Paper to be presented at

DRUID15, Rome, June 15-17, 2015

(Coorganized with LUISS)

Technology characteristics, firms? diversification strategies, and new product introduction: a multilevel perspective

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Abstract

Adopting a multi-level perspective, this study investigates the relationships between technology characteristics, firms? diversification strategies, and the market introduction of new products resulting from firms? proprietary technological solutions. Specifically, we analyze how the breakthrough nature and technological generality of inventions impact on the likelihood of firms to commercialize them via new products, while considering the cross-level effects exerted by both firms? technological diversification and R&D geographic dispersion strategies. Based on a sample of 11,385 patents and 1,783 trademarks registered at the U.S.P.T.O. in the energy conservation sector by 696 different companies, this study provides empirical evidence that technology characteristics contribute to explain the likelihood of product commercialization, and that such relationships can be thoroughly understood only by analyzing the specific firm-level context.

Jelcodes:O31,O32

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Abstract

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Keywords: new product introduction; technology characteristics; multilevel perspective; trademarks; energy conservation.

INTRODUCTION

It is widely recognized that firms commercialize their inventions in order to achieve the Schumpeterian rents that arise from the subsequent introduction of technological products on the market (Nerkar and Shane, 2007; Roberts, 1999). Indeed, the commercialization of innovative products positively influences firms' capability to cope with an increasingly dynamic market and in turn enhances their overall competitive performance and survival (Chandy *et al.*, 2006; Zahra and Nielsen, 2002). However, despite the growing technological and inventive potential, companies often remain unsuccessful at exploiting their own technological resources (Danneels, 2007; Thomke and Kuemmerle, 2002), hence highlighting a significant gap between their inventive and innovative outcomes. Thereby, a better understanding of the main factors affecting firms' capability to introduce products on the market based upon their own technological solutions has emerged more and more as an urgent academic and managerial issue (e.g., Chen, Chang, Hung, 2011; Zahra and

Nielsen, 2002). Accordingly, many scholars from different fields have attempted to address this topic, revealing that the introduction of new technology-based products is largely dependent on firm-specific characteristics and strategies (e.g., Hall and Bagchi-Sen, 2007), human resources (e.g., Smith, Collins, Clark, 2005), and environmental dynamics (e.g., Barbosa and Faria, 2011). Nevertheless, two main gaps still emerge. First, although companies own various technological resources, in turn embodying different characteristics (Dosi, 1988; Tassey, 2004), the effects of the attributes of firms' inventions have often been neglected. This seems to be, at least partially, because of the difficulties associated with observing and measuring the link between technological solutions and their resulting new products (Chandy *et al.*, 2006; Nerkar and Shane, 2007). Second, the majority of existing studies on new product introduction have focused on one level of analysis (e.g., firm level) only. This raises several concerns because recent research shows that theoretical and empirical phenomena can only be fully understood if cross-level effects are taken into account (Gupta, Tesluk, Taylor, 2007; Hitt *et al.*, 2007)

This paper addresses these research gaps and provides two fundamental contributions. First, we assess whether and to what extent technology characteristics affect companies' opportunities to introduce new products on the market resulting from their proprietary technological portfolios. Second, by taking into account the cross-level effects of firm-related strategies on the technological attributes, we provide more accurate insights into the multilevel nature of the process through which companies exploit their technological solutions.

Notably, we argue that technology characteristics can explain firms' inclination toward the commercialization of their inventions via new products, since they influence firms' capability to create and appropriate value from related inventions (e.g., Gilbert, 2006; Nerkar and Shane, 2007). In the present article, we focus on the breakthrough nature and the generality of inventions. These correspond to the degree of radicalness (Ahuja and Lampert, 2001; Kaplan and Vakili, Forthcoming) and the extent to which technologies can be applied in diverse industries (Bresnahan and Trajtenberg, 1995; Gambardella and Giarratana, 2013), respectively. Additionally, we also claim that since each company sets distinctive strategies to manage its R&D activities, the relationship between technology characteristics and the successful commercialization of these technologies depend on specific firm-level effects, as represented by two firms' diversification strategies, namely technological diversification and R&D geographic dispersion. The former reflects firms' strategic choice to expand their technological knowledge into a wide range of distinct domains (e.g., Argyres, 1996), whereas the latter implies the establishment of internationally dispersed R&D activities (e.g., Chen, Huang, Lin, 2012; Singh, 2008).

Our study develops hypotheses and tests them on a unique sample of 11,385 patents and 1,783 trademarks (TMs) successfully filed at the U.S.P.T.O. between 1980 and 2012 in the energy conservation sector by 696 companies; specifically, patents are used as a proxy for technological inventions, while TMs serve as a proxy for the introduction of related innovative products (Graham *et al.*, 2013; Krasnikov, Mishra, Orozco, 2009; Semadeni, 2006). Since our variables are not at the same level, we follow hierarchical linear modelling (HLM) regression procedures (Hofmann, 1997).

The reminder of the paper is structured as follows. In the next section, we present the theoretical basis for the research and develop the hypotheses for the empirical analysis. Then, the research methodology is exposed. Afterwards, empirical results are reported. Finally, we discuss the contributions, limitations, and future research directions of the study.

THEORETICAL BACKGROUND AND HYPOTHESES

Some studies have argued that the characteristics of firms' technological portfolios provide different opportunities, which in turn influence if and how the related inventions are commercialized (e.g., Chen *et al.*, 2011; Shane, 2001). Many scholars ascribe this issue to the fact that differences in the nature of technological solutions can affect firms' value creation and value appropriation capabilities (e.g., Gilbert, 2006; James, Leiblein, Lu, 2013; Nerkar and Shane, 2007). In fact, it has been shown that each invention presents different technological attributes (Dosi, 1988; Tassey, 2004), which exert different impacts on the extent of market acceptance (e.g., Chen *et al.*, 2011), the management of the new product development process, and the likelihood of knowledge leakage (James *et al.*, 2013; Nerkar and Shane, 2007). This follows previous research arguing that a basic prerequisite for commercialization is the willingness of firms to turn their technologies into marketable products (Nerkar and Shane, 2007; Schumpeter, 1934). This willingness is in turn dependent on the firms' capability to successfully introduce products that are valuable for the related market(s) and whose value can be appropriated (Nelson, 1959; Teece, 1986). Thus, technological attributes can be considered as relevant factors in explaining firms' choice to proceed with the exploitation and commercialization of their inventions (Nerkar and Shane, 2007; Shane, 2001). Thereby, an accurate analysis of the factors influencing invention commercialization at the technological portfolio level, besides the industry and firm levels, can provide useful insights to effectively leverage firms' proprietary technological solutions.

Previous work in the fields of technological innovation and market entry suggests different categorizations to identify the technological attributes that have the potential to create opportunities for the achievement of a sustainable competitive advantage (e.g., Edquist, 1997; Rogers, 2003). Among them, two of the most debated characteristics are the breakthrough nature of inventions and their generality. The former refers to those radically new technologies that are the foundation for subsequent technological developments (Ahuja and Lampert, 2001; Kaplan and Vakili, Forthcoming). The latter characterizes so-called generic technologies, which are technical solutions that perform general tasks and act as platforms for "complementary innovations", thus enabling a wide variety of market applications (Bresnahan and Trajtenberg, 1995; Gambardella and Giarratana, 2013). Several studies have recognized their relevance in triggering the invention commercialization process from both a value creation and appropriation perspective (e.g., Chen *et al.*, 2011; Gambardella and McGahan, 2010; Nerkar and Shane, 2007; Shane, 2001). Indeed, on the one hand, breakthrough and generic technological inventions have "the potential for delivering dramatically better product performance" (Utterback, 1994:158), as well as for serving as the basis for subsequent technological innovation (Ahuja and Lampert, 2001; Bresnahan and Trajtenberg, 1995). On the other hand, given the high efforts required for the commercialization of these types of technology, appropriability issues represent relevant driving forces behind the firms' willingness to commercialize them (e.g., Maine and Garnsey, 2006; Nerkar and Shane, 2007; Teece, 1986). Nevertheless, previous research has so far focused more on the development of breakthrough inventions rather than on their commercialization (Aarikka-Stenroos and Lehtimäki, Forthcoming). Similarly research on how generic technological solutions diffuse is scant (Thoma, 2009). Consequently, in the present study, we focus our attention on the breakthrough nature and generality of inventions in order to advance our understanding on their commercialization through the market introduction of new products.

