO patent filed in the technology domain over the period 1995–2001.

yet to be explored by the sample firms. This resulted in a panel dataset (1996–99) with 17,305 new-to-the-firm technology domains and potential entry decisions at the firm-technology domain level. Entry took place in 7.5 per cent of the cases: 1,301 entries in NTDs are observed by 166 firms. These entries encompass 117 of the 118 technology domains. The final dataset for analysis is restricted to 17,191 firm-technology combinations and 1,288 entries after removing outliers situated in the domain of biochemistry (which we discuss further below). The broad range of technology domains represented among the entries facilitates identification of the influence of characteristics of technology domains on entry decisions.

The dependent variable ‘entry in a NTD’ takes the value ‘0’ if a firm remains inactive in a NTD, and is coded ‘1’ if the firm starts to explore the NTD, as evidenced by a patent application. Once a firm initiates activities in a NTD, the corresponding firm-technology domain observation is no longer considered as a (potential) entry in subsequent years.

We note that most of the NTD entries are originating from internal R&D activities. Only in 3 per cent of the cases entry took place via acquisitions, as indicated by patent applications in a NTD by a subsidiary that was acquired in the entry year. Empirical results are robust to the removal of the acquisition-driven entry cases from the analyses. Inspection of our data demonstrates that the low number of acquisition-driven entries is related to the fact that firms often first invest internally in a technology domain before specialized target firms are acquired with specific expertise in that technology domain.

Given the bivariate nature of the dependent variable (entry in a NTD) and the time dependence of the entry process, we use a duration model to examine the determinants of firms’ entries in NTDs. We opted for the semi-parametric Cox proportional hazard model (Cox, 1972) because this model requires no upfront assumption concerning the distributional properties of the hazard rate of entry. The Cox model allows the baseline hazard to be fitted from the data. Ex-post calculation of the baseline hazard showed a declining function: as time elapses and firms do not enter a particular NTD, it becomes less likely that they will enter the NTD later. This is a common feature of duration models and is (partly) the result of stability in firm preferences over time. The Cox model specifies the hazard that a firm  $i$  enters a NTD  $j$  as the product of a baseline hazard  $h_0(t)$  and a firm-specific hazard, with the latter modelled as an exponential function of the model parameters  $\beta_x$  and regressors  $x_{ij}$ :  $h(t|x_{ij}) = h_0(t) \cdot \exp(x_{ij} \cdot \beta_x) \cdot \alpha_i$

The model is augmented with a stochastic (random) firm-level component  $\alpha_i$  that corrects for possible unobserved firm-specific effects such as differences in internal R&D organization. The firm-level component, or ‘frailty’ term, enters the hazard function in a multiplicative manner and has a mean of 1 and a variance of  $\theta$ . If the estimate of  $\theta$  differs significantly from zero, then the null hypothesis of no firm-level heterogeneity is rejected.

### Technological Performance in New Technology Domains

We test the hypotheses on the technological performance of firms in NTDs by examining the characteristics of the 1,288 entries in NTDs that occurred between 1996 and 1999. The dependent variable ‘technological performance in a NTD’ is measured as the citation-weighted number of patent applications of a firm in the NTD over a fixed

period of three years subsequent to the entry year. In about half of the cases (53 per cent), entry in a NTD was unsuccessful and did not result in follow-up patents in the first three years subsequent to entry. On average, our sample firms filed 1.4 follow-up patents in the NTDs, with a wide variety across the entry cases, ranging between 0 and 41 patents. Since the number of forward citations to any patent depends on the length of the citation window (Hall et al., 2005; Trajtenberg, 1990), we follow prior work by calculating the number of forward citations over a fixed four-year time window (see Hall et al., 2007).

The dependent variable is a count variable. In this case, count data models are preferred to linear regression models as they explicitly take into account the non-negativity and discreteness of the dependent variable (Cameron and Trivedi, 1998). We employ Negative Binomial count data models that control for over-dispersion in the dependent variable. Standard errors are clustered at the firm level to control for correlations in error terms due to unobserved firm characteristics.

### **Technological Opportunities**

Following prior work (e.g., Duguet and MacGarvie, 2005; Klevorick et al., 1995; Levin et al., 1985), we measure variations between technology domains in technological opportunities by differences in the importance of science as a source of relevant knowledge in these technology domains. More specifically, we approximate the level of technological opportunities in a technology domain at time  $t$  by the average number of citations to scientific literature in patents filed in the technology domain in  $t-1$ . As such, our indicator of technological opportunities is akin to the notion of ‘external enablers’ of opportunities, advanced by Davidsson (2015), as the more ‘exogenous’ constituent of the individual-opportunity nexus.

The rationale for adopting this indicator is twofold. First, a considerable number of new exploitable technological opportunities find their origin in new scientific discoveries and insights. Indeed, empirical evidence has been provided that scientific activities – and scientific references in patent documents – are indicative of subsequent technological and industrial development on a larger scale (e.g., Schmoch, 2007; Van Looy et al., 2006). In this respect, the occurrence of scientific references signals the relevance of scientific research for technology development in the domain and is likely to precede and signal future growth. Second, the strongest technological opportunities are likely to be present during the early phases of the development of technology domains. Such periods are characterized by relatively lower levels of available technical prior art (i.e., prior patents). In order to assess claims of novelty, examiners rely more often on other sources and on scientific references in particular. Hence, the presence of scientific references on patent documents signals the ‘greenfield’ character of the technology domain – which is associated with ample future growth opportunities.<sup>[2]</sup>

The indicator of technological opportunities is calculated using all EPO patents applied for between 1995 and 2001. Patents cite a variety of non-patent literature – journals, books, newspapers, company reports, industry-related documents etc., which not all refer to scientific sources (Callaert et al., 2006; Harhoff et al., 2003). We identified the subset of scientific references exhaustively by applying the machine-learning algorithm developed by

Callaert et al. (2012). With this algorithm we classified approximately half of the non-patent references as scientific. This number is comparable to numbers reported in prior studies on the nature of non-patent references (Callaert et al., 2006; Harhoff et al., 2003; Leten et al., 2014; Van Vianen et al., 1990). The 623,615 EPO patents examined include altogether 415,593 references to scientific literature.

