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Firms involving academics when developing technology: does it make a difference?

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Abstract

This paper analyzes the academic contribution to corporate technology development in Flanders (period 1991-2010) by contrasting firm patents implying the involvement of academics (at Flemish universities) with patents of the same firms developed in-house. We further distinguish between exploitation-oriented and exploration-oriented technology trajectories (i.e. technology developed within IPC classes in which firms are already active, or active for the first time respectively). The findings reveal that academically invented corporate patents are more diverse in terms of technological knowledge, more inspired by scientific findings and less incremental, compared to corporate patents without university involvement. If patent impact is considered, the picture is more complex. When examining social value, measured by forward citations without self-citations, university-invented corporate patents are of significantly less value. In terms of private value, measured by forward self-citations, no difference is found between firm-invented and university-invented corporate patents. When distinguishing between existing and novel (to the firm) technology domains, we find a disproportionally large share of exploratory patents involving academics, suggesting that firms do prefer to collaborate with universities when exploring knowledge outside their core technologies. It is found that collaborating with academic inventors in exploring novel domains spurs more cumulative innovation, measured by forward self-citations, than keeping development in-house. Only for small firms, engaging in such exploratory endeavor with academic inventors translates into faster growth in the new, jointly entered domains.

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Firms involving academics when developing technology: Does it make a difference?

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Abstract

This paper analyzes the academic contribution to corporate technology development in Flanders (period 1991-2010) by contrasting firm patents implying the involvement of academics (at Flemish universities) with patents of the same firms developed in-house. We further distinguish between exploitation-oriented and exploration-oriented technology trajectories (i.e. technology developed within IPC classes in which firms are already active, or active for the first time respectively). The findings reveal that academically invented corporate patents are more diverse in terms of technological knowledge, more inspired by scientific findings and less incremental, compared to corporate patents without university involvement. If patent impact is considered, the picture is more complex. When examining social value, measured by forward citations without self-citations, university-invented corporate patents are of significantly less value. In terms of private value, measured by forward self-citations, no difference is found between firm-invented and university-invented corporate patents. When distinguishing between existing and novel (to the firm) technology domains, we find a disproportionally large share of exploratory patents involving academics, suggesting that firms do prefer to collaborate with universities when exploring knowledge outside their core technologies. It is found that collaborating with academic inventors in exploring novel domains spurs more cumulative innovation, measured by forward self-citations, than keeping development in-house. Only for small firms, engaging in such exploratory endeavor with academic inventors translates into faster growth in the new, jointly entered domains.

Introduction

The importance of new knowledge for economic growth has since long been established in theories of technological progress and innovation (Schumpeter, 1934; Solow, 1957). Acknowledging this, firms have increasingly been investing in the development of new innovative products and processes. The increasing complexity and costs related to inherently uncertain R&D activities motivate firms to complement their internal R&D activities with sourcing external knowledge from a multitude of actors: universities and research centers, governmental institutions, customers, suppliers, industry associations, and even direct competitors (Chesbrough, 2003; Von Hippel, 1988). Witness to this are models and notions of innovation that evolve around interactions between heterogeneous actors such as the national innovation system notion (Freeman, 1987; Lundvall, 2010; Nelson, 1993), the open innovation model (Chesbrough, 2003, 2006) and the triple helix model (Etzkowitz & Leydesdorff, 1997, 1998; Leydesdorff & Etzkowitz, 1996, 1998). Over the last decades, a considerable number of empirical studies reported on the effects of increased university involvement in patenting or technology development activities. The following section outlines and summarizes relevant studies and findings in this respect.