The introduction of new products based on firms' proprietary inventions is not straightforward. It can be defined as a cumulative process of problem-definition and -solving activities (Rosenberg, 1982). As many problems are firm-specific, each company makes distinctive strategic choices to manage the creation and exploitation of its technological solutions. Indeed, although each technology has its own characteristics (Dosi, 1988; Tassey, 2004) and presents a specific set of technological opportunities (Shane, 2001), this is not necessarily recognized or exploited in the same way by different companies since they tend to adopt diverse strategies (McEvily, Eisenhardt, Prescott, 2004). We therefore recognize that firm strategic factors influence the effects of the technological attributes characterizing a firm's technological portfolio. In other words, the firm-level context modifies the extent of technological opportunities provided by the attributes of their inventions, by affecting their related capability to both create and appropriate value. This is in line with previous research showing that factors influencing innovation phenomena occur at different levels of analysis (Gupta *et al.*, 2007; Hitt *et al.*, 2007; Lepak, Smith, Taylor, 2007). More precisely, factors at a higher level (e.g., firm level) have cross-level effects on factors at a lower one (e.g., technological portfolio level) (Hitt *et al.*, 2007). Nevertheless, only a few studies have attempted to analyze innovation phenomena with this multilevel lens (e.g., Anderson, De Dreu,Nijstad, 2004; Crossan and Apaydin, 2010; Gupta *et al.*, 2007). We therefore propose a cross-level approach examining how firm-level variables interact with technology characteristics. Accordingly, the research design results in a nested hierarchical structure with two levels of random variation, namely the technological portfolio level (level 1) and the firm level (level 2).

In particular, at the firm level, we look at firms' diversification strategies in the context of R&D activities. Indeed, they have long interested management scholars (e.g., Argyres, 1996; Argyres and Silverman, 2004; Chen *et al.*, 2012; Ramanujam and Varadarajan, 1989). On the one hand, "firm R&D activities generally have an aim or product of commercial value in view" (Kuemmerle, 1998:112). On the other hand, diversification strategies in R&D contexts influence the quantity and type of technical knowledge available to firms, as well as their capabilities to recognize, leverage, and exploit novel technological opportunities (Argyres and Silverman, 2004; McEvily *et al.*, 2004). Specifically, so far, the literature has focused its attention on two main diversification strategies, as technological diversification and R&D geographic diversification, as means to improve firms' technological competences. Technological diversification is of interest because it affects absorptive capacity (Lin and Chang, Forthcoming), plays a preventive role against core rigidities (Leonard-Barton, 1992), and fosters recombination and cross-fertilization between different technological fields (Quintana-García and Benavides-Velasco, 2008). The geographic dispersion of R&D activities is an important strategic move as it enables firms to get closer to geographically distant markets and technological knowledge resources (Chen *et al.*, 2012). This allows firms to adapt technologies better to local market requirements and to get access to unique body of knowledge.

The breakthrough nature of inventions

Different studies have advocated the positive influence of breakthrough inventions on the creation of both private and social value (e.g., Harhoff *et al.*, 1999; Trajtenberg, 1990). In particular, the introduction of products based on breakthrough technologies has the potential to create significant value "in a specific market application" (Maine and Garnsey, 2006:376) or set the basis for the establishment of a totally new one (Achilladelis and Antonakis, 2001). Furthermore, they open up novel opportunities for interdisciplinary combinations of different inventions (Björkdahl, 2009), as well as they lead to the introduction of products significantly different from the current offerings in terms of technological performance (Aarikka-Stenroos and Lehtimäki, Forthcoming; Maine and Garnsey, 2006). This increases their "potential use value" (Amabile, 1996). Consequently, breakthrough technologies can lead to the introduction of really new products (Achilladelis and Antonakis, 2001) that can spur customer demand and in turn provide more profits for the innovating firm.

This type of technologies may also increase the appropriability of returns after commercialization, since they provide the possibility to establish learning curve and pioneering advantages given by preemptive positioning, reputation, and switching costs (Franco *et al.*, 2009; Levin *et al.*, 1987; Lilien and Yoon, 1990; Suarez and Lanzolla, 2007). Furthermore, the tacit and new knowledge underlying these technologies prevents imitation, since it makes the level of causal ambiguity higher (McEvily and Chakravarthy, 2002; Reed and Defillippi, 1990). New products based on radically new technologies may also be easier to protect from imitation since less prior art exists that could limit the potential to patent the new technology. Thus, the likelihood to appropriate returns from the commercialization of those breakthrough inventions increases, and so the probability for firms to invest in the commercial exploitation of those technologies (Ahuja and Lampert, 2001; Lepak *et al.*, 2007).

Commercializing radical inventions, however, has also some recognized drawbacks. First, the introduction of breakthrough products can cannibalize firms' existing value assets (Utterback, 1994). Indeed, the value created by the new radical technologies can substitute existing ones and hence reduce firms' overall returns (Hill and Rothaermel, 2003). Second, it requires the development of new technical skills and routines, which are difficult to build and implement. Therefore, if companies rely extensively on the exploitation of these inventions they might then lack the resources and capabilities to successfully launch them on the market (Hill and Rothaermel, 2003; Utterback, 1994). Third, technological breakthroughs are characterized by a high level of uncertainty and do not usually provide short term profits (O'Connor and Veryzer, 2001). Finally, customers may perceive breakthrough products as too complex and being too distant from their past experiences. This could create barriers to the recognition of those technologies' potential value and subsequent adoption (Aarikka-Stenroos and Lehtimäki, Forthcoming; Rogers, 2003). Hence, companies may be reluctant to an excessive reliance on this type of inventions. Given the positive and potentially negative effects if a technology becomes too radical, we posit the following hypothesis:

Hypothesis 1: The breakthrough nature of a technology has a curvilinear effect (inverted U) on the likelihood to commercialize it.

The technological generality of inventions

Technological generality may allow companies to create valuable products in a wide breadth of alternative markets and industrial fields (Gambardella and Giarratana, 2013; Maine and Garnsey, 2006). Despite this potential advantage, it provides "new opportunities rather than offering complete, final solutions" (Bresnahan and Trajtenberg, 1995:84). Accordingly, past research has shown that in order to take advantage from the different market opportunities opened up by a more general technology, companies need diverse complementary assets and adaptation efforts (Teece, 1986; Thomke and Kuemmerle, 2002).