The average number of citations to scientific literature varies importantly across technology domains, as shown in Table II. The average science citation intensity across the 118 technology domains is 0.29 (cites per patent). About 5 per cent of the domains feature a citation intensity of more than one scientific reference per patent, while about half of the domains exhibit rather small science citation intensities with averages of one citation per 10 or 100 patents, or no citations at all. The number of citations to scientific literature is the highest in the technology domain *biochemistry* (including microbiology and genetic engineering) with a citation rate of five on average. Other technology domains scoring relatively high on citations to science are organic chemistry, agriculture, medical and veterinary science, measuring and testing, and crystal growth. Technology domains that rank particularly low in opportunities are saddlery and upholstery, sewing, hand or travelling articles, jewellery, and opening/closing bottles.

Given the particularly high citation ratio measured for the biochemistry field – about 20 times greater than the average value of opportunities across domains – we examined the robustness of our analysis with respect to these potential outlier observations.<sup>[3]</sup> We also explored the possibility of curvilinear effects of technological opportunities in the entry and technological performance analyses, by including a linear and a quadratic term in the analyses. The estimates suggest an inverted U-shaped relationship, with the inflection point situated almost exactly at the opportunity value for biochemistry. Once the approximately 1 per cent of biochemistry observations were omitted, the inverted U-shape disappeared. While science citations are a powerful indicator of opportunities across a wide variety of technology domains, this suggests that the indicator also has its limitations. In the biochemistry field characterized by an extremely high propensity to cite scientific literature, science may be constitutive for technology development rather than a relatively rare event signalling novel opportunities emerging from new scientific findings and insights. Our findings appear to suggest that for this – ‘extreme’ – technology domain, higher levels of science intensity may actually signal more extended timeframes and higher levels of uncertainty rather than immediately addressable opportunities. Considering this evidence, we chose to omit all observations pertaining to the biochemistry field from the remaining analyses.

We take the natural logarithm of the science citation ratio as our measure of technological opportunities to reduce the skewness in the distribution of the measure. Since we observe the value zero for a limited number of technology domains, we add the value one before applying the logarithmic transformation. This has the advantage that domains with zero citation intensity obtain the value zero after transformation.<sup>[4]</sup>

### **Technology Competition**

We measure entry barriers and the degree of expected post-entry competition from established incumbents by the level of concentrated technology ownership in each

technology domain. We obtain a measure of ownership concentration in a technology domain at time  $t$  by using assignee name harmonizing algorithms (Van Looy et al., 2006) to identify patents belonging to the same firms. This method allows us to calculate the technology concentration indices on (partially) consolidated firm patent portfolios.

The precise measure is constructed as follows. Let  $N_i$  be the number of patents that firm  $i$  owns in a technology domain and  $N$  the total number of patents in the technology domain. The level of technology concentration of a technology domain is defined as  $1/\sum_i(N_i/N)^2$ : the 'number equivalent' (the inverse) of the Herfindahl index of concentration, representing the number of firms over which patents would have to be equally distributed in order to yield the same value of the index. The number equivalent can take values in a range from 1 (all patents are owned by a single firm) to  $+\infty$  (fully distributed ownership) and has better distributional properties than the Herfindahl index itself (Lipczynski et al., 2001). We take the natural logarithm of this measure to reduce initial skewness in its distribution. Since higher values correspond to less concentrated technology ownership, we operationalize (expected) technology competition as minus the logarithmically transformed number equivalent.

### Technological Relatedness

To calculate the level of technological relatedness of a NTD and the firm's existing technology portfolio, we start from a technology relatedness measure for each pair of technology domains. We consider two technology domains as more related if the patents classified in these technology domains cite each other more frequently. Such cross-citations are indicative of a shared knowledge base (Leten et al., 2007) and the importance of a particular technology domain for technology development in the other domain.

We use citation data for all granted EPO patents applied for between 1990 and 2003. The technology-relatedness measure is calculated from 969,471 cited patents listed on 456,340 citing patents. By comparing the observed and expected (random) number of citations between two technology domains, symmetric pair-wise technology-relatedness measures can be calculated. Let  $O_{ij}$  be the observed number of cited patents of technology domain  $j$  listed on patents of technology domain  $i$ , with  $O_i = \sum_j O_{ij}$ . A technology domain has a higher random probability of being cited the more patents belong to the domain. Let  $N_j$  be the number of patents that are classified in technology domain  $j$ , with the total number of citable patents  $T = \sum_j N_j$ . Without assumptions on the distribution of citations across technology domains, this gives the following expression for the expected (random) number of cited patents of technology domain  $j$  in citing patents of technology domain  $i$ :  $(E_{ij}) = O_i * (N_j/T)$ . The relatedness of two technology domains  $i$  and  $j$  ( $R_{ij}$ ) is then calculated as the ratio between the actually observed number of citations  $(O_{ij} + O_{ji})$  and the expected number of citations  $(E_{ij} + E_{ji})$ .

The pairwise relatedness measures are subsequently used to calculate the average level of technological relatedness between a NTD and the firm's existing technology portfolio. The technology portfolio of a firm in year  $t$  consists of all patent applications in the past five years. With  $P_j$  the total number of patents in the portfolio (with a total size of  $P$ ) that are classified in technology domain  $j$ , this gives the following expression

for the level of technology relatedness of a NTD  $i$  and a firm's existing technology base:  $\sum_j (P_j/P) * R_{ij}$ .