The university perspective: Characteristics of academic patents

A first line of empirical research focuses on the effects at the academic side. As universities have become increasingly involved in patenting activities, the question arises whether this growth in university-owned patents also influences the quality or impact of academic patents. A number of studies have investigated this. Henderson, Jaffe, and Trajtenberg (1998) explored the increase in US academic patenting that took place between 1965 and 1990, and found that before the introduction of the Bayh-Dole act until about the mid-eighties, US academic patents were more highly cited and cited by more diverse patents than a random sample of all patents. After that, however, this difference in terms of impact disappeared. In other words, the steep increase in volume and share of academic patenting was much higher than the increase in impact of these patents. The authors attribute this to shifts in university patenting behavior. Mowery and Ziedonis (2002) from their part argue that the increase was largely due to the entry of inexperienced university technology transfer offices which might also partially explain a decrease in impact.
At the same time, university ownership of patents reveals an incomplete picture of academic involvement in technological developments. Certain modes of industry-university collaboration might lead to arrangements whereby firms take ownership of the resulting inventions (e.g. contract research between the university and a firm, whereby it is agreed that the latter will own the intellectual property (IP) rights; or a university spin-off that owns the IP on the technology that was developed at the university). The fact that university ownership of patents reveals only a partial picture of actual academic involvement in technology development has been revealed in several studies (for an overview see Lissoni, Llerena, McKelvey, & Sanditov, 2008). Hence, a considerable share of patented technologies that arise from academic research are not owned by the universities, but nevertheless involve university researchers as inventor (so-called ‘university-invented’ patens). Therefore, considering contributions of academic inventors to

patents (besides university-owned patents) allows for a more encompassing delineation and identification of university involvement in technology development activities. This distinction between university-owned and university-invented (mostly firm-owned) patents has inspired more fine-grained analyses on the contribution of universities in technology development. In their study of patent activity of Flemish universities, Callaert, du Plessis, Van Looy, and Debackere (2013) found that university-owned patents receive more forward citations than university-invented (i.e. mostly firm-owned) patents. Their findings signal that the increase of academic patent activity – stimulated by policies granting ownership rights to universities – did not coincide with a decrease in their value. Sapsalis, van Pottelsberghe de la Potterie, and Navon (2006) analyzed a sample of Belgian academic patents (EPO) and observed that the value distributions of Belgian academically owned and academically invented EPO patents (owned by firms) are very similar. In addition, the authors observe that, conditional on being cited, academic patents are cited more than corporate patents (respectively 7.1 and 5.9 citations). The same conclusion was drawn in a recent study by Veugelers, Callaert, Song, and Van Looy (2012). Thursby, Fuller, and Thursby (2009) analyzed a sample of US university-invented patents and found that university-invented (US) patents assigned to firms are less basic than those assigned to universities. Crespi, Geuna, Nomaler, and Verspagen (2010), in their analysis of a sample of European university patents, conclude that there is little evidence in support of the contention that European university-owned patents would be more valuable than university-invented patents owned by firms. Sterzi (2013) performed a similar study, analyzing the value of UK academic patents by distinguishing between university-owned and university-invented patents. During the first 3 years, university-invented (corporate-owned) patents receive more citations than university-owned patents. This difference however erodes when considering longer time frames.

The firm perspective: Adding value by involving academics?

The previous studies stay within the realm of academic patents, in the sense that they consider the distinctiveness of university-owned patents vis-à-vis university-invented patents. A second line of research adopts a corporate perspective and examines whether firms benefit from the contribution of academic research. More aggregated empirical research, mostly based on the regional knowledge production function framework, indicates positive effects of university-industry collaborations on the level of regional economic and technological development (e.g. Ács, Audretsch, & Feldman, 1991, 1994; Ács, 2000; Anselin, Varga, & Ács, 1997, 2000; Autant-Bernard, 2001; Blind & Grupp, 1999; Buesa, Heijs, Pellitero, & Baumert, 2006; Cooke, Gomez Urange, & Extebarria, 1997; Del Barrio-Castro & Garcia-Quevedo, 2005; Feldman & Florida, 1994; Fischer & Varga, 2003; Jaffe, 1989; Piergiovanni, Santarelli, & Vivarelli, 1997; Piergiovanni & Santarelli, 2001; Leten, Landoni, & Van Looy, 2011; Leten, Landoni, & Van Looy, 2014; Saxenian, 1994). On the level of the firm, surveys of academic and industrial researchers have corroborated the contribution of university research to the development of new products and processes, leading to higher sales and cost savings (Mansfield, 1995, 1998) and to corporate patents (Tijssen, 2002). Faems, Van Looy, and Debackere (2005) provided additional empirical evidence showing that the variety of interorganizational collaboration relates to the effectiveness of firm's innovation strategies. Based on data from the Community Innovation Survey, they found that firms with a heterogeneous network of collaborative partners perform better in terms of the proportion of turnover realized by means of new or improved products. In addition, the authors distinguished between exploitation and exploration, and found that exploitation-oriented collaborations (with customers and suppliers) supported the improvement and further development of existing products, whereas exploration-oriented collaborations (with knowledge-generating institutes) were associated with turnover levels related to the creation of new products.