Indeed, from a resource- and capability-based view perspective, firms are generally characterized by resource constraints related to their tangible and intangible assets as well as to their financial and managerial capacity (Barney, 1991). Hence, they should put emphasis on a narrower range of market alternatives (e.g., Barney, 1991). In fact, the required complementary assets for each industry application are generally specialized and difficult to identify, (e.g., Rosenberg and Trajtenberg, 2004; Teece, 1986), thus leading to high adaptation costs. This implies that firms have to cope with the lack of all the required resources and capabilities if they want to sustain their exploitation efforts aimed at creating new value in a wide range of market applications (Gambardella and Torrisi, 1998; Maine and Garnsey, 2006). In addition, a focus on diverse markets can turn into diseconomies of scope because of the likelihood to conceive too many market ideas compared to a firm's ability to effectively screen, select, and implement them (Koput, 1997; Lin, Chen, Wu, 2006), thus increasing managerial complexity (Hitt, Hoskisson, Kim, 1997). Consequently, as an alternative to a more intricate internal commercialization strategy, it has been revealed that companies are more willing to license generic technologies to downstream specialized companies (Arora, Fosfuri, Gambardella, 2001; Gambardella and McGahan, 2010). In fact, in this case, the number of potential licensees is likely to be higher than for specific technologies, given the broad number of potential applications, hence reducing commercialization efforts (Gambardella and Giarratana, 2013; Gambardella and McGahan, 2010).

Furthermore, due to their interdisciplinary nature, generic technologies are more subject to technology spillovers, which make more difficult to capture the created value. In line with this reasoning, Bresnahanand Trajtenberg (1995) have identified the "dual appropriability problem". Specifically, they have highlighted the presence of spillover effects both within and between different industries, which reduces the incentive to internally leverage this type of inventions. Moreover, this effect is exacerbated because of the increasing tendency of technology owners to make the technology widely available for licensing (Gambardella and McGahan, 2010). Therefore, we expect that:

Hypothesis 2: The generality of a technology has a negative effect on the likelihood to commercialize it.

The moderating role of technological diversification

Technological diversification and the breakthrough nature of inventions

The development of breakthrough inventions comes with uncertainties regarding the related value creation process and market opportunities, thus requiring extensive and dedicated efforts in experimentation in order to identify the best way for leveraging those technological solutions (McEvily and Chakravarthy, 2002). In addition, their exploitation more likely creates significant value for a single industry (Maine and Garnsey, 2006). Accordingly, it has been argued that breakthrough innovations are favored by “a deep understanding of a particular knowledge domain, its assumptions and its potential weaknesses” (Kaplan and Vakili, Forthcoming). In this way companies may better recognize and leverage their actual technological potential if they follow a more focused strategy. Kodak for example was able to launch its first camera thanks to the choice of George Eastman “to employ a full-time research scientist to aid in the commercialization of a flexible, transparent film base”[1]. Similarly, Nespresso, a Nestlé group company, markets its revolutionary machine to have a cup of espresso coffee at home because it devoted remarkable efforts in the refinement and optimization of its espresso technology by focusing on the principle of high pressure extraction[2].

Extensive endeavors in exploring technologically distant domains can thus be seen as an obstacle to market radical inventions successfully (Quintana-García and Benavides-Velasco, 2008), since it diverts firms from the core aspects of this type of solutions. Indeed, technological diversification has been found to hinder the accumulation of the specialized knowledge stock required to effectively progress in the commercialization of technological breakthroughs (Bolli and Woerter, 2013). This in turn increases the risks to enter the market with poorly developed products that is reflected in the reduction of their “potential use value” (Amabile, 1996). Consequently, followers’ possibility to introduce products that perform better rises, hence undermining firms’ learning curve and pioneering advantages provided by their breakthrough inventions (Lilien and Yoon, 1990; Suarez and Lanzolla, 2007). Furthermore, high levels of technological diversification

[1] See http://www.kodak.com/ek/US/en/Our_Company/History_of_Kodak/Milestones_-_chronology/1878-1929.htm
[2] See http://www.nespresso.com/au/en/pages/coffee-machine-technology

can impede firms' ability to focus on their breakthrough solutions and fully recognize their potential. Hence, companies are more likely to fail conveying the technological benefits of the new products, which reduces market acceptance (Aarikka-Stenroos and Lehtimäki, Forthcoming; Rogers, 2003). Therefore, we hypothesize:

Hypothesis 3a: A firm's level of technological diversification weakens the positive linear effect of the breakthrough nature of a technology on the likelihood to commercialize it.

Technological diversification and technological generality

As more generic technologies are the cornerstones of different applications in a wide variety of sectors, both upstream and downstream complementary assets are required to adapt them to each market opportunity (Bresnahan and Trajtenberg, 1995; Lin and Chang, Forthcoming; Maine and Garnsey, 2004; Teece, 1986). However, firms face resource limitations (e.g., Barney, 1991). Thereby, expanding the breadth of firms' technological base to address the different commercial opportunities arising from generic solutions drastically increases R&D expenses (Lin *et al.*, 2006), and in turn reduces companies' resources to support the development of downstream complementary capabilities (e.g., manufacturing, distribution, and marketing) (Chiu *et al.*, 2008). Consequently, adaptation costs are exacerbated. This hindrance can further lead companies to redesign their business models respect to the commercialization of generic technologies, by favoring licensing strategies over the more expensive internal exploitation of those solutions (Conti, Gambardella, Novelli, 2013; Gambardella and McGahan, 2010).

Furthermore, given firms' resource constraints (Barney, 1991), developing all the required diverse technical complementary knowledge takes a long time. Thus, due to phenomena as technological knowledge depreciation (e.g., Griliches, 1987; Nooteboom *et al.*, 2007) and the higher probability of diffusion of more generic knowledge (Bresnahan and Trajtenberg, 1995), which indeed need a fast market entry, the possibility to capture the value arising from more generic inventions is reduced.

In addition, the risks of over diversification cannot be underestimated either. Indeed, being too technologically diversified adds complexity to the identification and recognition of the most profitable ideas when companies attempt to enter many industries with their general technologies (Lin *et al.*, 2006). In fact, diseconomies of scope can rise because of an increasing inability to effectively match a generic solution with the related diverse market applications (Gambardella and Torrisi, 1998; Lin *et al.*, 2006; Rosenberg and Trajtenberg, 2004). Therefore, we argue that:

Hypothesis 3b: A firm's level of technological diversification enhances the negative effect of the generality of a technology on the likelihood to commercialize it.

The moderating role of the geographic dispersion of R&D

Geographic dispersion of R&D and the breakthrough nature of inventions

Both researchers and practitioners have highlighted several concerns about the coordination and execution costs related to geographically dispersed R&D activities. According to Asakawa (2001), these are especially reflected in the so-called information-processing and autonomy-control perspectives. In particular, the former underlines the resulting higher communication costs, whereas the latter highlights the emergence of managerial constraints during the value creation process (see also (Chen *et al.*, 2012). High communication costs are particularly detrimental to leverage and commercialize breakthrough technologies. In fact, since these are generally distant and diverse from firms' prior knowledge, their related commercial exploitation is characterized by (complex) social interactions among organizational members (Kogut and Zander, 1992; Nahapiet and Ghoshal, 1998). These, in turn, require effective information sharing, which is however difficult to perform in a dispersed international context (Singh, 2008). Accordingly, as R&D units are scattered across geographical, cultural, and institutional boundaries, knowledge exchange and the application of joint research is hampered due to cognitive and cultural distance between members (Medcof, 1997; Singh, 2008). Indeed, the opportunities to steadily interact and refine the idiosyncratic languages required to exchange "fine-grained Information" (Uzzi, 1997), as well as to develop routines for knowledge exploitation (Capaldo and Messeni Petruzzelli, 2014), are lowered. Therefore, the possibility to fully recognize and exploit the potential of breakthrough inventions is reduced (O'Connor and Veryzer, 2001). This decreases the ability to launch new valuable products that can be more probably accepted in the market (Mascitelli, 2000). Furthermore, technological breakthroughs are particularly characterized by novel and tacit knowledge. This type of knowledge resides within individuals and it is therefore complex to make it explicit and to transfer it (Pavitt and Patel, 1999; Sorenson, Rivkin, Fleming, 2006). This means that, especially when the tacit knowledge underlying breakthrough technologies is shared between dispersed R&D labs, integrating it into a comprehensive whole requires remarkable efforts. Thereby, the extent of firms' appropriable value, despite easier to be captured (McEvily and Chakravarthy, 2002), is likely to be smaller if R&D activities are performed in an international context, hence reducing the incentive to exploit breakthrough inventions through the commercialization of new products. On the basis of this reasoning, we expect:

Hypothesis 4a: The level of a firm's geographic R&D dispersion weakens the positive linear effect of the breakthrough nature of a technology on the likelihood to commercialize it.