### Control Variables

The analysis controls for a range of other factors that may affect firms' choices to enter NTDs and the subsequent technological performance of firms in these NTDs. First, we include an indicator for the size of a firm's existing *patent portfolio*, measured as the logarithm of the number of patents applied by the firm over the past five years. Firms with large technology portfolios are more experienced in innovation and may be better positioned to develop technological competences in NTDs.

Second, we control for differences in the size of firms' *R&D investments*, measured as one-year lagged R&D expenditures (expressed in billions of USD). Firms that marshal more R&D investments are more likely to start, and sustain, the exploration of NTDs. R&D expenditure data is collected from Compustat, Worldscope and firms' annual reports.

Third, we include an indicator for firms' economic performance: the *profit margin* measured as the ratio of net profits to sales. Firms with a better (prior) economic performance may have deeper pockets to (successfully) enter into NTDs; profitability may also reflect otherwise unmeasured firm heterogeneity and managerial competences. Because we have no profit margin information for a small number of observations (5 per cent), we add an additional variable (*no profit margin info*) that takes the value 1 for these observations (and  $-1$  otherwise).

Fourth, we add an indicator for the level of technology diversification present in a firm's technology (patent) portfolio. A diversified technology base implies a broader set of knowledge components that can be (re)combined to create new innovations (Fleming, 2001; Hargadon and Sutton, 1997; Leten et al., 1997; Schumpeter, 1934). Technologically diversified firms may therefore be more likely to enter into NTDs and achieve a higher technological performance in those NTDs. On the other hand, at the highest diversification levels firms may be less likely to enter (the remaining) NTDs because they have already entered the most attractive domains. To control for these influences, we include the variable *technology diversification*, measured as the 'spread' of patents in a firm's five-year patent portfolio over the 118 technology domains. The diversification variable is measured as the inverse of the Herfindahl index and takes higher values for diverse technology portfolios. To allow for a potentially more complex influence of technology diversification on entry in NTDs we include both the linear and the quadratic term in the entry analyses.

Fifth, we include an indicator of the level of *product diversification* of firms. Firms with a more diverse product portfolio may be more inclined to build up competences in NTDs and may be more persistent in their endeavours in NTDs, as more products may simultaneously benefit from new technologies (Granstrand, 1998; Piscitello, 2004). The product diversification variable is measured as one minus the Herfindahl of the spread of firms' sales over the four-digit SIC industries in which a firm has reported sales (source: Compustat and firms' annual reports). Since we lack information for a small number of observations (8 per cent) on firms' product diversification, we add an additional variable (*no product diversification info*) that takes the value 1 for these observations (and  $-1$  otherwise).

Finally, we include a set of variables to control for differences across the five sectors, home regions (Europe, USA and Japan) and years (1996–99). Firms that belong to different sectors may have different needs and incentives to enter into NTDs. The *year* variables capture changes over time in the propensity of firms to enter into NTDs and patent inventions in those NTDs. The *home region* variables control for possible differences in the propensity of European, US and Japanese firms to apply for EPO patents. We use contrast codes rather than dummy coding to allow for a more direct comparison of group differences in the propensity to enter and perform in NTDs (Davis, 2010).

In the entry analysis, all explanatory variables are one-year lagged with respect to the year of (potential) entry. In the technological performance analyses, average values over the three-year period ('entry year' to 'entry year + 2') are taken for all explanatory variables. We mean-centred all continuous variables prior to the analyses and prior to creating the interaction terms. The main effects of the variables that are interacted (technological opportunities and technological relatedness) therefore are representative of the effects at the mean of the interacting variable. Mean centring, together with the use of contrast codes for all categorical variables, implies that the constant term in the performance model represents performance for an 'average' firm with average values for the continuous variables and zero values for the set of contrasts.

## Descriptives

Tables III and IV show the descriptive statistics and correlations for the dependent and explanatory variables in both models. Technological opportunities are correlated positively with entry and technological performance in NTDs, while technology competition correlates negatively with both. The tables also show a higher value for technological opportunities, and a lower value of technology competition, for the entered NTDs. These statistics provide some 'prima facie' evidence that firms are more likely to enter NTDs characterized by abundant technological opportunities and less concentrated technology ownership. None of the reported correlations between the independent variables is excessively high. The highest correlation is found between R&D expenses and patent portfolio size.

Table III. Descriptives and correlations for the entry into new technology domains analysis

	<i>Mean</i>	<i>Std. Dev</i>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Technology Entry	0.02	0.14								
(2) Technology Competition	-3.95	0.82	-0.07*							
(3) Technological Opportunities	0.16	0.21	0.04*	-0.06*						
(4) Technological Relatedness	0.48	0.59	0.09*	0.06*	0.08*					
(5) R&D Expenses	0.44	0.75	0.05*	0.06*	-0.04*	-0.12*				
(6) Patent Portfolio Size	4.79	1.53	0.06*	0.08*	-0.06*	-0.08*	0.60*			
(7) Profit Margin	0.05	0.50	0.01*	0.01*	0	0.01*	0.06*	0.10*		
(8) Technology Diversification	5.43	3.79	0.08*	0.08*	-0.03*	0.13*	0.13*	0.32*	0.01*	
(9) Product Diversification	0.50	0.28	0.03*	0.03*	-0.01*	0.06*	0.06*	0.13*	0.08*	0.28*

Notes: \* indicates significance at 5% level.