The abovementioned empirical support of academic contributions to firm innovative performance is based primarily on survey data about collaborations between universities and firms. An alternative way of measuring collaborations between universities and firms is by considering co-patenting as a reflection of firm-university collaboration. In a recent contribution of Belderbos, Cassiman, Faems, Leten and Van Looy (2014), it is shown that the value-appropriation challenges of IP sharing are clearly evident with intra-industry co-patenting, where partners are more likely to encounter overlapping exploitation domains. Co-patenting with universities on the other hand is associated with higher market value. However, in line with the above arguments on university-owned patents, co-ownership of patents reveals only a partial picture of university-industry collaboration in technology development. First, co-owned patents in general represent only a minor proportion of total patents. Not all collaborations between university and firms lead to patents. Moreover, if they do lead to patents, the ownership may not be shared by both the academic and the industry partner. This limitation can at least partly be resolved by going beyond ownership (i.e. universities as applicants) and by considering academic contribution on the inventor level. Considering contributions of academic inventors to firm patents allows for a more encompassing delineation and identification of university involvement in firms' technology development activities.

Studies that focus on firm patents and consider the effect of academic involvement in these patents are more scarce than those focusing on characteristics of academic patents (cf. supra). Three studies are notable in this respect. Czarnitzki, Hussinger, and Schneider (2009) compared university-invented patents to a control group of 'non-academic' patents (on which no university inventor appears) in Germany. Higher opposition rates are considered as a proxy for the more applied nature of the patented invention, indicating that it is closer to market applications. The authors observe that university-invented patents with firm applicants do not significantly differ from firm patents (in terms of opposition). Conversely, academic patents assigned to universities display a lower opposition rate than firm patents and firm-owned university-invented patents. The authors suggest that this is due to the fact that university-owned inventions are further away from market applications than corporate patents. Given their fundamental and complex nature, the technological content takes a longer time to diffuse (see also Sampat, Mowery, & Ziedonis, 2003). Therefore, according to Czarnitzki et al. (2009), university-owned patents would be less threatening to potential competitors and less likely to face oppositions. Ljungberg and McKelvey (2012) from their part analyzed a sample of Swedish academic patents, and compared university-invented patents within firm portfolios to patents belonging to the same firms but without academic involvement. Their results show that academic involvement mainly takes place in inventions that are highly related to firms' existing technological capabilities. They moreover show that firms' academic patents, as compared to their non-academic patents, receive less forward citations in firms' core technological fields but somewhat more in their marginal fields. From these results, Ljungberg and McKelvey (2012) suggest that firm-owned academic patents largely result from "demand pull" rather than "science push" and that firms involve academics mainly for problem-solving activities in their core technological fields. In consecutive research, Ljungberg, Bourelos, and McKelvey (2013) find that academic patents held by firms have a short-term disadvantage, measured in terms of number of forward citations, compared to non-academic firm patents, however this difference disappears in the long term. When controlling for the firm's technological profile (core versus non-core), academic and non-academic firm patents no longer differ significantly in value.

