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Breakthrough inventions, firm characteristics and technological sector dynamics

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Abstract

The aim of this paper is to analyze the impact of firm and sector characteristics on the quality of patents, once it has been controlled for patent characteristics. To do so, we perform a wide cross-sector analysis based on a large multi-sector database and the quality of patents is measured in terms of breakthrough inventions, that is, the top one percent most cited patents. Our results confirm previous results showing that the intrinsic characteristics of patents strongly explain breakthrough inventions. However, they also emphasize how firm characteristics, such as size, diversity and invention behavior, moderated by technological sector dynamics contribute to explain outstanding inventions.

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ABSTRACT. The aim of this paper is to analyze the impact of firm and sector characteristics on the quality of patents, once it has been controlled for patent characteristics. To do so, we perform a wide cross-sector analysis based on a large multi-sector database and the quality of patents is measured in terms of breakthrough inventions, that is, the top one percent most cited patents. Our results confirm previous results showing that the intrinsic characteristics of patents strongly explain breakthrough inventions. However, they also emphasize how firm characteristics, such as size, diversity and invention behavior, moderated by technological sector dynamics contribute to explain outstanding inventions.

Keywords: breakthrough patents; firm diversity; size

1. Introduction

The rapid rise of patenting over the past twenty years has raised a number of concerns regarding the value of patent rights and their underlying inventions. Although R&D efforts have increased during this period, the growth of patents has been twice as large in some industries, such as semiconductors (Hall and Ziedonis, 2001). The increase in patent productivity could be considered as an indicator of increased innovation and future economic growth. However, a number of recent papers suggest that the value of patents has decreased over time. Among the many reasons for this pattern, two are particularly key: firm patenting behavior and industry/technology characteristics.

First, although firms increase their patent filings to protect their inventions in order to build or maintain their technological leadership, they do also increasingly patent in a strategic way as they build up very large portfolios either to block rivals or to forestall hold-up situations (Blind et al. 2005). Second, the industry and technology characteristics also tend to favor patent filings and strategic behaviors. Technological opportunities have increased filings by new entrants as well as incumbents in industries based on information and communication technologies or biotechnologies, for example

(Hall, 2005). In complex product industries, where each product combines many patents held likely by different firms, filing growth has been consistently faster, as compared to discrete technologies, for which a product consist of a single patent. Consequently, companies increase patent portfolio size in order to increase their bargaining power in patent disputes (Noel and Schankerman, 2006). It has been argued that these patenting strategies tend to reduce their values, and as a result, companies tend apparently to accumulate low value patents that do not represent real inventions but rather aim first and foremost to hinder innovation by rivals (Blind et al. 2008).

Although, an increasing number of papers attest this pattern, we lack systematic cross-sector and large studies analyzing these issues. The aim of this paper is to investigate how firm characteristics, on the one hand, and the industry/technology characteristics, on the other hand, affect the value of their patents. Following the recent literature, we consider breakthrough patents, namely the top 1 most cited patents. This indicator is calculated based on the number of forward citations received, excluding self-citations at the patent family level. Based on this indicator, we investigate the extent to which company and industry characteristics affect the value of patents, thus answering the following questions: what determines the technological quality of patents? What type of assignees file breakthrough patents? There is a long-standing discussion questioning whether radical innovations emanate from small companies rather than incumbents. However, the size of the company is not a sufficient factor. Their degree of specialization, their relative technological position may also determine their propensity to file high quality patents. Finally, the characteristics of the technological area may moderate these findings. It is presumable that small innovators may file high quality patents when technological opportunities are high rather than in very mature technologies, where large incumbents may benefit from knowledge accumulation.

2. REVIEW OF THE LITERATURE

2.1. MEASURING THE VALUE OF INVENTIONS

The value of inventions may be measured in different ways. Most studies consider the technological value of individual patents based on forward citations, probably because these measures are easily available despite their known drawbacks. Breakthrough patents or inventions correspond to the most cited ones, either at the top 5 or top 1 percent (Trajtenberg, 1990, Ahuja and Lampert, 2001, Singh and Fleming, 2010, Kaplan and Vikili, 2012). The economic value may be evaluated through the patent right based on the cost of renewals (Schankerman and Pakes, 1986; Bessen, 2008) or through surveys asking patent holders to assign monetary values to individual patents (Harhoff et al. 2003; Gambardella et al. 2008). Finally, the economic value of patent portfolios has been assessed through its market value (Hall et al. 2005; McGahan and Silverman, 2006). These studies converge to show that economically important patents are also technically important ones, that is, the number of forward citations also explains the monetary value.

Among the determinants of forward citations and breakthrough inventions, the focus has been mainly on the scope of property rights, the technical content of inventions, as well as the inventor team characteristics. The quality of patents is assessed through the coverage of the associated property rights that are used as indicators of their market value such as the number of claims or the fact that patents are triadic or have a large geographical scope; these indicators are used as proxies for the size of the potential market for technologies (Sapsalis and Von Pottelsberghe de la Potterie, 2012). The knowledge or technical content of patents do also play a significant role for explaining their value (Cassiman et al 2008; Fleming et al, 2004; Kaplan and Vakili, 2012) based on the idea that more creative inventions imply a variety and a combination of accumulated knowledge and past experience. First, inventions incorporating more scientific knowledge, proxied by the number of non-patent literature such as scientific research papers, generate more valuable patents (Harhoff et al. 2003; Cassiman et al. 2008; Czarnitski et al. 2008; Gittelman and Kogut, 2003). Second, teams of researchers generate more economic and cognitive breakthrough patents than do lone inventors (Singh and Fleming, 2010; Kaplan and Vikili, 2012). Third, the recombination of knowledge captures the emergence of new technological ideas. Backward citations are generally considered as a proxy for the sources of knowledge. Radical inventions are more likely to cite patents belonging to other technological classes than those of the focal patent (Rosenkopf and Neckar, 2001). The recombination of technological knowledge may also be measured by the originality index (Hall et al., 2001), that is, the variety of technological classes in prior art or simply the coverage of the technological classes, that is, the number of IPC – International Patent Classifications – codes characterizing the focal patent.

However, these patent characteristics are not the only determinants of breakthrough patents. The firms' technological characteristics may also play a role, and this role may be moderated by the technological sector dynamics, which is discussed in the next two sections. Thus, this article intends to test the firms' characteristics moderated by sector characteristics once patent characteristics have been controlled for.

2.2. FIRM TECHNOLOGICAL CHARACTERISTICS AND PATENTING BEHAVIOR

The technological characteristics of firms as well as their patenting and learning behavior are known to influence their technological leadership and performance.

Entrepreneurial perspectives on innovation often assumes that small size innovators or new companies are more inclined to introduce radically new and path-breaking innovations since they are more flexible, less subject to technological path-dependence and inertia (Christensen and Bower, 1996). For these reasons, small companies have an advantage in managing technological change and they may more easily exploit opportunities to develop more radical innovations.