Table IV. Descriptives and correlations for the performance into new technology domains analysis

	<i>Mean</i>	<i>Std. Dev.</i>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Technological Performance	2.60	6.90								
(2) Technology Competition	-4.39	0.76	-0.06*							
(3) Technological Opportunities	0.21	0.26	0.14*	-0.10*						
(4) Technological Relatedness	0.84	0.79	0.13*	0.11*	-0.01					
(5) R&D Expenses	0.80	1.18	0.07*	0.08*	-0.08*	-0.26*				
(6) Patent Portfolio Size	5.76	1.32	0.01	0.14*	-0.11*	-0.32*	0.72*			
(7) Profit Margin	0.07	0.18	-0.03	0.05	-0.05	0.02	0.02	0.02		
(8) Technology Diversification	7.64	4.42	-0.04	0.15*	-0.04	0.09*	-0.07*	0.03	-0.11*	
(9) Product Diversification	0.58	0.22	-0.04	0.08*	-0.06*	-0.03	0.10*	0.11*	-0.07*	0.29*

Notes: \* indicates significance at 5% level.

## EMPIRICAL RESULTS

### Entry into New Technology Domains

The results of the Cox proportional hazard models analysing the antecedents of firms' decisions to enter into NTDs are presented in Table V. The coefficients displayed are exponentiated to allow for an interpretation of the coefficients as hazard ratios: they represent the proportional change in the probability to enter into NTDs due to a unit change in an independent variable. A hazard ratio that is larger (smaller) than one indicates an increase (decrease) in the probability to enter into NTDs. Model 1 only includes the control variables and Model 2 adds the two environmental characteristics. Technology relatedness is added in Model 3 and interacted with technological opportunities in Model 4. All models are highly significant, and the log-likelihood ratio tests reveal that the hypotheses-testing variables significantly increase the explanatory power of the models. The significant coefficients of the firm-specific random effect (the 'frailty' term  $\theta$ ) show that there is unobserved firm-specific heterogeneity in the process of entry in NTDs.

The coefficient estimates for the control variables show that firms with larger R&D budgets (models 2-4) and patent stocks are more likely to enter into NTDs, while no effect is found for prior profitability. There is weak evidence that firms with a diverse technology portfolio are more likely to enter into NTDs (models 3 and 4). The positive coefficient for product diversification indicates that firms active in multiple product markets have a greater propensity to explore NTDs. Entry into NTDs is least likely, all other things equal, in the pharmaceutical industry, and most likely in the chemical industry. The coefficients of the contrasts for the year variables suggest an upward sloping linear relationship between the entry year and the probability to enter into NTDs.

The richness of technological opportunities in a technology domain is positively and significantly related to entry decisions in NTDs in all hypotheses testing models, in

Table V. The determinants of entry into new technology domains

	Model 1			Model 2			Model 3			Model 4		
	Haz. Ratio	Std. Err.		Haz. Ratio	Std. Err.		Haz. Ratio	Std. Err.		Haz. Ratio	Std. Err.	
R&D Expenses	1.095	(0.071)		1.141*	(0.074)		1.134*	(0.069)		1.142*	(0.070)	
Patent Portfolio Size	1.210**	(0.050)		1.248**	(0.052)		1.339**	(0.054)		1.333**	(0.054)	
Profit Margin	1.531	(0.409)		1.505	(0.399)		1.495	(0.401)		1.486	(0.396)	
No Profit Margin Info	0.966	(0.123)		0.976	(0.125)		1.018	(0.126)		1.017	(0.126)	
Technology Diversification	1.050	(0.043)		1.069	(0.044)		1.071#	(0.043)		1.069#	(0.043)	
Technology Diversification2	1.000	(0.002)		0.999	(0.002)		0.999	(0.002)		0.999	(0.002)	
Product Diversification	1.910**	(0.435)		1.895**	(0.433)		1.809**	(0.399)		1.838**	(0.406)	
No Product Diversification Info	0.845	(0.095)		0.825#	(0.094)		0.816#	(0.088)		0.812#	(0.088)	
Pharmaceuticals vs. others	0.854**	(0.025)		0.859**	(0.025)		0.881**	(0.025)		0.884**	(0.025)	
IT Hardware vs. others	0.977	(0.031)		0.963	(0.030)		0.989	(0.030)		0.990	(0.030)	
Chemicals vs. others	1.099*	(0.047)		1.119**	(0.048)		1.101*	(0.045)		1.105*	(0.045)	
Electronics vs. others	0.895	(0.070)		0.900	(0.070)		0.963	(0.072)		0.965	(0.072)	
Japan vs. others	1.025	(0.034)		1.025	(0.034)		1.031	(0.032)		1.033	(0.033)	
EU vs. US	1.016	(0.062)		1.027	(0.063)		1.032	(0.060)		1.034	(0.060)	
Year (linear)	1.356**	(0.029)		1.243**	(0.028)		1.212**	(0.027)		1.210**	(0.027)	
Year (quadratic)	0.893*	(0.048)		0.900*	(0.046)		0.894*	(0.046)		0.895*	(0.046)	
Year (cubic)	0.980	(0.023)		0.989	(0.022)		0.986	(0.022)		0.985	(0.022)	
Technology Competition				0.508**	(0.019)		0.478**	(0.018)		0.479**	(0.018)	
Technological Opportunities				2.449**	(0.227)		2.542**	(0.242)		2.589**	(0.247)	
Technological Relatedness							1.704**	(0.042)		1.751**	(0.049)	
Opportunities * Relatedness										0.849#	(0.078)	
Firm-Specific Effect ( $\theta$ )	0.194**	(0.040)		0.196**	(0.040)		0.160**	(0.036)		0.162**	(0.036)	
Number of Subjects	17191			17191			17191			17191		
Number of Failures (Technology Entries)	1288			1288			1288			1288		
Log Likelihood	-12080			-11856			-11715			-11714		
Wald Chi2	452.39**			904.09**			1275.25**			1269.15**		
LR Test Model 2 vs. Model 1												
LR Test Model 3 vs. Model 2												
LR Test Model 4 vs. Model 3												
				282.34**								3.30#