Geographic dispersion of R&D and technological generality

The managerial constraints associated with R&D internationalization can be particularly harmful to the commercialization of generic technologies. Organizations face difficulties in coping with the managerial complexity associated with sharing and implementing ideas when they attempt to address diverse market opportunities that arise from more generic solutions (Hitt *et al.*, 1997; Lin *et al.*, 2006). These problems are expected to increase as the level of a firm's overseas R&D

activities grows. First, the difficulty of managing and coordinating numerous market applications and dispersed R&D labs at the same time is enhanced (Hitt *et al.*, 1997). Second, control problems can be worsened due to asymmetric information between the dispersed labs (Bresnahan andTrajtenberg, 1995), since incentive alignment and coordination among them are difficult. Third, although R&D internationalization may facilitate the acquisition of specialized complementary assets, the integration of the acquired assets is more challenging and complex due to high cultural and geographic distances (Singh, 2008; Teece, 1986). Furthermore, the geographic dispersion of R&D activities increases the risks of knowledge leakage and know-how spillovers to competitors (Kafouros *et al.*, 2008). In turn, this can make the dual externality problem more significant (Bresnahan and Trajtenberg, 1995), hence reducing firms' appropriation capabilities. Therefore, we state that:

Hypothesis 4b: The level of a firm's geographic R&D dispersion enhances the negative effect of the generality of a technology on the likelihood to commercialize it.

METHODS

Industry setting

The energy conservation is an appropriate setting for several reasons. First, environmental sustainability is more and more recognized as a source of new business opportunities (Shrivastava, 1995; Unruh and Ettenson, 2010). Hence, the development of energy conservation technologies and the introduction of related products have significantly risen during the last decades (Albino *et al.*, 2014; Diaz-Rainey and Ashton, 2008). Second, the introduction of more environmentally friendly products is strongly dependent on firms' technological efforts (Dangelico and Pujari, 2010), thus revealing a tight link between inventive and innovative activities. Third, besides its technological intensity, the energy conservation sector is characterized by the presence of diverse types of technological domains, such as building insulation, energy storage, and low energy lighting (OECD/IEA, 2011), hence making firms's technological diversification an important issue. Fourth, environmental sustainability is of global interest. The technical knowledge underlying the development of energy conservation technologies is geographically dispersed (Albino *et al.*, 2014). Finally, since intellectual property (IP) protection plays a relevant role in the energy sector (OECD/IEA, 2011), patents and TMs are valid proxies to capture technology-based inventions and their commercialization by means of new products.

Data collection

In order to test the proposed hypotheses, we need to analyze data about firms' proprietary technological inventions as well as product introductions incorporating those technologies. To achieve this aim, we propose a novel methodological approach linking firms' patent portfolios to their related TM portfolios. Patents have been widely used to assess firms' technological resources (e.g., Silverman, 1999). In addition, the literature has suggested different measures that are useful to evaluate some characteristics of the patented inventions (e.g., Conti, Gambardella, Mariani, 2014; Trajtenberg, Henderson, Jaffe, 1997). TMs identify products on the market. The IP and brand management literature has often recognized them as means to establish and maintain firms' reputation. However, in the recent years, scholars have also considered TM data as a measure of firms' downstream capabilities (e.g., Fosfuri and Giarratana, 2009) and as an indicator of (technological) product innovation (Flikkema, De Man, Castaldi, 2014; Mendonça, Pereira, Godinho, 2004). Indeed, TMs identify and distinguish the source of the goods or services (Lanham Act, 1982), are positively correlated to R&D expenditures, and have been proven to be consistently more used by innovative than non-innovative companies (e.g., Daizadeh, 2009; Mendonça *et al.*, 2004). Furthermore, companies more often filed for TMs in the latest stages of the innovations process, such as product launch and commercialization. Therefore, differently from R&D expenditures and patents, which reflect the early stages of the innovation process, they can be considered more closely representative of innovations actually introduced on the market (Flikkema *et al.*, 2014). In addition, TM data contains information about the technological resources used in the related product(s) and are publicly available for a long time series. Thereby, it is possible to search TMs related to a specific technological field over time.

As a first step, we collected all the patents successfully filed at the U.S.P.T.O. between 1980 and 2007 and belonging to the energy conservation sector. The year 1980 can be considered a turning point for the energy conservation sector, especially in the U.S. Indeed, as a consequence of the oil crisis, the U.S. "Energy security act[3]" was set and energy conservation represented one of the key points of interest, as also confirmed by the proclamation of the "National energy conservation days" declared by President Jimmy Carter in the same year[4]. We collected all patents belonging to the "Energy conservation" class, as identified by the International Patent Classification (IPC) Green Inventory[5] (Albino *et al.*, 2014). The IPC Green inventory was developed by the World Intellectual Property Organization in 2008 and provides a connection between the Environmentally Sound Technologies[6] (ESTs) and the IPC classification. In particular, it divides ESTs in seven green technological classes, which are in turn distinguished into a hierarchical set of technological fields. In this paper, we refer to the "Energy conservation" class and its related fields (see Appendix A), thus searching and identifying all patents assigned to the respective IPC codes. After identification, we collected related bibliographic information, such as filing and issue years, forward, backward, and scientific-based citations, claims, and additional information about inventors and assignees. We excluded all those patents that are not assigned to a company after checking for assignees' names. In fact, a single firm may appear in the database as multiple assignee names (e.g., "Procter and Gamble", "Procter & Gamble", "P&G"). As done in prior works, we treated parents and subsidiaries as single units. This procedure yielded a sample of 11,638

[3] Public Law 96-294-JUNE 30, Energy security Act, 1980.
[4] See http://www.presidency.ucsb.edu/ws/?pid=33336.
[5] See http://www.wipo.int/classifications/ipc/en/est.
[6] In the chapter 34 of Agenda 21 (UN, 1992), ESTs have been defined as "technologies that have the potential for significantly improved environmental performance relative to other technologies".

patents owned by 722 companies. However, we did not find required company data for 26 firms, such as firm size and related industrial SIC code(s). Hence, we restricted the sample to the 11,385 patents possessed by 696 firms for which we have all the necessary information. Furthermore, since there is usually not a direct and unique relationship between an invention and a marketed product, we focus on the technological portfolio level. The unit of analysis of the study is therefore the patent portfolio developed by a focal firm in a given year and in a given technological field (see Appendix B). This procedure yielded a total of 3,393 observations (4.88 portfolios per company, on average).

For the second step of the data collection process, we used TMs registered at the U.S.P.T.O. as a proxy for the introduction of new products. In particular, TMs in the U.S. market usually demonstrate a products' "use in commerce", i.e. the actual commercialization of a product bearing the TM. In other words, in order to make the use of the TM valid, the TM owner has to prove that the product(s) related to a given TM is actually commercialized on the market (Graham *et al.*, 2013; Krasnikov *et al.*, 2009; Semadeni, 2006). This provides us with further confidence on the effectiveness of using TMs as a valid proxy for new product introduction.