Our study aims to add to the evidence by comparing the nature and impact of university-invented corporate patents, compared to corporate patents without academic inventors. Taking into account the insights from previous studies, when analyzing the corporate patents, we also explicitly distinguish between trajectories of an exploitative and of an explorative nature. We focus on the Flemish region in Belgium, which is of specific interest (especially in comparison to the Swedish case, cf. Ljungberg & McKelvey, 2012) due to the relatively high proportion of university-owned patents, compared to a reference group of OECD countries. This high contribution of universities in technology development in Belgium and Flanders is primarily incited by institutional regulations, aimed explicitly at stimulating the 'entrepreneurial' role of universities (see Debackere & Veugelers, 2005). The Swedish system from its part is characterized by the professor's privilege, implying that the ownership of IP from university research generally remains with the academic researcher, rather than with the university. Such different legislative framework conditions have a significant and considerable impact, especially on the amount of technological activity observed at universities. The difference in the share of patents held by universities between Belgium (11%) and Sweden (0,1%) are a striking illustration of this effect.

Hypotheses

We focus on the question whether corporate patents involving academic inventors are distinctive from corporate patents developed within the firm. Based on the existing literature, the following propositions are made:
When academics are involved in the development of technology, resulting patents are more diverse in terms of technological and scientific prior art, compared to corporate patents developed in-house (Hypothesis 1A). As a consequence, when academics are involved in patenting, this will result in more impact, compared to corporate patents developed in-house (Hypothesis 1B). When exploring new technological fields, the involvement of academic researchers in industry patenting will allow firms to speed up learning and reap the benefits of collaborating more, measured by patent impact, compared to exploring new technological fields by relying on in-house resources (Hypothesis 2). Furthermore, engaging in exploratory technology development jointly with universities will enable a firm to achieve faster technological growth in those novel technology domains (Hypothesis 3).

Data and Methodology

First, we analyze the difference in nature and impact between corporate patents developed in-house versus patents developed in collaboration with universities. Second, we distinguish between exploratory and exploitative technological activities and assess whether it is more beneficial to collaborate with universities (compared to keeping technology development in-house) when entering novel technology domains. Patent data are extracted from the PATSTAT database, October 2011 edition. The academically invented corporate patents involve inventors from Flemish universities: University of Leuven (KU Leuven), University of Antwerp (UA), University of Hasselt (UH) and University of Brussels (VUB). For each of these universities, the academic patents that are applied for by firms have been identified. In a next step, a control group is created, consisting of patents owned by the same firms and situated in the same time period as the academically invented patents, but developed within the firm. Only granted EPO and USPTO patents are considered, with application years ranging from 1991 to 2010, and within the same technology domains as the academically invented corporate patents.

University-invented versus firm-invented corporate patents

The main variable of interest reflects whether the firm-owned patent involves an academic inventor or not. A firm patent will be labeled as academic if it involves at least one (Flemish) academic inventor. Identifying university inventors is not a straightforward exercise since the institutional affiliation of inventors is not provided by patent documents. Researchers have dealt with this issue in various ways. Czarnitzki, Hussinger, and Schneider (2011) identified patents invented by German professors by searching the inventors' names for keywords like "Prof. Dr." and variations of it. Lissoni et al. (2008) matched names and surnames of inventors with those in the staff lists of universities, and verified by email and by phone the identity of the matches, in order to exclude homonyms. Another approach relies on matching author names of scientific publications with those of patent inventors (Dornbusch, Schmoch, Schulze, & Bethke, 2012). We followed the second approach, conducting name matching between staff lists of Flemish universities (1990-2009) and patent inventor names, appearing on granted EPO and USPTO patents with application years ranging from 1991-2010. Surnames of academic personnel were matched with name lists of patent inventors. In a next step, the matched pairs were inspected to eliminate false hits. For the remaining, potential, matches, the academic researchers were contacted directly to confirm their involvement as an inventor. Only confirmed matches were retained, and therefore priority was given to precision over recall when identifying the academically invented patents. 484 firm patents could eventually be identified as having at least one academic inventor (from a Flemish university) and are therefore labeled as academically invented. The ECOOM-Eurostat-EPO PATSTAT Person Augmented Table (EEE-PAT) (Van Looy, du Plessis, & Magerman, 2006) was used for sector assignment. Only firm-owned patents were retained. For instance, patents that are owned jointly by firms and other sectors, e.g. higher education institutions, were excluded. Next, patents with multiple firm applicants were dropped. The remaining firm applicants were the starting point for constructing the control group of patents developed within the firm. One factor complicating the exhaustive identification of the firms' patent portfolios pertains to the large heterogeneity in applicant names appearing on patent documents, including spelling mistakes, typographical errors and name variants. Harmonized patentee names were used from the EEE-PAT (Magerman, Van Looy, & Song, 2006) and in a second stage, applicant names were further harmonized by applying search keys. For every firm applicant an average of 22 name variants was found in PATSTAT (Table 1).