Notes: \*, \*\*, # indicate significance of at the 1, 5, and 10 per cent levels. Continuous variables are mean-centred. Reported coefficients are hazard ratios. Results of Cox Proportional Hazard models with shared frailty at the firm level.

support of Hypothesis 1. The estimated hazard ratios indicate that the probability of a firm to enter into a NTD rises by approximately 150 per cent per unit increase in the measure of technological opportunities. This result implies, for example, that firms are, *ceteris paribus*, one and a half times more likely to enter the technology domain ‘medical and veterinary science’ which is characterized by high levels of technological opportunities (1.87, see Table II) than the technology domain ‘printing’ which features lower levels of opportunities (0.054, see Table II).<sup>[5]</sup>

The interaction term of technological opportunities and technological relatedness in Model 4 is estimated as smaller than one (0.849) but only weakly significant at the 10 per cent level.<sup>[6]</sup> Given that the coefficients are exponentiated, a coefficient smaller than one implies that the effect of technological opportunities on NTD entry is negatively, rather than positively, moderated by the level of technological relatedness of a NTD and the firm’s existing technology resources. Hence, Hypothesis 2 has to be rejected, as it predicted a positive moderation effect. The weakly significant negative moderation effect reduces the positive effect of technological opportunities only mildly for NTDs that feature a higher than average relatedness to the firm’s existing technology portfolio. Estimations show that the effect of technological opportunities is reduced from a 150 per cent increase in the probability of entry for average related NTDs to a 113 per cent increase in this probability for closely related NTDs – while the effect rises to an 180 per cent increase for an unrelated NTD.<sup>[7]</sup> Relatedness itself has an appreciable effect on entry: the estimated hazard ratio evaluated at the mean of technological opportunities implies that the likelihood of entry into a moderately related domain<sup>[8]</sup> is 75 per cent larger than the hazard of entry into a completely unrelated domain.

Hypothesis 3 is supported by the negative and significant effect of technology competition, as indicated by a hazard ratio smaller than one. A unit increase in technology competition (which is slightly more than a standard deviation change) in Model 4 reduces, *ceteris paribus*, the probability to enter into a NTD by 52 per cent.

### **Technological Performance in New Technology Domains**

The results of the Negative Binomial regression models of the determinants of firms’ technological performance in NTDs after entry are reported in Table VI. The coefficients are exponentiated to allow for an interpretation as incidence-rate ratios: they represent the proportional change in the technological performance in a NTD due to a unit change in the independent variable. Model 5 includes the control variables only, and the hypotheses-testing variables are added in Models 6–8. The models are strongly significant as indicated by the Chi-square test statistics. The inclusion of the hypotheses-testing variables significantly increases the explanatory power of the model, as indicated by the three Log-Likelihood ratio test statistics.

The coefficient estimates of the control variables indicate that the technological performance of firms in NTDs is higher when firms spend more resources on R&D. No significant differences in technological performance in NTDs are found across firms active in different industries and originating from different home regions. The coefficients of the contrasts for the year variables show both linear and cubical elements in the pattern of technological performance in NTDs over time. Given that continuous variables are

Table VI. The determinants of technological performance in new technology domains

<i>IRR</i>	<i>Model 5</i>		<i>Model 6</i>		<i>Model 7</i>		<i>Model 8</i>	
	<i>Std. Err.</i>	<i>IRR</i>						
Constant	2.740**	2.742**	(0.768)	2.552**	(0.813)	2.572**	(0.786)	
R&D Expenses	1.190#	1.212*	(0.104)	1.228*	(0.100)	1.233**	(0.100)	
Patent Portfolio Size	0.928	0.950	(0.075)	1.022	(0.074)	1.027	(0.074)	
Profit Margin	0.379	0.779	(0.845)	0.729	(0.761)	0.892	(0.774)	
No Profit Margin Info	0.878	1.107	(0.342)	1.113	(0.373)	1.215	(0.385)	
Technology Diversification	0.998	1.001	(0.017)	1.000	(0.016)	1.000	(0.016)	
Product Diversification	0.697	0.781	(0.299)	0.912	(0.342)	0.944	(0.348)	
No Product Diversification Info	1.285	1.078	(0.192)	1.059	(0.182)	0.989	(0.154)	
Pharmaceuticals vs. others	1.007	0.964	(0.053)	0.968	(0.051)	0.948	(0.047)	
IT Hardware vs. others	1.003	0.975	(0.048)	0.980	(0.043)	0.971	(0.043)	
Chemicals vs. others	1.006	1.015	(0.053)	1.022	(0.051)	1.017	(0.050)	
Electronics vs. others	1.144	1.079	(0.115)	1.171	(0.120)	1.130	(0.114)	
Japan vs. others	0.970	0.978	(0.044)	0.996	(0.042)	0.997	(0.041)	
EU vs. USA	0.938	0.973	(0.092)	1.001	(0.082)	1.002	(0.080)	
Year (linear)	0.940*	0.931**	(0.025)	0.930**	(0.026)	0.932*	(0.026)	
Year (quadratic)	1.050	1.071	(0.064)	1.111#	(0.068)	1.102	(0.065)	
Year (cubic)	1.064*	1.086**	(0.029)	1.086**	(0.028)	1.089**	(0.027)	
Technology Competition		0.856*	(0.067)	0.794**	(0.065)	0.779**	(0.064)	
Technological Opportunities		2.793**	(0.819)	2.558**	(0.676)	2.805**	(0.754)	
Technological Relatedness				1.647**	(0.136)	1.671**	(0.143)	
Opportunities * Relatedness						2.221*	(0.813)	
Over-dispersion parameter ( $\alpha$ )	3.557**	3.420**	(0.236)	3.205**	(0.223)	3.182**	(0.218)	
Number of Observations	1288	1288		1288		1288		
Log Likelihood Value	-2410	-2396		-2374		-2371		
Wald Chi2	24.43#	40.02**		79.01**		80.05**		
LR Test model 6 vs. Model 5		27.55**		44.81**				
LR Test model 7 vs. Model 6								
LR Test model 8 vs. Model 7								