A defined technological classification for TM data does not exist. Hence, in order to link TMs to products in the energy conservation sector we adopted a keyword approach, which has been considered as an effective strategy in the absence of a well-defined classification (Shapira et al., 2014). Accordingly, we selected a set of keywords related to each technological field using the descriptions provided by the IPC green inventory (see Appendix C). Using these keywords, we manually searched for TMs applied for at the U.S.P.T.O. and owned by the patent assignees above identified. Each result was read and examined by the authors in order to avoid the inclusion of TMs that may contain some of the selected keywords but do not refer to the energy conservation field. Since we are interested in analyzing the introduction of a product within five years after the development of the related patent portfolio (see the definition of the dependent variable in the next section), we considered TMs registered between 1981 and 2012. This process yielded a final sample of 1,783 TMs.

Measures

New product introduction. New product introduction measures the commercialization of the respective underlying technology. We operationalize new product introduction as the likelihood that a firm had applied for a TM during the five years after the development of a patent portfolio in the same technological field. Thus, this is a binary variable taking the value one or zero. We consider a five years moving window to evaluate the introduction of a product (e.g., Lilien and Yoon, 1990) because, as revealed by the previous literature, technological knowledge depreciates sharply, usually during the first five years (Griliches, 1979; Griliches, 1987; Katila, 2002; Nooteboom *et al.*, 2007; Stuart and Podolny, 1996). This is caused by technological obsolescence, knowledge dissemination, forgetting, and turnover of the organizational members that own the specific knowledge. It follows that most of the economic value and the competitive advantage coming from technological knowledge would be lost if it was not used within a short to medium time frame. This pattern strongly characterizes the green energy sector (e.g., Grübler and Wilson, 2013), which is in the focus of our study. Moreover, several researches (e.g., Klaassen *et al.*, 2005; Kobos, Erickson, Drennen, 2006; Miketa and Schrattenholzer, 2004; Watanabe, Wakabayashi, Miyazawa, 2000) have found that the time lag between R&D expenditures and commercialization ranges from two to five years in the energy sector.

Breakthrough nature. This variable is measured as the number of breakthroughs developed in a patent portfolio. In order to identify breakthrough patents, we refer to the number of forward citations received by each patent. Indeed, patents that are cited by subsequent patents are deemed to be more radical, and technologically more relevant than those that are less cited (e.g., Ahuja and Lampert, 2001; Harhoff *et al.*, 1999). Specifically, we first identified the top five percent of highly cited patents in the sample for each year. Then we marked these patents as breakthroughs (e.g., Conti *et al.*, 2014; Singh and Fleming, 2010). Finally, we counted the number of breakthrough patents in each patent portfolio per year.

Technological generality. We measure technological generality as the average value of the generality index of each patent in a patent portfolio (Gambardella and Giarratana, 2013). Specifically, a single patent's generality index is calculated as:

$$Generality\ index = 1 - \sum\left(\frac{C_{iP}}{\sum_i C_{iP}}\right)^2,$$

where C_{iP} indicates the number of citations received by the patent P in the U.S. class i (Trajtenberg *et al.*, 1997). This measure represents the range of different classes in which patents that have cited a focal patent are classified. A patent class represents a particular set of technological problems (Corredoira and Banerjee, Forthcoming). Hence, the higher (less) the number of different patent classes where citing patents are registered, the more (less) widespread the impact that the focal patent has had. Specifically, we first calculated the generality index for each patent and, then, we averaged the value of patents' generality index in a patent portfolio per year.

The Herfindahl index is a well-established measure for the degree of concentration in diversification studies (e.g., Argyres, 1996; Argyres andSilverman, 2004; Lin and Chang, Forthcoming). Therefore, based on the sample of patents described in the data section, we employ two Herfindahl-type indexes to measure the levels of technological diversification and R&D geographic dispersion of the companies included in our study. Particularly, we consider their green patent portfolios, since they can better represent the firms' specific technological efforts undertaken to launch environmentally friendly products on the market (e.g., Dangelico and Pujari, 2010).

Technological diversification. In order to measure a firm's level of technological diversification, we assess the degree to which a company builds a diversified repertoire of technology portfolio in the seven different technological fields of the "Energy conservation" class identified by the IPC Green Inventory (e.g., Lin *et al.*, 2006; Lin and Chang, Forthcoming). Specifically:

$$Technological\ diversification = \sqrt{1 - \sum_{i=1}^{7}(\frac{X_{iF}}{\sum_i X_{iF}})^2},$$

where X_{iF} indicates the number of patents assigned to the firm F in the technological field i.

R&D geographic dispersion. Following previous studies (Lahiri, 2010; Singh, 2008), we compute the geographic dispersion of firms' R&D activities as follows:

$$R\&D\ geographic\ dispersion = 1 - \sum_k(\frac{n_k}{n})^2,$$

where n is total number of patents that the firm has successfully applied for, and n_k refers to the subset of these patents whose first inventor is located in the country k.

A number of control variables are included in the model. At the technological portfolio level, we first control for the size of the patent portfolio (*Portfolio dimension*) (Bessen, 2008), by counting the number of patents in each portfolio. Second, we calculate the average size of teams, in terms of number of different inventors involved in the development of the patents included in a patent portfolio (*Team size*) (Singh, 2008). Third, we average the number of a patent's scientific-based citations to compute the scientific nature of a patent portfolio (*Scientific nature*) (Trajtenberg *et al.*, 1997). Fourth, we include a variable counting the number of joint patents in a patent portfolio (*Joint patents*) (Capaldo and Messeni Petruzzelli, 2014) in order to account for cooperative dynamics in the invention process. Fifth, we average the value of the breadth of technological base included in the patents of a patent portfolio (*Technological breadth).* Specifically:

$$Technological\ breadth = \frac{1}{N}(1 - \sum s_{ij}^2),$$

where N is the total number of patents in a patent portfolio, and s_{ij} refers to the fraction of patents cited by patent that belong to U.S. class j out of n technological categories assigned to the patents by the U.S.P.T.O. (Trajtenberg *et al.*, 1997). Sixth, we average the number of claims reported in the patent documents (*Claims*) (Bessen, 2008). At the firm level, we first include the firm size, as measured by the natural logarithm of the number of employees (*Firm size*). Second, we measure the extent of firms' business diversification (*Business diversification*), by counting the number of different SIC codes assigned to a firm. Third, we control for firms' scientific attitude (*Scientific attitude*), as measured by the natural logarithm of the number of scientific articles published by a company on journals indexed in SCOPUS database. Fourth, we include two binary variables that consider whether patent assignees are included in the stock market (*Stock market*), and whether they are an independent (value one) or a subsidiary (value zero) company (*Ownership*). Finally, since we use data from the U.S.P.T.O., we add a dummy variable set equal to one whether a company's headquarter is located in the U.S. in order to control for differences between U.S. and non-U.S. firms (*Location*).

Model specification

In order to account for the nested and multilevel nature of our data, we use HLM for two level data (HLM2) to test our model. HLM is explicitly considered as "a conceptual and statistical mechanism for investigating and drawing conclusions regarding the influence of phenomena at different levels of analysis" (Hofmann, 1997:273; see also Nielsen and Nielsen, 2013). Specifically, since our dependent variable is a dichotomy binary one, we use a HLM model for binary outcomes (Raudenbush *et al.*, 2011). Furthermore, since our goal is to provide more generalizable results about the likelihood of firms to introduce new products based on their proprietary breakthrough and generic inventions, and how the two considered diversification strategies affect this probability, we discuss results using the "population-average model" (Raudenbush *et al.*, 2011). The $\chi 2$ statistics of the empty model indicate that the variance at technological portfolio level is significantly different from zero, thus suggesting that HLM2 is the most suitable analytical strategy (see Nielsen and Nielsen, 2013). For robustness, we put a middle level between the firm and technological portfolio levels, as represented by the technological field level, hence obtaining a 3-level nested structure: technological portfolios nested within technological fields, in turn nested within companies. The $\chi 2$ statistics of the new empty model indicate that the variances at both firm and technological field levels are not significantly different from zero. This implies that the presence of different technological fields does not add variance to model, hence supporting the use of HLM2.