However, these arguments of flexibility and size have been called into questions. First, the fact that small companies are more innovative than large ones seems to be verified only in some specific contexts depending on the maturity of technologies, the size of markets and type of competition (Katula and Schane, 2005). Second, larger companies have a higher propensity to do research, benefit from cumulative innovations and have the opportunity to explore large technological areas. On the one hand, some authors equate technological specialization and knowledge accumulation. Kim and Kogut (1996) argue that larger firms are more innovative because they are more specialized and have the opportunity to build on prior experience in innovation activities. On the other hand, large and multinational companies act on different product markets, and use larger knowledge bases to cope with increasingly complex products and technologies (Breschi et al. 2003; Cantwell et al. 2000). These companies are even more innovative given that they develop and use technologies that are not only at the core of their competences but also at their periphery (Patel and Pavitt, 1997). And this diversity enables them to combine and recombine diverse knowledge bases thus favoring the capacity to innovate and produce radical inventions (Grandstrand et al. 1997; Garcia Vega, 2006; Abernathy and Clark, 1985). And indeed, it is now well known that large diversified incumbents do play a significant role as a source of innovation (Patel and Pavitt, 1997; Granstrand, 1998; Breschi et al. 2003; Leten et al. 2007) and even of major innovations (Methé et al. 1996).

For these reasons, the debate has shifted from new and small innovators to new innovators to the industry. Thus, the key question is not necessarily the size of innovators, but rather, their level of diversification and their capacity to use their already existing and accumulated knowledge to enter new technological sectors and markets. As highlighted by Tushman and Anderson, (1986), if major technical changes often originate from firms outside the industry, they are not necessarily introduced by small firms, but rather by large diversified incumbents coming from other industries. As a consequence, two types of large firms may be distinguished - industry incumbents and diversified entrants (Methe et al. 1997). First, industry incumbents have been shown to be major sources of innovations especially when knowledge is highly cumulative (Methé et al, 1996), second diversified established firms entering new industries are also major innovators since they benefit from possible cross-fertilization and technology fusion (Klepper, 1988; Leten et al. 2007). However diversification also has a cost inducing diminishing returns. Leten et al. 2007 show that diversification has an inverted u-shape relationship with technological performance (Leten et al. 2007).

As a consequence, we expect large and diversified firms to have a higher propensity to produce breakthrough patents. Companies may have difficulties producing breakthrough patents when entering new technological fields, unless they are diversified.

Besides their size and their level of diversification, the firms' patenting and learning behavior are also determining to understand how breakthrough patents are produced. Ahuja and Lampert (2001) show that companies filing patents based on technologies in which (1) they have no prior experience, or (2) that are based on newly developed technologies tend to create more breakthrough inventions. Our assumption is that firms producing patents based on novel or emerging technologies have a higher propensity to file breakthrough patents. In this paper, we do not only consider these sources of inventions, but we do also consider to what extent diversified or small innovators gain advantage when they have these types of patenting and learning behaviors.

2.3. TECHNOLOGICAL SECTOR CHARACTERISTICS

The relationship between the firms' characteristics, especially diversity and the learning behavior and performance may also be more complex and context specific. First, technological diversification depends on technological sectors' characteristics (Patel and Pavitt, 1997; Stephan, 2002). There is a high variance in technological diversification not only across firms but also across technological sectors, which need to be controlled for in order to capture how technological diversification affects the quality of inventions. Thus, the fact that large incumbent firms have an innovative advantage may be moderated by industry characteristics such as market concentration or technological opportunities (Acs and Audretsch, 1990; Malerba and Orsenigo, 1996; Fai, 2007; Castellani et al., 2010).

3. DATA AND VARIABLES

3.1. SAMPLE CONSTRUCTION

Data used in this analysis come from OST-PATSTAT database (2011, October edition). PATSTAT is the most comprehensive patent dataset covering more than 80 patent offices all over the world. The analysis focuses on equivalent patent group having at least a European application among its members and with priority date between 1999 and 2006. The information concerning patent citations (backward and forward) comes from the whole database (i.e. 1990 up to 2010).

Equivalent patents have been identified adopting the standard definition (i.e. patents having exactly the same set of priority dates) and following the rules suggested by Martinez (2010) in order to solve priority-date chains and loops. This definition is also known as a *strict* definition of patent family and is assumed to aggregate patents covering exactly the same invention. The oldest priority date has been assigned to each equivalent group of patents. Since more than one European patent could belong to the same equivalent group, we have decided to select only the oldest one among them: in this way we obtain one-to-one correspondence between patent and equivalent group. This does not imply a loss of generality but simplifies the analysis, since there is some information that concerns patents (e.g. legal events, such as opposition) and other that makes sense treating only at the level of equivalent groups, such as citations. In this context, patent and equivalent group are therefore treated as synonymous. Concerning the citations, we follow OECD practices, to consider, for the backward citations, all the citations reported in the patent application document independently of patent offices cited, and, for forward citation, to consider only those citations made to patents belonging to equivalent groups with at least a European application. Thus, we limit the forward citations only to European equivalents. In both cases, backward or forward citations, we always refer to the citations for equivalent group and never to single patent.

We adopted three further restrictions in order to assign patents to firm and sector variables without any arbitrary assumption. First, concerning firms, we have eliminated all the patents applied by more than one organization. Second, we have not considered those patents that do not belong to a unique technological domain. Indeed, patent officers classify each patent according to IPC classification. Each patent can be easily assigned to more than one IPC codes. Following WIPO classification (35 classes), we have affected each patent to some classes according to IPC. It could happen that some patents have been assigned to more than one of WIPO 35 classes. If it is the case and if, for a patent, it has not been possible to identify a predominant class (i.e. having a relative majority), this patent has been excluded from our selection. Please note that these two further restrictions have been adopted only for selecting the patents sample and not to calculate the explanatory variables (e.g. number of citing patents or firm diversity). Finally, we restrict our sample to private applicants, i.e. firms. Finally, from the 907,544 original equivalent groups with at least a European Patents over the period 1999 and 2006 we reduced our sample to 562,523, i.e. 61.98% of the starting population.

The original data have been treated in order to improve their reliability. In particular we have identified a code for applicant. PATSTAT does not provide a unique code identifying firm over different applications so we have run an algorithm able to aggregate applicants given their name's similarity and geographical localization (country level). In this way, it was possible to give a unique code to the same applicant. Given the procedure adopted, we can assume that the code assigned is able identify organization at the plant-level. So the firm variables used in our empirical exercise concerns this level of the analysis, the most disaggregated one. This implies that the intragroup relations have not been taken in account. Moreover the self-citations have been identified using this firm code as well.

3.2. VARIABLE DESCRIPTION AND MODEL

3.2.1. DEPENDENT VARIABLE

The dependent variable identifies *Breakthrough* inventions, which indicate highly cited patent families. It takes the value 1 if the patent family is among the 1% most cited patents within the same application year and technological area (Singh and Fleming, 2010) and 0 otherwise. The variable is based on the number of forward citations received by the patent family within the first 5 years without self-citations. [1]

We estimate a probit regression model of the likelihood that a patent is among the most cited patent families.

$$\begin{aligned} &\text{Breakthrough} = \beta_0 + \beta_1 \text{Firm Characteristics} + \beta_2 \text{Sector characteristics} \\ &+\beta_3 \textit{controls} + \text{technological area indicators} + \\ &\text{year dummies} + \varepsilon \end{aligned}$$

Technological area and year fixed effects are introduced in order to account for systematic differences across technologies and years. Finally, to cope with possible correlation between patent quality within the same firm, we use robust standard errors that are clustered on the firm's identifier.