*Notes:* \*, \*\*, # indicate significance of at the 1, 5, and 10 per cent levels. Continuous variables are mean centred. Reported coefficients are incidence-rate ratios (IRR). Results of Negative Binomial Regression models. Standard errors are clustered at the firm level.

mean centred and categorical variables contrast coded, the estimated incidence ratio of the constant term (about 2.5) implies that an average firm under average circumstances records about 2.5 post-entry citation-weighted patents.

Technological opportunities are associated with greater technological performance, with the estimates suggesting a substantial 170–180 per cent increase in patent performance due to a unit increase in opportunities. This result implies that the technological performance in, for instance, the technology domain ‘medical and veterinary science’ which is characterized by high levels of technological opportunities, is on average almost double the performance in the technology domain ‘printing’ which features low levels of opportunities.

In Model 8, the interaction effect between technological opportunities and technological relatedness is positive – as indicated by an incidence-rate ratio larger than one – and significant. This lends support to Hypothesis 4: the effect of technological opportunities on the technological performance in NTDs is positively moderated by the technological relatedness between the NTD and the firm’s existing technology portfolio. Further calculations show that for firms with a closely related technology base, the effect of a unit increase in technological opportunities rises from 180 to 427 per cent, while for unrelated fields the effect of opportunities is no longer significant. Relatedness itself also enhances performance: the estimated incident rate ratio implies that patent performance is 67 per cent higher in a domain with moderate relatedness than in an unrelated domain, given an average level of technological opportunities.

Hypothesis 5 is supported by a significant incidence-rate ratio smaller than one for technology competition. A unit increase in the technology competition variable in Model 8, a little more than a standard deviation increase, reduces the technological performance of firms in a NTD, on average, by 22 per cent.

### Supplementary Analysis

We conducted a number of supplementary analyses to examine the robustness of our findings. We examined the sensitivity of results in the performance analyses to the inclusion of firm fixed effects. Firm fixed effects control for possible remaining firm level heterogeneity affecting the technological performance in NTDs. Coefficient identification in a fixed-effect model is only possible in case there are multiple-entries for the sample firms, reducing the sample to 1201 observations, and the inclusion of fixed effects reduces residual variation in particular for firms with few entries in NTDs. Fixed-effect analyses produced qualitatively similar results for the hypotheses testing variables. The main difference was that the standard error of the interaction effect between technological relatedness and technological opportunities increased, such that the coefficient fell just below conventional significance levels ( $p = 0.11$ ).

We conducted additional analyses in which we substituted the two variables capturing the size of firms’ technology activities in the model (R&D expenses and patent portfolio size) by firm size (measured by the logarithm of the number of employees). Firm size had a positive and significant effect in both the entry and technological performance models. The coefficients of the hypotheses-testing variables were unaffected, while significance levels increased.

We also examined the robustness of findings in case of a stricter definition of 'newness' of technology domains. We extended the time window during which firms should not have filed for patent applications in a technology domain from 5 to 10 years. This reduced the number of firm-domain combinations for the entry analysis to 15,800 and the number of entries into NTDs to 897. The empirical results did not alter materially. The only more substantive difference was that the (non-hypothesized) weak negative interaction effect between technological relatedness and technological opportunities in the entry model became insignificant.

We conducted additional analysis to further explore the nature of the interaction effect of technological opportunities and technological relatedness in the entry analysis. One possibility is that the lack of support for Hypothesis 2 is due to differences in the interplay between technological opportunities and technological relatedness depending on the available R&D resources of firms. Large firms with ample R&D resources may be less technologically constrained in the exploration of technological opportunities. Since our sample primarily includes large R&D intensive firms, we divided the sample based on R&D budgets at the bottom 25th percentile. Results indeed showed a negative moderation effect for the large firms, contrasting with a positive moderation effect for firms with smaller R&D budgets, but in both subsamples the estimated coefficients were insignificant.

## DISCUSSION

Building up competences in NTDs is essential to ensure the long-term viability of firms in dynamic technology environments. It presents substantial managerial challenges because it involves considerable resources, technical and commercial outcomes are uncertain, and failed attempts can disturb existing operations. While this has inspired researchers to examine how internal processes and resources can facilitate firms in developing competences in NTDs, the role of the external (technology) environment has remained underexposed. In particular, extant research has not factored in the notion that the success of firms' innovation activities depends on the actions and innovation outcomes of competitors (Katila and Chen, 2008; McGahan and Silverman, 2006).

The current study contributes to the literature on (technology) exploration by highlighting the crucial role of environmental characteristics in determining the direction and success of technology development. We suggest that a more complete understanding of firms' entry and performance in NTDs requires consideration of two key characteristics of the technology environment: technological opportunities and technology competition. Competition from established firms in a technology domain reduces both the probability of entry and the subsequent technological performance within the NTD. The richness of technological opportunities in technology domains attracts firm entries, but only firms possessing related technological resources are likely to capitalize on those emerging opportunities. While internal characteristics constitute the breeding ground for new technology initiatives, successful broadening of technological capabilities is shaped as well by the actions of competitors and by the interaction of internal resources and opportunities in the environment.