Insert Table 1 about here

In the next phase of data collection, only the EPO and USPTO granted patents (with application years from 1991-2010) of the firm-owned patents were extracted from PATSTAT. Next, the inventor names on the corporate patents were matched with the names of the university inventors to verify whether no academic inventors were involved in these patents. Finally, only patents with the exact same IPC 4-digit combinations as the academically invented patents were retained. We ended up with 123,637 firm patents developed within the firm.

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Insert Table 2 about here

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Table 2 shows the distribution of patents by their technological field (IPC 1-digit), applying fractional counts for patents assigned to more than one class. The domains A (human necessities) and C (chemistry, metallurgy) are most represented among university-invented corporate patents (respectively 31.16% and 34.61%), whereas the domains G (physics) and C (chemistry, metallurgy) are most represented among firm-invented corporate patents (respectively 40.10% and 20.35%). For both groups of patents, domains D (textiles, paper), E (fixed constructions) and F (mechanical engineering, lighting, heating, weapons, blasting) are least represented.

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Insert Table 3 about here

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Table 3 gives the breakdown by patent system. The ratio of EPO to USPTO patents does not differ much between the different types of patents, approximately 70% are USPTO granted patents. The higher cost of patenting at EPO - and their lower grant rate compared to USPTO -, are resulting in a majority of USPTO patents in our sample (Quillen & Webster, 2001; van Pottelsberghe de la Potterie & François, 2009).

Technology trajectories

Taking into account the insights from previous studies, we also explicitly distinguish between trajectories of an exploitative and of an exploratory nature. Activities in a new or existing (from a firm perspective) technological domain, exploratory versus exploitative activities respectively, are measured by means of technology class information on patents (Belderbos, Faems, Leten, & Van Looy, 2010). The International Patent Classification System (IPC) provides a common classification of patents into at least one technology field. For the purpose of this paper, the IPC 4-digit level will be used, considering a patent as exploratory when it is assigned to a technological field that is new to the firm. If the firm did not patent in the technology domain in the past 5 years (t-5 to t-1), the patent is labeled as exploratory in year t, with t being the application year of the focal patent. If a patent is allocated to different IPC 4-digit classes, the patent can be exploratory in multiple technology domains. Due to potential differences between patent systems in how technology classification schemes are used (IPC versus USPC), only patents within the same patent system will be considered when measuring exploratory activities. As can be seen in Table 4, the majority of patents are classified as exploitative. Within the group of 484 university-invented corporate patents, 109 are labeled as exploratory.

Within the group of 123637 firm-invented corporate patents, 658 are labeled as exploratory.