3.2.3. THE INDEPENDENT VARIABLES

We estimate the impact of firm and sector characteristics on the patent value, controlling for patent characteristics.

Regarding firm characteristics, we consider *the stock of patents over 5 years*. This variable captures the level of technological inventiveness of a firm. In order to identify possible differences between various categories of firms, we distinguish three categories of innovators, whether they are small (first quartile), medium (second and third

[1] In the Appendix, we report the same specifications using the number of forward citations whithin a five year window (self-citations excluded) as the dependent variable using a Negative Binomial model in order to check the robustness of our results.

quartile) or large (fourth quartile). The quartiles have been computed for each year and technological area and based on the stock of patents over 5 previous years. We expect the size to have a positive impact on the probability of producing a breakthrough patent.

We do also consider the *firm's technological diversity.* It is computed as the inverse of the Herfindhal index (Leten et al. 2007). It indicates if the firm's patents are spread over technological areas. We expect this variable to have an inverted u-shape relationship with performance.

Following Ahuja and Lampert, (2001), we identify novel and emerging technologies. To identify novel technologies, we use two indicators: *New IPC code to the firm* is a dummy equal to 1 when the focal patent is characterized by an IPC code which has not been used in the four previous years, and 0 otherwise. Since an IPC code may be two restrictive, we do also consider *New technological area to the firm* which takes the value 1 if the patent belongs to a technological area new to the firm and 0 otherwise. We do also consider if the patent is based on the most recent technologies. *Emerging technologies* takes the value 1 if the focal patent cites other patents that have been applied for during the previous two years. Although these variables may be considered as patent characteristics, we do consider them rather as indicators of the companies' technological behavior and especially the fact that they are broadening their knowledge bases and use or compete with the most recent inventions.

Regarding sector characteristics, we consider three variables: *new entrants*, the *Technological Area Patent Growth* as well as the *concentration* of each technological sector. These variables are computed at the technological area level. The first two variables are supposed to be proxies for technological opportunities. Concentration is rather a variable characterizing the fact that most inventions within a sector are issued by a limited number of firms.

The regression analysis employs several control variables regarding patent characteristics. Among the many possible controls (see section 2.1), we decided to focus on a limited number, thus following recent research (Singh and Fleming, 2010; Cassiman et al. 2008): the *Number of inventors* involved in the invention; the patent technological *scope* is the number of technological areas to which the patent refers, *the number of non patent references*, is the number of scientific and other publics*, the number of patent reference*, that is the number of backward citations and finally the fact that the patent is *granted* or not.

The following tables provide some descriptive statistics for the variables (Table 1). The correlation matrix is reported in the appendix.

Table 1. Descriptive statistics

Variable	# Observations	Mean	Std. Dev.	Min	Max
Small	562523	.2344224	.4236377	0	1
Medium	562523	.5077037	.4999411	0	1
Large	562523	.2578739	.4374646	0	1
Patent stock - 5 years	562523	796.0563	2534.939	1	58429
Firm technological diversity	562523	4.670185	3.248304	1	20.04718
New IPC code to the firm	562523	.4112419	.4920594	0	1
New tech. area to the firm	562523	.1676074	.3735176	0	1
Emerging technologies	562523	.4762579	.4994364	0	1
New entrants	562523	1.022673	.3383843	.59325	4.690832
Technological Area Patent Growth	562523	1.739858	8.009798	-25.2381	106.1404
Concentration	562523	.0047116	.0032638	.0010337	.013434
# inventors per patent	562523	3.673174	1.934391	1	62
# of Non Patent ref.	562523	1.516361	2.984792	0	117
Patent scope	562523	3.962172	3.844164	1	98
# of patent ref.	562523	2.659116	3.285405	0	211
Granted	562523	.3591711	.4797579	0	1

4. Results

Table 2 shows the results of the probit model estimations for the **basic configurations including patent controls and firm characteristics.** Models 1 and 2 confirm the previous literature investigating the impact of size and technological diversity. First, the size of assignees in terms of patenting strongly contributes to explain highly cited inventions. Second, technological diversity does have an inverted u-shape relationship with technological performance (Leten et al. 2007). This last result is significant controlling for technological and year fixed effects. However, it does not hold once the patent characteristics are controlled for, diversity remains only slightly significant and more over it becomes negative which now contrasts with previous results (Model 4 to 8). This suggests that breakthrough inventions are rather a matter of size over diversity (Model 7) and that specialized firms are more likely to introduce breakthrough patents (Model 7 and 8). This does also show that the link between firms' characteristics and breakthrough patents is far from being as simple as Model 1 to 2 suggest.

Before testing more complex characteristics of firms, we present the patent characteristics effects. Confirming the literature, model 4, with only patent controls, highlights the importance of patent characteristics. Indeed, every patent control has a positive and surprisingly very stable impact. Thus, the number of inventors, the number of backward citations (from patent and from non-patent references), the patent scope and the fact that the patent is granted highly influence the probability of the patents to be a breakthrough patent.

These results mean that patent characteristics are more important than firms' characteristics to explain breakthrough patents. However, the fact that the firms' size and diversity remains significant, does also suggest these specific mechanisms have to be distinguished from invention related aspects usually emphasized in the literature.

Table 3 further investigates this result by considering **how the firms' characteristics contribute to explain important inventions**. In particular, we introduce proxies that evaluate the firm's capability to investigate new technological areas and to mobilize new knowledge bases. Interactions between variables are also introduced.

Table 3 shows three interesting results. First of all, when a small assignee, in terms of patenting, is diversified, it has a higher probability to make a breakthrough[2] (Model 2). This supports the view that, in some cases, small firms have higher probability than larger ones to radically invent. Indeed, it seems that it is the combination of size and diversity which allows this result, and suggests that firms with small patent portfolios spread over a limited number of technological areas find it easier to keep technological coherence, thus increasing its ability to file highly cited patents (Leten et al. 2007). This result also confirms the work of Katula and Shane (2005) in which, small firms produce more radical innovation in specific contexts. The difference here is that we do identify a firm characteristic while they consider external effects such as sector.

Moreover, even though the firm's capacity to patent in a new technological area has no impact per se (Model 5), it positively influences breakthrough patenting when associated with diversity (Model 6). This result suggests that there is a learning effect due to diversification. Diversified firms are more able to identify technological opportunity in other domains. This is in line with Cassiman et al. (2005) and Henderson and Cockburn (1996). This result also confirms that diversified incumbents coming from outside the industry/technological sector are more able to make a breakthrough in other domains (Tushman and Anderson, 1986).

Finally, the capability of firms to use recent knowledge, measured by *emerging technologies variable,* strongly impacts the probability of breakthrough patents confirming Ahuja and Lampert's results (2001) (Model 7). This suggests that firms that

[2] This situation corresponds to companies for which the level of technological diversity is around 10 on a 20 scale (see descriptive statistics).

use and/or compete with the latest inventions, are probably also at the technological frontier, and thus they are more likely to invent top technologies. On the other hand, being diversified does not provide a premium to companies using emerging technologies; the interaction with diversity is not significant[3].