RESULTS

Table 1 reports descriptive statistics and pairwise correlations, showing relatively low values and hence avoiding multicollinearity concerns. Table 2 presents the results of the hypotheses testing. We used distinct models, with Model 1 serving as the baseline model that includes the control and moderating variables, Models 2–6 serving as partial models that introduce the main effects and the level 2-1 interactions, and Model 7 serving as the full model that incorporates all variables. Model 1 reveals that, at the firm level, the probability to introduce new products increases with the degree of firms' scientific attitude ($\gamma = 0.09$, $p < 0.001$), with the presence of a firm in the stock market ($\gamma = 0.33$, $p < 0.10$), and with the level of R&D geographic dispersion ($\gamma = 0.95$, $p < 0.10$). At the technological portfolio level, results show a positive influence of *Team size* ($\gamma = 0.08$, $p < 0.05$), *Technological breadth* ($\gamma = 0.36$, $p < 0.05$), and *Claims* ($\gamma = 0.01$, $p < 0.10$) on new product introduction.

Model 2 presents the main effects. Consistent with Hypotheses 1 breakthrough inventions have an inverted U-shaped relationship with the probability to be embedded in marketable products. Specifically, the linear term of *Breakthrough nature* is positive ($\gamma = 0.41$, $p < 0.01$), whereas its squared term is negative ($\gamma = -0.04$, $p < 0.05$). Thus, beyond a certain threshold, the breakthrough nature of inventions becomes detrimental to the likelihood that it gets commercialized by means of new product introduction. Similarly, consistent with Hypothesis 2, *Technological generality* is negatively related to the likelihood of introducing products on the market (γ = -0.94, p < 0. 001). Models 3 and 4 include the moderation effects of the technological diversification strategy. Model 3 does not support Hypothesis 3a. The coefficient of the interaction term between *Technological diversification* and *Breakthrough nature*, despite negative, is not significant (γ = -0.22, p > 0.10). In model 4, *Technological diversification* has a negative moderating effect on *Technological generality* (γ = -1.57, p < 0.10), hence supporting Hypothesis 3b. Models 5 and 6 test the last two hypotheses. Model 5 shows a negative moderating effect of *R&D geographic dispersion* on the relationship between the breakthrough nature of inventions and the likelihood of introducing new products (γ = -0.21, p < 0.05), thus confirming Hypothesis 4a. In model 6, the negative effect of *Technological generality* on new product introduction is further enhanced by *R&D geographic dispersion* (γ = -3.31, p < 0.01), hence confirming Hypothesis 4b.

Robustness checks

In order to test the reliability of our findings, we conduct several robustness checks. First, we control for a potential curvilinear impact of technological generality on the probability of new product introduction. The related model, which includes the squared term of *Technological generality*, does not show the presence of a curvilinear effect, hence supporting our initial assumption. Second, we incorporate cross-level interactions of the squared term of breakthrough nature with the two moderating variables (*Technological diversification* and *R&D geographic dispersion*). These interactions are found to be not statistically significant, indicating that technological diversification and the geographic dispersion of R&D activities mostly influence the linear trajectory of the breakthrough nature of inventions. Third, we consider alternative measures of the breakthrough nature of inventions. Since citation behavior may change in respect of different technological classes, instead of considering the top five percent of highly cited patents per each year, we consider the top five percent of highly cited patents per each year and per each of the seven technological fields. In this case, Hypothesis 1 gains marginal support, as the squared term of *Breakthrough nature* was negative yet marginally insignificant ($p = 0.105$). In addition, we also consider the top three percent of highly cited patents per year. Resulting models confirm the expected trajectories for all our hypotheses, although Hypotheses 1 and 4a are marginally supported ($p = 0.186$ and $p = 0.228$, respectively).

<*Insert Table 1 about here*>

<*Insert Table 2 about here*>

DISCUSSION

Based on a sample of 11,385 patents and 1,783 TMs registered at the U.S.P.T.O. by 696 companies, we study how the likelihood of firms to exploit their proprietary technological portfolios by introducing new products varies by the level of the breakthrough nature and technological generality of their inventions, while considering the cross-level effects exerted by a firm's technological diversification and R&D geographic dispersion strategies. According to our hypotheses, we show that the likelihood to introduce new products based on companies own technological inventions increases with their breakthrough nature until it reaches an optimal level after which it declines. The level of technological generality has a negative impact on the likelihood to commercialize these inventions. Our findings further reveal that companies with highly dispersed R&D activities are less likely to commercialize breakthrough inventions, whereas the level of technological diversification does not moderate the relationship between a technology's breakthrough nature and its commercialization. Finally, our results show that the negative impact of technological generality is further enhanced when the related inventions are owned by companies that pursue a technological diversification strategy and possess highly dispersed R&D facilities.

Recognizing that “leveraging technological competence into new products is at the heart of why companies cultivate these resources; yet, studies examining product outcomes are rare” (McEvily *et al.*, 2004:715), we believe these findings suggest several theoretical and managerial implications.

Theoretical implications

First, we provide empirical evidence that the attributes of firms’ technological portfolios actually affect the likelihood to exploit propriety technologies by introducing new products on the market. We ascribe these effects to theories suggesting that these attributes influence firms’ value creation and value appropriation capabilities (Gilbert, 2006; James *et al.*, 2013; Nerkar and Shane, 2007). Hence, we can support the view that these characteristics of technological inventions, besides other factors such as firms’ strategies and the state of the external environment (e.g., Barbosa and Faria, 2011; Hall and Bagchi-Sen, 2007), need to be carefully evaluated by companies in their decision to undertake a new product development project. Moreover, we contribute to the extant literature analyzing the role of technology characteristics (Nerkar and Shane, 2007; Shane, 2001), by considering the firms’ entire technological portfolios, rather than a specific single invention (see Nerkar and Shane, 2007). More specifically, our results allow us to advance our understanding of breakthrough and generic technologies’ commercialization (Aarikka-Stenroos and Lehtimäki, Forthcoming; Thoma, 2009).

Second, we find empirical evidence for the assumption that commercialization activities at the technology level can only be fully understood by incorporating firm-level effects. This is of particular interest, since academics have so far only analyzed the commercialization process of inventions on one level of analysis. By adopting this cross-level approach, we are more confident about the validity of our contributions since the multilevel perspective is seen to be crucial for improving the understanding of important phenomena in management studies (Gupta *et al.*, 2007; Hitt *et al.*, 2007). More particularly, our findings show that despite the potential advantages of firms’ technological diversification and the geographic dispersion of their R&D activities, they appear to negatively contribute to the probability of firms to leverage more radical and generic technologies. On the one hand, technological diversification increases the managerial constraints associated with the exploitation of generic technologies and reduces the resources needed to acquire downstream complementary assets. On the other hand, R&D geographic dispersion hampers the knowledge sharing process underlying the exploitation of breakthrough inventions, as well as increases the complexity of coordinating numerous market applications and dispersed R&D labs at the same time. Overall, these findings illustrate that the successful commercialization of certain types of technologies is contingent upon strategic firm-level factors. This refines earlier work in this domain (e.g., Chen *et al.*, 2011; Nerkar and Shane, 2007).