Insert Table 4 about here

Patent indicators

Several patent indicators are of relevant interest when testing our hypotheses.
First, the number of backward patent citations is a frequently used indicator reflecting the extent to which a patent relies on previous technological knowledge. The more patents cite prior art, the more it is situated in the vicinity of those cited patents and hence, the more likely that they cover incremental innovations (Podolny & Stuart, 1995).
The number of backward citations to non-patent literature, the so-called non-patent references (NPRs), reflect proximity between science and technology (Callaert, Van Looy, Verbeek, Debackere, & Thijs, 2006). They reflect the science intensity of the patent, whereas backward patent citations reflect the technical background.
The originality of the invention refers to the diversity of technology fields present in the backward patent citations and was developed by Trajtenberg, Henderson, and Jaffe (1997). The originality score will be low if a patent cites prior art stemming from a narrow set of technology domains, whereas a patent will be more original if its backward citations are spread over a wide range of fields. It is calculated as 1 – the Herfindahl index reflecting the concentration of backward citations across technological classes (IPC 3-digit level). The originality index cannot be calculated if a patent does not cite any prior art.
Whereas the previous variables are backward-looking, we also include patent indicators that measure impact. Previous literature has shown that forward patent citations are indicative of patent importance and quality (Lanjouw & Schankerman, 2004; Trajtenberg, 1990). The analysis in this paper will distinguish between 10-year forward citations without self-citations (forward net citations) and 10-year forward self-citations, where the latter signal subsequent inventions by the same firm. The recent work of Belenzon (2012) reveals that self-citations are signaling economic or private value for the firm.
When testing the third hypothesis, the technological growth in newly entered fields is considered as the dependent variable of interest. For an exploratory patent (i.e. with at least one exploratory technology domain) in application year t, the growth is measured as the firm's number of granted patents in year t+1 to t+5 situated in the newly entered technology domain. The unit of analysis will no longer be the patent, but the technological activity of an applicant within its exploratory IPC 4-digit class within a patent system (EPO / USPTO) in year t+1 until t+5, with t being the application year of the initial exploratory patent.

Control variables

Several patent and firm characteristics will be controlled for throughout the analyses. When testing Hypothesis 1 and 2 where the patent is the unit of analysis, controls will include the application year, patent system, applicant, number of inventors, IPC 3-digit classes and technology scope, i.e. the number of different IPC 3-digit classes to which the patent is assigned. When testing Hypothesis 3, controls will include the application year, applicant, patent system, and the IPC 1-digit dummy of the exploratory technology domain.

Analyses and Results

Table 5 provides descriptive statistics of the patent indicators and control variables used in our analyses. In terms of forward self-citations firm-invented corporate patents display higher average impact than university-invented firm patents. When looking at the forward citations without self-citations (forward net citations), the same holds. When averaging the backward-looking indicators, a clear pattern can be seen. In case universities are involved in patenting, the patents have on average less backward citations, more non-patent references and higher originality scores. Furthermore, university-invented firm-owned patents involve more inventors on average and are assigned to more technology domains, reflected by the number of IPC 3-digit classes. The correlation matrix is presented in Table 6.

Insert Table 5 and 6 about here

Hypothesis 1A and 1B

In this section, we will assess whether there are differences between patents developed in-house and patents developed in collaboration with academic inventors in terms of prior art and impact. Table 7 displays the results of the backward-looking indicators, and Table 8 the indicators of impact.

Insert Table 7 about here

In Table 7 a binary probit regression model is introduced, with the dependent variable taking on the value of one if the corporate patent is resulting from university-industry collaboration and zero if the firm patent is developed within the company. Control variables are the patent system, technology scope, number of inventors, application year, applicant and technology domain(s). Table 7 shows that in terms of backward-looking indicators, a corporate patent is more likely to result from collaboration with an academic inventor when the number of backward patent citations is lower. Hence, university-invented firm-owned patents are significantly less incremental. The more original a patent is, the higher the probability that it results from collaboration with an academic inventor. Firm-invented corporate patents are found to be significantly less original. The higher the number of non-patent references, the higher the likelihood that the corporate patent involves an academic inventor.

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Insert Table 8 about here

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Table 8 displays the results of the negative binomial regressions on the forward-looking indicators of impact. No significant difference is revealed between university-invented and firm-invented firm-owned patents when forward self-citations are analyzed. Firm patents with academic inventors and without academic inventors spur the same amounts of cumulative innovation. When looking at the number of forward citations without self-citations, the results reveal that firm patents developed in-house have significantly more forward net citations than firm patents involving an academic inventor. Robustness checks were conducted with 5-year forward citations and all forward citations, and revealed similar results.