Thus introducing more precise firm characteristics contributes to a better understanding of breakthrough patents, confirming their role as another mechanism underlying outstanding inventions. Moreover, this contributes to investigate further, those companies' characteristics that go beyond more traditional indicators such as diversity and size. This highlights the need for more information on the firms' capability to mobilize new knowledge-bases and access new markets, proxied by new technological area to the firm. Indeed, when we characterize more precisely firms, we observe that their basic characteristics become even less important, as diversity and size do not remain significant. This suggests that size, when tested alone, is a proxy of other firms' characteristics, however when estimated with other variables, size becomes less important in determining breakthrough patents.

Table 4 tests **how technological sector characteristics may explain the quality of patents and moderate firm characteristics.** First, the sector fixed-effects have already shown strong specificities (see Table 2). However, in order to further investigate the dynamics of technological areas, three sector characteristics are tested, *New entrants* and *Patent growth* as proxies for technological opportunities, as well as *concentration.* New entrants and *Patent growth* appear to have a negative impact on the quality of patents. This result could be linked to the recent debate on patent upsurge indicating that sectors in which the patent rate is high is probably a sector in which less valuable patents are applied for (Hall, 2005), but this raises a need for further investigations. However, the impact is positive if associated with diversity. Diversified firms in technological areas with a high patent growth are more likely to file for breakthrough patents. By contrast, it is surprising that concentration does not impact the probability to breakthrough.

Finally, when we introduce firms and sector variables in the same model, the results are rather stable, which confirms the need to take into account firms and sector specificities in order to analyze the quality of patents (Table 5).

[3] This result is not reported in the paper. It is available on request from the authors.

Table2. Breakthrough Patents – Basic regressions & Controls
Specification search

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FIRM VARIABLES								
Firm technological diversity	0.033***	0.021*	-0.001		-0.002	0.000	-0.005+	-0.007+
	[4.12]	[2.39]	[-0.38]		[-0.24]	[0.06]	[-1.72]	[-1.75]
Firm technological diversity Square	-0.002***	-0.002*			-0.000	-0.000		
	[-3.32]	[-2.50]			[-0.48]	[-0.66]		
Patent stock - 5 years	0.000***					0.000***	0.000***	
	[5.48]					[5.02]	[4.93]	
Size (Ref.: Large inventors)								
Medium		-0.063*	-0.069*		-0.047+			-0.048+
		[-2.37]	[-2.53]		[-1.69]			[-1.72]
Small		-0.111***	-0.135***		-0.055			-0.060+
		[-3.38]	[-4.01]		[-1.59]			[-1.70]
PATENT CONTROLS								
# inventors per patent				0.059***	0.059***	0.059***	0.059***	0.059***
				[13.15]	[12.93]	[13.03]	[13.06]	[12.95]
# of Non Patent ref.				0.004**	0.004**	0.004**	0.004**	0.004**
				[2.72]	[2.86]	[2.69]	[2.65]	[2.85]
Patent scope				0.029***	0.029***	0.029***	0.029***	0.029***
				[13.34]	[13.23]	[13.23]	[13.28]	[13.28]
# of patent ref.				0.019***	0.019***	0.019***	0.020***	0.019***
				[14.68]	[14.52]	[14.64]	[14.64]	[14.54]
Granted				0.107***	0.106***	0.108***	0.108***	0.106***
				[10.61]	[10.45]	[10.61]	[10.65]	[10.45]
TECHNOLOGICAL SECTOR (Ref.: Transport)								
Analysis of biological materials	-0.033	-0.036	-0.037	-0.132*	-0.133*	-0.131*	-0.131*	-0.133*
	[-0.52]	[-0.57]	[-0.58]	[-2.03]	[-2.05]	[-2.02]	[-2.02]	[-2.06]
Audio-visual technology	-0.015	0.017	0.024	0.008	0.021	-0.003	-0.002	0.022
	[-0.33]	[0.38]	[0.54]	[0.19]	[0.47]	[-0.07]	[-0.05]	[0.50]
Basic communication processes	0.031	0.049	0.060	0.093+	0.101+	0.091+	0.093+	0.103*
	[0.59]	[0.93]	[1.13]	[1.82]	[1.96]	[1.79]	[1.83]	[2.00]
Basic materials chemistry	-0.041	-0.033	-0.029	-0.172***	-0.163***	-0.164***	-0.164***	-0.162***
	[-0.92]	[-0.74]	[-0.65]	[-3.83]	[-3.62]	[-3.65]	[-3.64]	[-3.60]
Biotechnology	-0.012	-0.016	-0.016	-0.203***	-0.205***	-0.202***	-0.202***	-0.205***
	[-0.26]	[-0.33]	[-0.35]	[-4.21]	[-4.24]	[-4.19]	[-4.20]	[-4.24]
Chemical engineering	0.063+	0.063+	0.064+	0.000	0.004	0.006	0.006	0.004
	[1.70]	[1.71]	[1.73]	[0.00]	[0.11]	[0.16]	[0.17]	[0.12]
Civil engineering	0.204***	0.184***	0.169***	0.268***	0.258***	0.267***	0.264***	0.255***
	[5.59]	[4.94]	[4.52]	[7.38]	[6.89]	[7.29]	[7.21]	[6.81]
Computer technology	-0.016	-0.003	0.000	0.012	0.017	0.009	0.009	0.018
	[-0.45]	[-0.08]	[0.01]	[0.32]	[0.45]	[0.23]	[0.24]	[0.46]
Control	0.006	0.008	0.006	0.053	0.055	0.054	0.054	0.055
	[0.13]	[0.17]	[0.12]	[1.12]	[1.18]	[1.15]	[1.14]	[1.17]
Digital communication	0.043	0.059	0.066	0.074+	0.077+	0.065	0.067	0.078+
	[0.99]	[1.37]	[1.55]	[1.69]	[1.79]	[1.52]	[1.55]	[1.82]
Electrical machinery, apparatus, energy	-0.023	-0.014	-0.015	-0.032	-0.026	-0.032	-0.033	-0.026
	[-0.69]	[-0.42]	[-0.45]	[-0.95]	[-0.77]	[-0.96]	[-0.98]	[-0.78]
Engines, pumps, turbines	-0.050	-0.036	-0.032	-0.067	-0.056	-0.064	-0.064	-0.056
	[-1.07]	[-0.75]	[-0.67]	[-1.40]	[-1.18]	[-1.36]	[-1.35]	[-1.16]
Environmental technology	0.085	0.087	0.088	0.043	0.047	0.047	0.048	0.047
	[1.44]	[1.48]	[1.49]	[0.73]	[0.80]	[0.81]	[0.81]	[0.81]