Third, our study provides additional insights into the continuing debate concerning the measurement of innovation performance. In order to better capture the commercial impact of inventions, we use TM data as a mean to effectively measure whether technologies have been embodied in products introduced on the market (e.g., Semadeni, 2006). In fact, TM data overcomes the well-known drawbacks of other objective innovation measures (i.e., R&D expenditures and patents) that do not reflect market activities (Flikkema *et al.*, 2014; Mendonça *et al.*, 2004). It further has the advantage that it can be linked to specific technologies or technology portfolios which make it better to test causal relationships between inventive activity and commercialization outcome at the technology and related product level. Our approach therefore helps to overcome the traditional difficulties associated with measuring the link between technological solutions and related new product introductions (Chandy *et al.*, 2006).

Finally, we focus our attention upon a novel research setting, as reflected by energy conservation technologies, included in the so-called eco-innovation realm (Albino *et al.*, 2014; Berrone *et al.*, 2013), which are more and more at the center of the current academic and political debate for their capability to enable the shift towards a sustainable society and to promote economic growth (OECD/IEA, 2011; Shrivastava, 1995). Thereby, we are also able to shed new light on the factors favoring the translation of these new and important technologies into marketable products.

Indeed, commercial activities are of foremost importance in the eco-innovation context (Albino *et al.*, 2014), yet scant attention has been posed on the conditions allowing companies to take advantage from their inventive sustainable efforts in this field of 'green' technology (Berrone *et al.*, 2013).

Managerial implications

Results from our analyses also provide useful insights for managers. First, managers are advised to understand the double-edge sword of the breakthrough nature of inventions. Despite their high technological and market potential, breakthrough technologies may undermine existing value assets or might not be fully accepted by customers if they pass a certain level of radicalness. In this case, higher levels of an invention's breakthrough nature reduce the commercialization potential for the respective technology. Second, given the high adaptation costs and the low probability to appropriate the value from generic technologies, an external commercialization strategy might be considered as a more effective way to economically profit from these types of invention, rather than an internal commercialization route by means of new products. This in fact can be considered a very effective strategy to deploy more generic solutions across many different markets and to capture a greater share of their value (Gambardella and Giarratana, 2013). According to the foregoing discussion, it is therefore important for managers to critically analyze the characteristics of their technological portfolio in order to better decide on the firm's commercialization strategy. Third, the likelihood to have breakthrough and generic inventions turned into marketable products seems to depend on firms' diversification strategies. Specifically, managers can expect to face hindrances in the commercialization of more generic solutions when the breadth of firms' technological knowledge is broad due to the emergence of diseconomies of scope and related managerial and resource constraints. Similarly, managers must be aware that the communication costs and increased managerial difficulties resulting from higher levels of geographic R&D dispersion may limit the possibility to leverage both breakthrough and generic technologies. In other words, understanding the impact of relevant firm-level variables (e.g., diversification strategy) on the technological portfolio level puts managers in a better position to exploit firms' technological solutions more effectively. Fourth, managers have to increasingly respond to the regulatory pressures towards environmental sustainability (Berrone *et al.*, 2013). They cannot overlook the relevant economic impact coming from multiple eco-innovative activities either (Shrivastava, 1995; Unruh and Ettenson, 2010). Therefore, our findings guide managers to focus on those factors that are most critical for commercializing more environmentally friendly products based on energy conservation technologies.

Limitations and future research

Despite the promising findings, our study has some shortcomings that may provide opportunities for future research. First, our work is limited to the energy conservation sector. Future research may expand this study to other industries for ensuring the generalizability of our results to other technological domains. A priori, however, we expect that our theoretical arguments will remain consistent also in other areas such as transportation, building, electronics, and telecommunication (OECD/IEA, 2011). Second, since we collected TMs registered at the U.S.P.T.O., our work mainly refers to products commercialized in the U.S. market. On the one hand, this represents an advantage, since in this case TMs usually demonstrate a product's "use in commerce" (Graham *et al.*, 2013; Semadeni, 2006). Nevertheless, on the other hand, this calls for further investigations in other markets in order to capture potential market specific dynamics. Third, whilst the breakthrough nature and technological generality represent two of the most relevant technology characteristics (Ahuja and Lampert, 2001; Gambardella and Giarratana, 2013), other technology attributes such as technological simplicity or compatibility can be taken into account (Chen *et al.*, 2011). Fourth, additional firm-level or network-level factors might be considered. Future studies may analyze the upstream and downstream alliances established by companies, which are more and more required to support and complement firms' internal innovative activities

(Gulati, 1998). Fifth, our study focuses on internal commercialization strategies. Future works may study how companies manage external and internal invention commercialization strategies, simultaneously. Finally, in the present research we have not assessed the financial success of the commercialized products, hence opening the door to a further interesting line of inquiry.

In conclusion, this study offers new important insights on the relationships between technology characteristics and the likelihood of commercializing related technologies via the market introduction of new products (Nerkar and Shane, 2007). Furthermore, adopting a multilevel perspective (Gupta *et al.*, 2007; Hitt *et al.*, 2007), we show that the effects of technology characteristics on commercialization can only be thoroughly understood in the specific firm-level context.

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APPENDIX A – "ENERGY CONSERVATION" CLASS AND RELATED IPC CODES

Table A below shows the seven technological fields of the energy conservation class and related IPC codes for data collection, as identified by the IPC Green Inventory.

<Insert Table A about here>

APPENDIX B – DEFINITION OF THE UNIT OF ANALYSIS

Table B1 represents our dataset of patents. For each patent, it is shown the assignee, filing year, and technological fields (the other bibliographic information are not reported). Our unit of analysis is the patent portfolio owned by a specific company, which in turn has been developed in a given year and belongs to a specific technological field. Thereby, the first observation is composed by the first three patents, since they are all assigned to firm A, applied for in 2000, and classified in the "Low energy lighting" field. Differently, the fourth and fifth patents are still assigned to company A and filed for in 2000, but they belong to a different field. Hence, they constitute the second observation. Again, since the sixth and seventh patents differ from the fourth and fifth respect to the filing year and from the first three patents respect to the technological field, they form the third observation. Finally, the last observation includes the last three patents, which are those assigned to company B, filed for in 2005, and classified in the "Thermal building insulation" field. Table B2 shows a summary of the four observations.

<Insert Table B1 about here>

<Insert table B2 about here>

APPENDIX C – KEYWORDS DEFINITION

Storage of electrical energy
(storage and energy) - (storage and power) - (energy and conservation) - (power and conservation) – (electric and conservation) – (electric and storage) – (electric and conservation) - (electricity and conservation)

Power supply circuitry
"power saving modes" - "power saving" - (energy and saving) - (power and saving) - (energy and reduction) - (power and reduction)

Measurement of electricity consumption
"measurement of electricity consumption" - (electrical and measurement) - "measure consumption" - "energy measurement" - "power measurement" - (energy and measurement) - (power and measurement) - (measurement and consumption)

Storage of thermal energy
"heat energy" - "thermal energy" - (heat and storage) - (thermal and storage)

Low energy lighting
"Low energy lighting" - LED - OLED - PLED - (light and low) - (lighting and low) - (light and energy) - (light and reduction) - (lighting and energy) - (lighting and reduction)

Thermal building insulation, in general

(building and insulation) - (building and thermal) - (building and save) – (building and storage)

Recovering mechanical energy
“recovering mechanical energy” - “recovering energy” - “reusing energy” - (recover and energy) - (mechanical and energy) or (chargeable and vehicles) - (accumulator and vehicles)