Hypothesis 2

Next, a distinction is made between exploitative and exploratory technology trajectories and the firm patents resulting from these. A comparison of the exploratory versus exploitative patents using a χ^2 test reveals a significant difference ($p < 0.01$). The exploratory sample contains more university-invented patents than expected and the exploitative sample contains more firm-invented patents than expected. These results seem to indicate that when firms develop their knowledge internally, they prefer to do this in technology domains that are already familiar to them, whereas when firms explore knowledge outside their core technologies, they are relatively more willing to collaborate with academic inventors. Another analysis was conducted where two additional variables were included in a modified specification of the aforementioned models assessing impact (Table 9). First, a dummy variable was added indicating whether the patent is assigned to at least one technology domain in which the respective firm did not patent before, i.e. whether the patent is considered to be exploratory. In case the patent is labeled as exploitative, the dummy is set to zero. To assess whether the firm is more able to reap the benefits of collaborating with academic inventors when it is exploring new technology domains, an interaction variable was constructed including either the 10-year forward net citations or the 10-year forward self-citations. Table 9 shows that in terms of forward net citations no evidence for an interaction effect was found: exploring new technology domains with academic inventors does not seem to have an added value in terms of social value, i.e. economic value for others than the firm. However, when analyzing forward self-citations, the interaction effect is found weakly significant. Exploratory firm-owned patents have significantly more forward self-citations when they are university-invented than when they are developed within the firm. Hence, when exploring new technology domains, involving a university inventor is related to more economic value for the firm. When exploiting existing technology domains, keeping development within the firm is related to more cumulative innovation by the firm. Robustness checks were conducted with 5-year forward citations and all forward citations, and revealed similar results. When all forward self-citations are analyzed, the interaction effect is even more significant.

Insert Table 9 about here

Hypothesis 3

When only analyzing technologies of a more exploratory nature, our unit of analysis changes to the technology domain that is novel to the firm, within a given patent system. In total, 816 exploratory trajectories are identified, involving 139 firm applicants and 108 technology domains (IPC 4-digit level). As previously mentioned, a given technology domain can be novel to multiple firms. Notwithstanding only 767 patents were labeled as exploratory, a higher number of exploratory trajectories (816) is identified because one 'novel' patent can imply multiple new technology domains, hence novel IPC 4-digit classes. Descriptive statistics on the technological growth in newly entered fields are revealed in Table 10.

Insert Table 10 about here

The average technological growth of university-invented trajectories is considerably lower than those of firm-invented trajectories. The latter result in a higher number of patents assigned to the new domains in the five-year time period after entering. To check whether involving an academic inventor in exploring new domains is related to the technological growth in those domains, a negative binomial regression was performed with technological growth as dependent variable, controlling for patent system, application year, applicant and the IPC 1-digit class of the novel technology domain. Results are displayed in Table 11.

Insert Table 11 about here

Our explanatory variable of interest, whether a patent is university-invented or not shows to be insignificant. Entering new technology domains by developing the necessary knowledge with universities is not related to higher technological growth, measured in terms of the number of patents situated in those novel technological fields five years later. Next, the sample was split in trajectories of large and medium firm applicants on the one hand, and small firm applicants on the other hand. The firm size dummy was constructed by matching firm names in Amadeus 2012 based on the Jaro-Winkler distance (Vervenne, Callaert, & Van Looy, 2014). When considering the split sample of large and medium firm applicants, results are the same. However, when conducting the analysis for small firms only, our explanatory variable of interest becomes significant. This means that for small firms, entering novel technology domains together with universities will enable faster technological growth in those exploratory domains.

Conclusion and Discussion

In this study, we compare the nature and impact of university-invented corporate patents versus corporate patents without academic inventors. We focused on the question whether and to what extent academic involvement implies a distinctive contribution to industry patenting, by contrasting university-invented and firm-invented corporate patents. Taking into account the insights from previous studies, when analyzing the firm-owned patents, we also explicitly distinguish between trajectories of an exploitative and of an exploratory nature, whereby the latter are patents situated in one or multiple technology domains that are new to the firm.