Food chemistry	0.097+	0.086+	0.083	0.001	-0.006	0.002	0.001	-0.007
	[1.85]	[1.65]	[1.59]	[0.01]	[-0.11]	[0.03]	[0.02]	[-0.13]
Furniture, games	0.077	0.065	0.055	0.130**	0.122*	0.127**	0.125**	0.120*
	[1.64]	[1.35]	[1.14]	[2.78]	[2.57]	[2.69]	[2.65]	[2.53]
Handling	0.139***	0.127***	0.117**	0.175***	0.170***	0.175***	0.173***	0.168***
	[3.73]	[3.41]	[3.17]	[4.76]	[4.59]	[4.74]	[4.72]	[4.57]
IT methods for management	0.264***	0.259***	0.251***	0.325***	0.323***	0.323***	0.322***	0.321***
	[5.20]	[5.07]	[4.92]	[6.23]	[6.14]	[6.18]	[6.16]	[6.12]
Machine tools	0.125**	0.117**	0.109*	0.138**	0.137**	0.141***	0.139***	0.135**
	[2.90]	[2.74]	[2.54]	[3.28]	[3.26]	[3.35]	[3.30]	[3.21]
Macromolecular chemistry, polymers	-0.026	-0.014	-0.008	-0.151***	-0.139**	-0.142**	-0.141**	-0.138**
	[-0.58]	[-0.32]	[-0.17]	[-3.50]	[-3.20]	[-3.28]	[-3.27]	[-3.19]
Materials, metallurgy	0.115**	0.117**	0.118**	0.046	0.052	0.053	0.053	0.052
	[2.77]	[2.81]	[2.84]	[1.09]	[1.22]	[1.26]	[1.26]	[1.22]
Measurement	-0.062	-0.053	-0.050	-0.073	-0.069	-0.076	-0.076	-0.069
	[-1.24]	[-1.06]	[-1.00]	[-1.46]	[-1.40]	[-1.55]	[-1.54]	[-1.39]
Mechanical elements	0.066*	0.060+	0.057+	0.088**	0.085**	0.088**	0.087**	0.084*
	[2.02]	[1.84]	[1.74]	[2.70]	[2.59]	[2.70]	[2.68]	[2.57]
Medical technology	-0.012	-0.028	-0.044	-0.064+	-0.072*	-0.066+	-0.070*	-0.076*
	[-0.36]	[-0.80]	[-1.28]	[-1.90]	[-2.06]	[-1.94]	[-2.06]	[-2.17]
Micro-structural and nano-technology	0.469***	0.492***	0.494***	0.481***	0.500***	0.489***	0.489***	0.501***
	[4.16]	[4.33]	[4.35]	[4.31]	[4.42]	[4.35]	[4.35]	[4.43]
Optics	-0.097+	-0.081	-0.077	-0.121*	-0.109+	-0.118*	-0.118*	-0.108+
	[-1.73]	[-1.42]	[-1.36]	[-2.18]	[-1.94]	[-2.13]	[-2.13]	[-1.93]
Organic fine chemistry	-0.022	-0.018	-0.014	-0.242***	-0.240***	-0.241***	-0.241***	-0.240***
	[-0.42]	[-0.31]	[-0.25]	[-4.00]	[-3.76]	[-3.91]	[-3.91]	[-3.75]
Other consumer goods	0.006	0.010	0.006	0.062	0.062	0.055	0.054	0.061
	[0.11]	[0.18]	[0.11]	[1.11]	[1.10]	[1.01]	[0.99]	[1.09]
Other special machines	0.149***	0.140***	0.133***	0.153***	0.150***	0.156***	0.154***	0.149***
	[3.90]	[3.65]	[3.46]	[4.08]	[4.01]	[4.15]	[4.11]	[3.98]
Pharmaceuticals	0.011	-0.006	-0.020	-0.353***	-0.365***	-0.358***	-0.361***	-0.369***
	[0.30]	[-0.17]	[-0.53]	[-8.25]	[-8.42]	[-8.21]	[-8.30]	[-8.50]
Semiconductors	-0.038	-0.023	-0.017	-0.090+	-0.079	-0.086+	-0.085+	-0.078
	[-0.76]	[-0.46]	[-0.33]	[-1.81]	[-1.57]	[-1.72]	[-1.71]	[-1.55]
Surface technology, coating	-0.088	-0.082	-0.080	-0.141*	-0.132*	-0.132*	-0.132*	-0.132*
	[-1.60]	[-1.49]	[-1.45]	[-2.53]	[-2.37]	[-2.38]	[-2.38]	[-2.37]
Telecommunications	-0.017	0.005	0.013	0.012	0.019	0.004	0.006	0.021
	[-0.46]	[0.13]	[0.35]	[0.34]	[0.53]	[0.12]	[0.16]	[0.58]
Textile and paper machines	-0.017	-0.012	-0.011	-0.039	-0.032	-0.034	-0.034	-0.032
	[-0.37]	[-0.26]	[-0.23]	[-0.82]	[-0.67]	[-0.71]	[-0.71]	[-0.67]
Thermal processes and apparatus	0.081+	0.092+	0.092+	0.106*	0.110*	0.100*	0.099*	0.110*
	[1.68]	[1.89]	[1.88]	[2.22]	[2.30]	[2.09]	[2.08]	[2.30]
Constant	-2.189***	-2.088***	-2.026***	-2.444***	-2.389***	-2.442***	-2.429***	-2.376***
	[-67.46]	[-46.68]	[-47.96]	[-76.56]	[-48.75]	[-66.71]	[-72.39]	[-51.02]
Observations	562,523	562,523	562,523	562,523	562,523	562,523	562,523	562,523
Log Likelihood	-43788	-43777	-43788	-42436	-42424	-42416	-42417	-42425
LLnull	-44012	-44012	-44012	-44012	-44012	-44012	-44012	-44012
D.F.	44	45	44	46	50	49	48	49
Chi2	343.2	294.4	287.6	1096	1119	1156	1152	1117

Robust z-statistics in brackets – Clustered by firms
Include Year fixed effects
*** p<0.001, ** p<0.01, * p<0.05,+ p<0.1

Table 3. Breakthrough patents – Firm characteristics - Probit regression

	(1)	(2)	(3)	(4)	(5)	(6)	(7)