Table 1. Descriptive statistics and pairwise correlations

		Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	**New product introduction**	0.16	0.37	0.00	1.00	1																
2	**Breakthrough nature**	0.17	0.71	0.00	15.00	.13**	1															
3	**Technological generality**	0.48	0.25	0.00	0.94	-.04*	.11**	1														
4	**Portfolio dimension**	3.35	9.30	1.00	249.00	.08**	.50**	.03	1													
5	**Scientific nature**	2.48	7.08	0.00	152.00	.08**	.11**	.07**	.14**	1												
6	**Team size**	2.49	1.42	1.00	15.00	.10**	.08**	.04**	.04*	.04*	1											
7	**Joint patents**	0.11	0.53	0.00	9.00	.09**	.19**	.00	-.05**	.46**	-.01	1										
8	**Technological breadth**	0.45	0.25	0.00	1.00	.05**	.07**	.13**	.14**	.00	.25**	.07**	1									
9	**Claims**	8.20	8.20	0.69	14.07	.04*	-.04*	-.01	-.19**	.11**	-.14**	.03	.09**	1								
10	**Firms size**	11.63	12.30	0.00	266.00	.04*	.06**	.04*	-.02	.14**	.04*	-.05**	.14**	-.19**	1							
11	**Business diversification**	1.14	0.39	1.00	3.00	.01	-.00	-.01	-.06**	.08**	-.06**	-.04*	.05**	-.06**	.13**	1						
12	**Ownership**	0.62	0.48	0.00	1.00	-.02	-.01	.02	-.08**	.05**	-.06**	-.01	.04*	-.03*	.27**	.08**	1					
13	**Stock market**	0.28	0.45	0.00	1.00	.09**	-.03	-.04*	-.08**	.04*	-.04*	.05**	.08**	-.07**	.34**	-.02	.32**	1				
14	**Scientific attitude**	1.07	2.81	0.00	11.17	.13**	.01	.03	-.09**	.12**	-.05**	.05**	.08**	-.07**	.39**	.023	.22**	.27**	1			
15	**Technological diversification**	0.13	0.21	0.00	0.78	.11**	.02	.04*	-.05**	.11**	-.06**	.02	.11**	-.04*	.33**	.10**	.15**	.17**	.36**	1		
16	**R&D geographic dispersion**	0.05	0.13	0.00	0.72	.07**	-.00	-.06**	-.04*	.03	.02	-.02	.03	.015	.07**	.05**	-.02	.06**	.01	.11**	1	
17	**Location**	0.50	0.50	0.00	1.00	-.03	.06**	.15**	.24**	-.07**	.08**	-.12**	-.13**	.18**	-.26**	.02	-.03	-.11**	-.17**	-.10**	-.00	1

n= 3,393; *p<0.05; **p<0.01

Table 2. Hierarchical linear modeling results (with robust standard errors)

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Intercept	-2.21***	-1.93***	-1.94***	-2.08***	-1.93***	-2.02***	-2.15***
	(0.38)	(0.39)	(0.39)	(0.39)	(0.39)	(0.39)	(0.39)
Firm level							
Firms size	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Business diversification	-0.04	-0.04	-0.05	-0.04	-0.05	-0.04	-0.04
	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)
Ownership	-0.25	-0.24	-0.25	-0.23	-0.24	-0.23	-0.23
	(0.21)	(0.21)	(0.21)	(0.21)	(0.21)	(0.21)	(0.21)
Stock market	0.33$^+$	0.35$^+$	0.35$^+$	0.34$^+$	0.35$^+$	0.34$^+$	0.33$^+$
	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
Scientific attitude	0.09***	0.09***	0.09***	0.09***	0.09***	0.09***	0.09***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Technological diversification	0.58	0.67$^+$	0.72$^+$	1.31*	0.66$^+$	0.70$^+$	1.28*
	(0.39)	(0.39)	(0.4)	(0.55)	(0.39)	(0.39)	(0.55)
R&D geographic dispersion	0.95$^+$	0.84	0.82	0.85	0.97$^+$	1.92**	1.89**
	(0.51)	(0.52)	(0.52)	(0.52)	(0.52)	(0.67)	(0.67)
Location	0.05	0.13	0.13	0.12	0.12	0.10	0.10
	(0.18)	(0.18)	(0.18)	(0.18)	(0.18)	(0.18)	(0.18)
Technological portfolio level							
Portfolio dimension	-0.00	-0.00	-0.00	-0.00	-0.01	-0.00	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Scientific nature	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Team size	0.08*	0.08*	0.08*	0.08*	0.08*	0.08*	0.08*
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Joint patents	0.09	0.10	0.10	0.10	0.10	0.09	0.09
	(0.09)	(0.09)	(0.09)	(0.09)	(0.10)	(0.10)	(0.10)
Technological breadth	0.36*	0.35*	0.35$^+$	0.36*	0.33$^+$	0.35*	0.35$^+$
	(0.17)	(0.18)	(0.18)	(0.18)	(0.18)	(0.18)	(0.18)
Claims	0.01$^+$	0.01$^+$	0.01$^+$	0.01	0.01	0.01$^+$	0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Breakthrough nature		0.41**	0.44**	0.40**	0.49***	0.41**	0.48***
		(0.13)	(0.14)	(0.13)	(0.13)	(0.13)	(0.13)
Breakthrough nature squared		-0.04*	-0.04$^+$	-0.04*	-0.05**	-0.04*	-0.04*
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Technological generality		-0.94***	-0.95***	-0.60**	-0.94***	-0.73***	-0.46*
		(0.20)	(0.20)	(0.21)	(0.20)	(0.22)	(0.21)
Level 2-1 Interactions							
Technological diversification			-0.23				-0.15
x Breakthrough nature			(0.28)				(0.26)
Technological diversification				-1.57$^+$			-1.35
x Technological generality				(0.93)			(0.90)
R&D geographic dispersion					-1.21*		-0.97$^+$
x Breakthrough nature					(0.53)		(0.53)
R&D geographic dispersion						-3.31**	-2.83*
x Technological generality						(1.17)	(1.15)
***χ*2 statistics**	1787.19***	1780.07***	1772.44***	1771.63***	1783.40***	1798.28***	1787.51***

n= 3,393; +p<0.1; *p<0.05; **p<0.01; ***p<0.001

Table A. "Energy conservation" technological fields and related IPC codes. Source:
http://www.wipo.int/classifications/ipc/en/est/

Energy conservation	
Technological field	*IPC codes*
Storage of electrical energy	B60K 6/28, B60W 10/26, H01M 10/44-10/46, H01G 9/155, H02J 3/28, 7/00, 15/00
Power supply circuitry	H02J, H02J 9/00
Measurement of electricity consumption	B60L 3/00, G01R
Storage of thermal energy	C09K 5/00, F24H 7/00, F28D 20/00, 20/02
Low energy lighting	F21K 99/00, F21L 4/02, H01L 33/00-33/64, 51/50, H05B 33/00
Thermal building insulation, in general	F21K 99/00, F21L 4/02, H01L 33/00-33/64, 51/50, H05B 33/00, E04C 1/40, 1/41, 2/284-2/296, E06B 3/263, E04B 2/00, E04F 13/08, E04B 5/00, E04F 15/18, E04B 7/00, E04D 1/28, 3/35, 13/16, E04B 9/00, E04F 13/08
Recovering mechanical energy	F03G 7/08, B60K 6/10, 6/30, B60L 11/16

Table B1. Example of dataset of patents

Patent number	Assignee	Filing year	Technological field
1	A	2000	Low energy lighting
2	A	2000	Low energy lighting
3	A	2000	Low energy lighting
4	A	2000	Thermal building insulation
5	A	2000	Thermal building insulation
6	A	2002	Thermal building insulation
7	A	2002	Thermal building insulation
8	B	2005	Thermal building insulation
9	B	2005	Thermal building insulation
10	B	2005	Thermal building insulation

Table B2. Unit of analysis

ID portfolio	Company	Filing year	Technological field	Number of patents
1	A	2000	Low energy lighting	3
2	A	2000	Thermal building insulation	2
3	A	2002	Thermal building insulation	2
4	B	2005	Thermal building insulation	3