The empirical results did not lend support to the hypothesis that the presence of related technological resources determines firms' ability to recognize and act on

technological opportunities. Hence, while firms are on average more likely to enter into NTDs situated in the vicinity of their existing technology base – a finding consistent with prior studies suggesting the path-dependent nature of technology search (Cantwell and Fai, 1999; Dosi, 1982; Dowell and Swaminathan, 2006; Garud and Karnøe, 2001; Helfat, 1994; Kim and Kogut, 1996; Martin and Mitchell, 1998; Nelson and Winter, 1977; Stuart and Podolny, 1996) – such technological relatedness does not seem to constrain the responsiveness of firms to technological opportunities in NTDs.

This finding is intriguing and suggests that firms are equally attracted to technological opportunities in distal and proximal technology domains. This finding may be specific to the setting of our empirical research, however: R&D intensive firms with broad resources to conduct exploratory R&D and to scan external developments in patenting. Firms with ample resources for R&D, a well-developed sensing strategy consisting of activities such as patent scouting and venturing, will keep a close watch on a broad spectrum of technological opportunities and patenting trends. However, our results also show that many entries into unrelated NTDs that are rich in technological opportunities turn out to be unsuccessful. Together, these findings suggest the need for further theorizing on the practice of technology exploration in large R&D intensive firms.

### **Implications for Research**

Our study re-affirms the original propositions advanced by Nelson and Winter (1977, 1982). Nelson and Winter depicted firm behaviour as shaped simultaneously by ‘organizational genetics’ (available resources and competences, including technological ones) and the ‘selection’ environment, which poses threats to firms but also provides opportunities, especially to firms that have the appropriate profile to seize them. The complementary nature of the resource-based view on firms’ behaviour, with a focus on internal resources and processes, and the industrial organization literature, which emphasizes the importance of environmental (technological) characteristics for the effectiveness of firms’ technology strategies hence suggests the need to use integrative frameworks in future theory development.

Our findings contribute to the recent debate whether distal or proximate search provide most advantages to firms (Gavetti, 2012; Winter, 2012). Our results can be interpreted as indicating that for R&D intensive firms, proximate search dominates, but distal search may occur in technology domains rich in technological opportunities. At the same time, success is most assured in case of proximate search. Hence, search behaviour and success chances are heterogeneous and depend on the munificence of the technology environment. Environments may often present themselves to firms as a trade-off between stepwise proximal exploration with a higher probability of success, and distal exploration of a potentially more promising trajectory but with a much lower rate of success. We note that our study explored this trade-off by examining both the antecedents of entry and the drivers of subsequent technological performance in NTDs, while prior studies have only looked at one of these dimensions (e.g., Helfat, 1994). The suggestion for future research is to adopt a more encompassing perspective, examining both entry and performance in (technology) exploration behaviour.

Our study also has implications for the literature on (technological) opportunities (Shane, 2001; Teece et al., 1997; Zahra, 2008). Teece et al. (1997) advanced the idea that (technological) opportunities are firm-specific: *'Not only do firms in the same industry face menus with different costs associated with particular technological choices, they are also looking at menus containing different choices'* (Teece et al., 1997, p. 524) and this notion is consistent with the view in the entrepreneurship literature that (business) opportunities are 'created' (Davidsson, 2015). While our findings are generally in agreement with this notion, they also provide a more nuanced view. On the one hand, the pattern of related entry into NTDs suggests that firms are exploring different menus in technology domains depending on their existing technology portfolios. On the other hand, recognition of relevant technological opportunities is less constrained and more diverse in resource rich firms, where technology exploration tends to have characteristics of a trial and error approach spanning also unrelated but promising technology domains. Our study also suggests that opportunities of a technological nature have an observable qualification, which is in agreement with the dominant view in the industrial organization literature (Jaffe, 1986; Scherer, 1965) and with views expressed in contributions to the entrepreneurship literature (e.g., Shane and Venkataraman, 2000; Zahra, 2008).

Finally, our findings inform the broader strategic management literature on knowledge sourcing and innovation through M&As and alliances. The theoretical rationale for some of the stylized facts concerning the performance effects of technology based M&As has an interesting parallel with the arguments in our paper. Ahuja and Katila (2001) and Cloudt et al. (2006) show that an acquirer is most likely to benefit from M&As if the technology base of the target firms differs, but is not too distant, from the technology base of the acquirer. Similarly, research on technology alliances has found that while information inflows from strong 'local' ties are beneficial, alliances with new and distant partners may be required to expose the firm to new innovative ideas (Gilsing et al., 2008; Hagedoorn et al., 2011; Sampson, 2007; Uzzi, 1997; Vanhaverbeke et al., 2015). Our study suggest that the direction and performance effects of search for M&A targets or alliance partners will also be governed by the technological opportunities embedded in the domains in which partners and target firms are active – and not only by their proximity to the technology base of the focal firm. A promising avenue for future research is the examination of the role of M&As and alliances in the identification and successful exploration of opportunity rich NTDs.

### **Managerial Implications**

Our findings suggest that capitalizing on technological opportunities is conditional on a related knowledge base to enact knowledge integration. If related resources are absent, technology development efforts may be less effective and technology transition trajectories are more hazardous. At the same time, large R&D intensive firms do experiment with technology entry in unrelated but opportunity rich domains. A case of unsuccessful entry in NTDs may illustrate the importance of these notions for managerial practice. In 2000, Royal Dutch Shell decided to diversify into various types of renewable energy sources, each of which implied entering NTDs with ample (perceived) technological opportunities: solar power, wind power, hydrogen energy and biofuels. Between 2004

and 2009, Shell invested approximately 1.7 billion USD in the development of renewable energy technology. In 2009 however, Shell announced a withdrawal from wind, solar, and hydrogen energy. Only biofuels, where the chemical capabilities of the firm could be leveraged, were retained in the technology and business portfolio (The Guardian, 2009). This example illustrates how large firms can experiment with, and invest substantial resources in, the development of unrelated technologies deemed rich in technological and business opportunities – while the absence of related capabilities increases the risk of failure. This suggests that firms should carefully balance the need to master a range of new technologies in technology intensive industries (Granstrand, 1998; Pavitt and Patel, 1997) with the constraints due to the characteristics of firms' existing technological capabilities.