VARIABLES							
Firm technological diversity	-0.007+	-0.006	-0.007+	-0.010*	-0.007+	-0.008*	-0.007+
	[-1.75]	[-0.94]	[-1.74]	[-2.19]	[-1.75]	[-2.01]	[-1.73]
Medium size	-0.048+	-0.034	-0.046	-0.049+	-0.049+	-0.054+	-0.045
	[-1.72]	[-0.60]	[-1.62]	[-1.73]	[-1.75]	[-1.89]	[-1.62]
Small size	-0.060+	-0.101+	-0.050	-0.044	-0.068+	-0.063+	-0.054
	[-1.70]	[-1.74]	[-1.41]	[-1.23]	[-1.86]	[-1.74]	[-1.54]
Medium size x Firm technological diversity		-0.003					
		[-0.44]					
Small size x Firm technological diversity		0.019*					
		[2.03]					
New IPC code to the firm			-0.015	-0.056**			
			[-1.16]	[-2.64]			
New IPC code to the firm x Firm technological diversity				0.009*			
				[2.46]			
New tech. area to the firm					0.016	-0.042+	
					[0.99]	[-1.66]	
New tech. area to the firm x Firm technological diversity						0.019**	
						[3.06]	
Emerging technologies							0.126***
							[13.76]
# inventors per patent	0.059***	0.059***	0.059***	0.058***	0.059***	0.059***	0.058***
	[12.95]	[12.96]	[12.93]	[12.90]	[12.95]	[12.96]	[12.94]
# of Non Patent ref.	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**
	[2.85]	[2.88]	[2.87]	[2.91]	[2.83]	[2.87]	[3.15]
Patent scope	0.029***	0.029***	0.029***	0.029***	0.029***	0.029***	0.029***
	[13.28]	[13.21]	[13.16]	[13.12]	[13.27]	[13.24]	[13.13]
# of patent ref.	0.019***	0.019***	0.019***	0.019***	0.019***	0.019***	0.017***
	[14.54]	[14.52]	[14.52]	[14.52]	[14.54]	[14.54]	[14.00]
Granted	0.106***	0.106***	0.106***	0.106***	0.107***	0.107***	0.111***
	[10.45]	[10.43]	[10.41]	[10.38]	[10.49]	[10.50]	[10.87]
Constant	-2.376***	-2.377***	-2.376***	-2.359***	-2.376***	-2.367***	-2.431***
	[-51.02]	[-37.64]	[-50.97]	[-49.18]	[-51.02]	[-50.35]	[-52.49]
Observations	562,523	562,523	562,523	562,523	562,523	562,523	562,523
Log Likelihood	-42425	-42419	-42424	-42419	-42424	-42419	-42327
LLnull	-44012	-44012	-44012	-44012	-44012	-44012	-44012
D.F.	49	51	50	51	50	51	50
Chi2	1117	1148	1119	1134	1117	1145	1387

Robust z-statistics in brackets – Clustered by firms
Include Year and Technological area fixed effects
*** p<0.001, ** p<0.01, * p<0.05,+ p<0.1

Table4. Breakthrough Patents – Firm Characteristics moderated by technology patterns

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Firm technological diversity	-0.007+	-0.007+	-0.007+	-0.007+	-0.007+	-0.001	-0.007+	-0.007+
	[-1.75]	[-1.90]	[-1.73]	[-1.73]	[-1.75]	[-0.25]	[-1.73]	[-1.73]
Medium size	-0.048+	-0.048+	-0.045	-0.045	-0.048+	-0.047+	-0.045	-0.045
	[-1.71]	[-1.70]	[-1.61]	[-1.61]	[-1.71]	[-1.67]	[-1.62]	[-1.62]
Small size	-0.060+	-0.061+	-0.054	-0.054	-0.060+	-0.062+	-0.054	-0.054
	[-1.71]	[-1.72]	[-1.55]	[-1.55]	[-1.70]	[-1.76]	[-1.55]	[-1.54]
Tech. Area Patent Growth	-0.002*	-0.005**	-0.002*	-0.004**				
	[-2.30]	[-3.05]	[-2.31]	[-2.84]				
Firm technological diversity x Tech. Area Patent Growth		0.000*						
		[2.08]						
Emerging technologies			0.126***	0.123***			0.126***	0.128***
			[13.76]	[13.42]			[13.76]	[8.05]
Emerging technologies x Tech. Area Patent Growth				0.002+				
				[1.78]				
Concentration					14.241	20.947+	14.377	14.649
					[1.39]	[1.81]	[1.40]	[1.43]
Firm technological diversity x Concentration						-1.220+		
						[-1.72]		
Emerging technologies x Concentration								-0.520
								[-0.19]
# inventors per patent	0.059***	0.059***	0.058***	0.058***	0.059***	0.058***	0.058***	0.058***
	[12.96]	[12.96]	[12.95]	[12.96]	[12.96]	[12.92]	[12.95]	[12.95]
# of Non Patent ref.	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**
	[2.86]	[2.87]	[3.15]	[3.15]	[2.86]	[2.87]	[3.16]	[3.16]
Patent scope	0.029***	0.029***	0.029***	0.029***	0.029***	0.029***	0.029***	0.029***
	[13.31]	[13.32]	[13.16]	[13.13]	[13.24]	[13.24]	[13.09]	[13.09]
# of patent ref.	0.019***	0.019***	0.017***	0.017***	0.019***	0.019***	0.017***	0.017***
	[14.56]	[14.57]	[14.02]	[14.02]	[14.54]	[14.55]	[14.00]	[14.00]
Granted	0.106***	0.106***	0.110***	0.110***	0.106***	0.107***	0.111***	0.111***
	[10.41]	[10.39]	[10.83]	[10.82]	[10.43]	[10.46]	[10.85]	[10.85]
Constant	-2.378***	-2.375***	-2.433***	-2.431***	-2.447***	-2.479***	-2.503***	-2.504***
	[-51.09]	[-51.00]	[-52.57]	[-52.51]	[-37.59]	[-35.96]	[-38.46]	[-38.24]
Observations	562,523	562,523	562,523	562,523	562,523	562,523	562,523	562,523
Log Likelihood	-42421	-42417	-42323	-42322	-42423	-42419	-42326	-42326
LLnull	-44012	-44012	-44012	-44012	-44012	-44012	-44012	-44012
D.F.	50	51	51	52	50	51	51	52
Chi2	1123	1125	1396	1392	1119	1125	1388	1389

Robust z-statistics in brackets – Clustered by firms
Include Year and Technological area fixed effects
*** p<0.001, ** p<0.01, * p<0.05,+ p<0.1

Table 5. Firm and technological area variables and interactions

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Firm technological diversity	-0.007+	-0.007+	-0.009	-0.009	-0.007+	-0.007+	-0.007	-0.007
	[-1.72]	[-1.71]	[-1.14]	[-1.14]	[-1.73]	[-1.72]	[-1.04]	[-1.04]
Medium	-0.044	-0.043	-0.023	-0.023	-0.046+	-0.046+	-0.029	-0.029
	[-1.55]	[-1.54]	[-0.42]	[-0.42]	[-1.65]	[-1.65]	[-0.53]	[-0.53]
Small	-0.048	-0.047	-0.067	-0.067	-0.065+	-0.065+	-0.089	-0.089
	[-1.34]	[-1.33]	[-1.14]	[-1.14]	[-1.79]	[-1.78]	[-1.49]	[-1.49]
New IPC code to the firm	-0.010	-0.010	-0.043*	-0.043*				
	[-0.78]	[-0.80]	[-2.05]	[-2.05]				
New tech. area to the firm					0.020	0.020	-0.016	-0.016
					[1.29]	[1.28]	[-0.59]	[-0.59]
Emerging technologies	0.126***	0.126***	0.101***	0.101***	0.126***	0.126***	0.125***	0.125***
	[13.72]	[13.77]	[3.41]	[3.41]	[13.78]	[13.82]	[7.81]	[7.81]
Tech. Area Patent Growth	-0.002*				-0.002*		-0.006***	-0.006***
	[-2.17]				[-2.20]		[-3.42]	[-3.42]
New entrants		-0.081*	-0.108*	-0.108*		-0.082*		
		[-2.56]	[-2.37]	[-2.37]		[-2.58]		
Concentration	12.009	9.720	9.896	9.896	12.167	9.881	12.825	12.825
	[1.18]	[0.95]	[0.97]	[0.97]	[1.19]	[0.97]	[1.25]	[1.25]
Medium x Firm technological diversity			-0.004	-0.004			-0.004	-0.004
			[-0.61]	[-0.61]			[-0.56]	[-0.56]
Small x Firm technological diversity			0.013	0.013			0.013	0.013
			[1.42]	[1.42]			[1.34]	[1.34]
New IPC code to the firm x Firm technological diversity			0.008*	0.008*				
			[2.07]	[2.07]				
New tech. area to the firm x Firm technological diversity							0.013*	0.013*
							[2.04]	[2.04]
Emerging technologies x New entrants			0.029	0.029				
			[1.03]	[1.03]				
Emerging technologies x Concentration			-0.716	-0.716			-0.216	-0.216
			[-0.26]	[-0.26]			[-0.08]	[-0.08]
Emerging technologies x Tech. Area Patent Growth							0.002+	0.002+
							[1.65]	[1.65]
Tech. Area Patent Growth x Firm technological diversity							0.000*	0.000*
							[2.10]	[2.10]
New entrants x Firm technological diversity			0.002	0.002				
			[0.37]	[0.37]				
# inventors per patent	0.058***	0.058***	0.058***	0.058***	0.058***	0.058***	0.058***	0.058***
	[12.96]	[12.93]	[12.91]	[12.91]	[12.97]	[12.94]	[12.99]	[12.99]
# of Non Patent ref.	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**	0.004**
	[3.18]	[3.19]	[3.23]	[3.23]	[3.14]	[3.15]	[3.19]	[3.19]
Patent scope	0.029***	0.029***	0.029***	0.029***	0.029***	0.029***	0.029***	0.029***
	[13.00]	[12.95]	[12.86]	[12.86]	[13.13]	[13.07]	[13.04]	[13.04]
# of patent ref.	0.017***	0.017***	0.017***	0.017***	0.017***	0.017***	0.017***	0.017***
	[14.00]	[13.98]	[13.94]	[13.94]	[14.02]	[14.00]	[13.99]	[13.99]
Granted	0.110***	0.109***	0.109***	0.109***	0.111***	0.110***	0.110***	0.110***
	[10.79]	[10.72]	[10.69]	[10.69]	[10.86]	[10.80]	[10.84]	[10.84]
Constant	-2.492***	-2.428***	-2.398***	-2.398***	-2.493***	-2.428***	-2.493***	-2.493***
	[-38.27]	[-35.56]	[-28.23]	[-28.23]	[-38.29]	[-35.59]	[-31.75]	[-31.75]

Observations	562,523	562,523	562,523	562,523	562,523	562,523	562,523	562,523
Log Likelihood	-42322	-42320	-42312	-42312	-42321	-42320	-42308	-42308
LLnull	-44012	-44012	-44012	-44012	-44012	-44012	-44012	-44012
D.F.	53	53	59	59	53	53	59	59
Chi2	1399	1389	1425	1425	1396	1386	1432	1432
Dep.Var	top1dom	top1dom	top1dom	top1dom	top1dom	top1dom	top1dom	top1dom

Robust z-statistics in brackets
*** p<0.001, ** p<0.01, * p<0.05, + p<0.1

5. Conclusion

The aim of this paper is to identify the impacts of firm and sector characteristics on the quality of patents, once patent characteristics have been controlled for. Our results confirm that intrinsic characteristics of patents strongly explain breakthrough inventions, as highlighted in the literature. However, they also contribute to show to what extent firm and sector characteristics tend to influence this type of performance. Indeed, our results do highlight the importance to take into account the complexity of patenting and learning behaviors of the firms.

This suggests that understanding the sources of breakthrough patents is more complex than expected. For instance, a number of studies find that size or diversity matters. This paper shows that it is only a part of the story. First, size matters but small innovators may also produce breakthrough inventions, in some conditions, that is, when they have some degree of diversity. Second, two apparently contrasting results seem to coexist: non-diversified large firms produce breakthrough patents as do small-diversified innovators. It is possible to reconcile these two results considering diversified firms' capacity to enter a new technology area and/or mobilize emerging technologies. And the role played by the latter is true independently from firm size or its degree of diversification. Moreover, that suggests that breakthrough patents are more likely for emergent technology. When the technology becomes mature, breakthrough patent are scarcer. Technological sector also matters to explain the quality of patent.

Our article is limited to patent information. If this allows to perform a wide cross-sector analysis based on a huge dataset, it represents also the main limitation. Only patent-based variables are available for capturing firms' characteristics and behaviors. Further research is nevertheless needed to go further in the characterization of firms and sectors. Indeed, it could be interesting to test the impact of the internationalization of firm and also to better proxy the size of the firms. Financial data seem necessary.

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Appendix – Correlation table and robustness checks

Table A1. Correlation table

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	small	1.00															
2	Medium	-0.56	1.00														
3	Large	-0.33	-0.60	1.00													
4	Patent stock - 5 years	-0.17	-0.22	0.42	1.00												
5	Firm technological diversity	-0.42	-0.06	0.48	0.35	1.00											
6	New IPC code to the firm	0.43	-0.13	-0.27	-0.18	-0.26	1.00										
7	New tech. area to the firm	0.55	-0.25	-0.25	-0.14	-0.30	0.51	1.00									
8	Emerging technologies	-0.05	**-0.00**	0.05	0.03	0.03	-0.06	-0.06	1.00								
9	Nouveaux_e~t	-0.01	0.01	-0.00	0.02	0.00	0.06	0.02	0.06	1.00							
10	Taux_crois~e	-0.01	0.01	0.00	-0.04	-0.04	0.26	0.03	0.02	0.48	1.00						
11	Concentrat~n	0.03	-0.03	0.00	0.18	0.22	-0.12	-0.12	0.04	0.20	-0.02	1.00					
12	# inventors per patent	-0.10	0.02	0.08	0.02	0.08	-0.09	-0.10	0.06	-0.01	-0.03	-0.03	1.00				
13	# of Non Patent ref.	0.03	-0.00	-0.03	-0.03	-0.06	0.00	0.02	0.07	0.06	-0.01	-0.06	0.12	1.00			
14	Patent scope	-0.04	-0.01	0.04	-0.01	0.07	0.09	-0.03	0.08	0.07	0.12	-0.02	0.14	0.11	1.00		
15	# of patent ref.	-0.21	0.05	0.15	0.07	0.19	-0.17	-0.18	0.21	-0.00	-0.04	0.06	0.12	0.21	0.11	1.00	
16	Granted	-0.06	0.04	0.01	-0.04	-0.00	0.05	-0.03	-0.04	0.03	0.14	-0.04	-0.03	-0.09	0.07	-0.03	1.00