A second implication is the need to take into account rival firms' strategies and technology development efforts. If technological opportunities present themselves as observable to a variety of R&D intensive firms with the resources to explore a wide range of NTDs, opportunity rich areas are likely to become 'crowded' areas of technology development. This reduces the chances of success in carving out a sustainable presence, in particular if firms lack the benefits of scope and cross-fertilization in unrelated domains. These considerations are only strengthened if leadership positions become entrenched in technology domains and incumbents raise entry barriers to defend their technology leadership.

## Limitations

Our study is subject to a number of limitations, which highlight avenues for further research. A first limitation is our focus on large R&D intensive firms. While this assures a rich pattern of entry in NTDs, our results are less likely to be representative of small firms in high-tech industries. We suggest that future research also takes these firms as a focus of attention to examine if entry into promising NTDs is indeed more constrained to related technologies in contrast to the broader technology exploration pattern that we observed in large R&D intensive firms.

Future work could also refine and further develop the operationalization of the concepts of technological opportunities and technology competition. We used a specific measure of technological opportunities: the relevance of scientific knowledge in the technology domain. While this indicator has a strong prior in theory and empirical work (Klevorick et al., 1995; Levin et al., 1985) and has a robust relationship with NTD entry and performance across technology domains, our analysis revealed that this measure is less able to identify exploitable opportunities in the domain characterized by the highest propensity to draw on scientific knowledge (biochemistry). In domains with an extreme reliance on scientific prior art, higher levels of science intensity might actually signal more extended timeframes and higher levels of uncertainty rather than immediately addressable opportunities. Future research would benefit from a better understanding of the specific (life cycle) dynamics in domains characterized by high levels of dependence on science, which in turn may result in more suitable indicators of exploitable technological opportunities in those domains.

Future research could also explore the possibility of utilizing direct evidence of aggressive patent strategies of incumbent firms. One way to identify such strategies is to examine the composition of firms' patent portfolios to see if their patents invalidate the 'novelty' of entrants' patents (e.g., Grimpe and Hussinger, 2014). Finally, in line with suggestions by O'Reilly and Tushman (2008) and Teece (2007), future research may envisage to include variables that reflect organizational design choices and practices that enable the development of capabilities in NTDs.

## CONCLUSION

Firms' choices to enter into NTDs and their subsequent technological performance in these NTDs are governed both by firm-level factors and environmental conditions. Perspectives that stress the environment as a key determinant of technology entry and resource-oriented perspectives emphasizing firm-level antecedents complement and interact to explain heterogeneous patterns of entry and performance in NTDs. Our study reveals the roles of firm-level related technological resources, the richness of technological opportunities, and technology competition by strong incumbents as key antecedents of entry and success in NTDs. While the absence of a related technology base does not discourage firms to enter domains that are rich in technological opportunities, firms do require related technological expertise in order to successfully exploit technological opportunities post-entry. Environmental munificence thus presents itself often to firms as a trade-off between proximal exploration with higher probability of technological success, and distal exploration in potentially more promising technology domains with reduced chances of success.

## ACKNOWLEDGEMENTS

This research was supported by FWO (Flemish Science Council) grant number G073013N. We are grateful to the editor Andrew Corbett and the three anonymous reviewers for comments on earlier drafts. We wish to thank ECOOM at KU Leuven for data support.

## NOTES

- [1] The precise nature of entrepreneurial opportunities has remained an issue of debate, i.e., whether opportunities are there to be discovered or whether they are created through enactment by entrepreneurs (e.g., Alvarez and Barney 2013; Foss and Foss, 2008; Klein, 2008; Venkataraman and Sarasvathy, 2001). For a more elaborate overview on the notion of entrepreneurial opportunities and its constituents, we refer to Davidsson (2015) who advances a distinction between external enablers, new venture ideas and opportunity confidence to characterize the 'individual-opportunity' nexus more accurately. As outlined by Davidsson (2015), actors exert influence on enablers but for most actors, such changes are 'exogenous' and hence can be labelled as 'environmental'.
- [2] We note that surveys of patent inventors (Fleming and Sorenson, 2004; Tijssen, 2001) have shown that inventors are aware of a significant part of the scientific papers cited in their patents, such that scientific references are seen as indicators of the 'usage' of scientific discoveries by firms in their technology activities (Fleming and Sorenson, 2004). The role of scientific information derived from citations to the scientific literature on patent documents as an indicator of technological opportunities has been validated as strongly correlated with survey-based measures of the importance of science for innovation processes (e.g., Duguet and MacGarvie, 2005).
- [3] We are indebted to one of the reviewers for this suggestion.

- [4] Adding the minimum sample value instead of the value one creates large negative values after transformation. Models with an alternative variable applying such a transformation give comparable results.
- [5] Given the log transformation for technological opportunities,  $\ln(1 + 1.87) - \ln(1 + 0.054) \approx 1$ .
- [6] This finding furthermore appeared less than robust in alternatively specified models, such as models with an increased time window to establish domains that are new to the firm.
- [7] These calculations follow from estimating alternative models at different levels of centring. Unrelated NTDs have a relatedness value of zero; closely related NTDs are taken as having a value of relatedness (1.6) equal to the mean + 2 standard deviations of relatedness in the entry analysis.
- [8] Moderately related domains are defined as domains with a relatedness value of 1.

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