All correlation significant at a 1% level expect the bold one

Table A2. Number of forward citations – Firm characteristics
Negative Binomial

VARIABLES	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Firm technological diversity	-0.009+	-0.007	-0.009+	-0.013*	-0.009+	-0.010+	-0.009+
	[-1.83]	[-0.70]	[-1.81]	[-2.18]	[-1.83]	[-1.90]	[-1.74]
Medium size	-0.051	-0.013	-0.046	-0.050	-0.050	-0.052	-0.047
	[-1.39]	[-0.18]	[-1.27]	[-1.36]	[-1.36]	[-1.42]	[-1.30]
Small size	-0.048	-0.067	-0.031	-0.024	-0.039	-0.037	-0.045
	[-1.13]	[-0.93]	[-0.73]	[-0.57]	[-0.90]	[-0.85]	[-1.08]
Medium size x Firm technological diversity		-0.007					
		[-0.75]					
Small size x Firm technological diversity		0.014					
		[1.44]					
New IPC code to the firm			-0.029**	-0.075***			
			[-2.94]	[-3.82]			
New IPC code to the firm x Firm technological diversity				0.010**			
				[2.61]			
New tech. area to the firm					-0.018+	-0.049*	
					[-1.66]	[-2.50]	
New tech. area to the firm x Firm technological diversity						0.010*	
						[2.00]	
Emerging technologies							0.170***
							[25.00]
# inventors per patent	0.082***	0.081***	0.081***	0.081***	0.082***	0.081***	0.081***
	[23.79]	[23.85]	[23.74]	[23.68]	[23.78]	[23.74]	[23.84]
# of Non Patent ref.	0.006***	0.006***	0.006***	0.006***	0.006***	0.006***	0.005***
	[3.73]	[3.76]	[3.76]	[3.80]	[3.75]	[3.76]	[3.70]
Patent scope	0.044***	0.044***	0.044***	0.044***	0.044***	0.044***	0.043***
	[21.94]	[22.09]	[21.81]	[21.79]	[21.94]	[21.94]	[21.79]
# of patent ref.	0.040***	0.040***	0.040***	0.040***	0.040***	0.040***	0.034***
	[18.50]	[18.79]	[18.47]	[18.45]	[18.48]	[18.47]	[16.67]
Granted	0.115***	0.116***	0.115***	0.115***	0.115***	0.115***	0.120***
	[13.25]	[13.19]	[13.20]	[13.13]	[13.20]	[13.20]	[13.79]
Constant	-2.004***	-2.022***	-2.002***	-1.982***	-2.004***	-1.999***	-2.066***
	[-37.34]	[-26.45]	[-37.26]	[-35.49]	[-37.34]	[-36.88]	[-38.88]
Constant	0.585***	0.585***	0.585***	0.585***	0.585***	0.585***	0.578***
	[47.75]	[47.71]	[47.70]	[47.57]	[47.75]	[47.75]	[47.14]
Observations	562,523	562,523	562,523	562,523	562,523	562,523	562,523
Log Likelihood	-572785	-572768	-572777	-572761	-572783	-572779	-572271
LLnull	-603283	-603283	-603283	-603283	-603283	-603283	-603283
D.F.	49	51	50	51	50	51	50
Chi2	10373	10492	10337	10457	10380	10482	11996

Robust z-statistics in brackets – Clustered by firms
Include Year and Technological area fixed effects
*** p<0.001, ** p<0.01, * p<0.05,+ p<0.1

TableA3. Number of forward citations – Firm Characteristics moderated by technology patterns - Negative Binomial

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Firm technological diversity	-0.009+	-0.009+	-0.009+	-0.009+	-0.008	-0.009+	-0.009+	-0.010*
	[-1.81]	[-1.72]	[-1.73]	[-1.82]	[-1.38]	[-1.73]	[-1.73]	[-1.98]
Medium size	-0.051	-0.047	-0.047	-0.051	-0.050	-0.047	-0.047	-0.051
	[-1.40]	[-1.32]	[-1.32]	[-1.39]	[-1.38]	[-1.30]	[-1.30]	[-1.40]
Small size	-0.046	-0.044	-0.044	-0.048	-0.048	-0.045	-0.045	-0.047
	[-1.10]	[-1.05]	[-1.05]	[-1.12]	[-1.14]	[-1.08]	[-1.08]	[-1.10]
Tech. Area Patent Growth	0.011***	0.011***	0.010***					0.010***
	[13.22]	[13.23]	[10.11]					[6.54]
Firm technological diversity x Tech. Area Patent Growth								0.000
								[1.13]
Emerging technologies			0.164***				0.165***	
			[23.66]				[15.92]	
Emerging technologies x Tech. Area Patent Growth			0.002**					
			[2.88]					
Concentration				-22.415*	-20.770+	-22.735*	-23.298*	
				[-2.16]	[-1.75]	[-2.19]	[-2.21]	
Firm technological diversity x Concentration					-0.292			
					[-0.42]			
Emerging technologies x Concentration							1.107	
							[0.60]	
# inventors per patent	0.082***	0.081***	0.082***	0.082***	0.081***	0.081***	0.081***	0.082***
	[23.82]	[23.87]	[23.87]	[23.81]	[23.75]	[23.86]	[23.87]	[23.86]
# of Non Patent ref.	0.006***	0.005***	0.005***	0.006***	0.006***	0.005***	0.005***	0.006***
	[3.71]	[3.68]	[3.68]	[3.72]	[3.72]	[3.68]	[3.69]	[3.73]
Patent scope	0.044***	0.043***	0.043***	0.044***	0.044***	0.043***	0.043***	0.044***
	[21.98]	[21.84]	[21.80]	[22.16]	[22.16]	[22.02]	[22.02]	[22.01]
# of patent ref.	0.040***	0.034***	0.034***	0.040***	0.040***	0.034***	0.034***	0.040***
	[18.53]	[16.68]	[16.68]	[18.45]	[18.53]	[16.62]	[16.62]	[18.51]
Granted	0.117***	0.122***	0.122***	0.116***	0.116***	0.120***	0.120***	0.117***
	[13.41]	[13.95]	[13.94]	[13.26]	[13.31]	[13.80]	[13.80]	[13.41]
Emerging technologies		0.170***				0.170***		
		[25.14]				[24.99]		
Constant	-1.996***	-2.058***	-2.055***	-1.894***	-1.902***	-1.955***	-1.952***	-1.991***
	[-37.44]	[-39.00]	[-38.89]	[-24.73]	[-22.93]	[-25.69]	[-25.35]	[-36.94]
Constant	0.583***	0.575***	0.575***	0.585***	0.585***	0.578***	0.578***	0.583***
	[47.61]	[47.00]	[47.00]	[47.76]	[47.77]	[47.15]	[47.15]	[47.53]
Observations	562,523	562,523	562,523	562,523	562,523	562,523	562,523	562,523
Log Likelihood	-572541	-572024	-572018	-572774	-572773	-572259	-572259	-572535
LLnull	-603283	-603283	-603283	-603283	-603283	-603283	-603283	-603283
D.F.	50	51	52	50	51	51	52	51
Chi2	10794	12486	12577	10513	10507	12146	12170	11203

Robust z-statistics in brackets – Clustered by firms
Include Year and Technological area fixed effects
*** p<0.001, ** p<0.01, * p<0.05,+ p<0.1