First, our findings do confirm that working with academics introduces additional novelty and diversity (Hypothesis 1A). University-invented firm patents are shown to be more diverse in terms of technology, as indicated by their significantly higher originality scores (e.g. Trajtenberg et al., 1997). With this finding, we complement the evidence found by Thursby et al. (2009) that university-invented firm patents are less basic than university-owned patents; as we show that these university-invented firm patents are more original than firm-invented corporate patents. Second, university-invented firm patents are closer to scientific findings than firm-invented corporate patents, as indicated by their higher number of references made to scientific literature. This finding is similar to previous studies showing that academic involvement in patenting is related to more science infusion, measured by the number of non-patent references (e.g. Czarnitzki, Hussinger, Schneider, 2012). Third, the results also suggest that firm-invented corporate patents are more of an incremental nature, as reflected by their significantly higher number of backward citations.

When turning our attention to differences in impact of university-invented vis-à-vis firm-invented patents, no evidence is found to support the hypothesis that the novelty and diversity implied by involving university inventors would lead to higher private value for the firm, measured by the number of forward self-

citations (Hypothesis 1B). In terms of forward net citations, i.e. social value, it is found that firm-invented corporate patents have higher impact than corporate patents involving academic inventors, which rejects our hypothesis. Ljungberg et al. (2013) found that academic patents held by firms have a short-term disadvantage that disappears in the long term. After controlling for firms' core and non-core technologies, the disadvantage disappears and firms' core technologies are found to have higher value, regardless of whether they are university-invented or firm-invented patents. At the same time, it must be noted that the institutional and legislative context regarding university IP in Sweden differs much from Belgium (cf. supra). In case Swedish university-invented patents mainly reside with firms, and Flemish university-invented patents mainly stay with the universities, this has to be taken into account when comparing findings.
Next, our findings revealed that university-invented patents are relatively more prominent in the exploratory technology trajectories. If firms decide to involve academic researchers in their technology development activities, this results in a disproportionally large share of patents being exploratory. If, on the other hand, firms keep their development process in-house, this results in a larger than expected share of patents being exploitative. This finding suggests that firms choose to collaborate with universities when pursuing more risky and uncertain ideas (i.e. when entering technology domains in which they lack experience). Indeed, some scholars have argued that firms mostly involve academic researchers in early stages of technology development (Crespi et al., 2010; Ljungberg, 2011; Ljungberg & McKelvey, 2012), which is consistent with our findings.
Considering the importance of academic contribution especially in exploratory trajectories, one could assume that university-involvement in exploratory trajectories would enable a firm to speed up learning, and hence to benefit more from science-industry collaborations than when they rely on in-house exploration only (Hypothesis 2). Evidence for this interaction effect was found when examining the forward self-citations. Entering novel technology domains will result in more economic value for the firm if they do it in collaboration with academic inventors. In other words, keeping development in-house when exploring knowledge outside core technologies will spur less cumulative innovation, relative to developing the new technologies together with universities. On the other hand, when developing within the realm of existing technology domains, involving an academic inventor is related to less cumulative innovation by the firm.
Finally, considering the importance of academic contribution especially in exploratory trajectories, one could assume that university involvement in exploratory trajectories would enable a firm to speed up learning, and hence to grow faster in the newly entered technological fields than when they rely on in-house exploration only (Hypothesis 3). This hypothesis was only confirmed for small firm applicants. When small firms rely on in-house resources for exploring, we find that growth in the new technology domain(s) during the five-year time period after initial exploration is less outspoken than when academic inventors were involved. In other words, when exploring new technological fields, the involvement of universities will allow small firms to develop a patent portfolio within these new fields more rapidly. However, this effect is absent when

considering large and medium firm applicants. The findings suggest that only small firms seem to benefit from involving universities in industry patenting, in terms of achieving faster technological growth in the novel technology domains.
To summarize, this study adds evidence to the under-exploited research area of analyzing the effect of academic contributions in industry patenting, further distinguishing between both exploitative and exploratory trajectories of firms. University involvement is shown to contribute in terms of diversity and novelty: university-invented corporate patents are more original, less incremental and more inspired by scientific findings than firm-invented corporate patents. When examining social value, measured by forward net citations, university-invented corporate patents are of significantly less value. In terms of private value, measured by forward self-citations, no difference is found between firm-invented and university-invented corporate patents. However, when distinguishing between existing and novel (to the firm) technology domains, it is found that collaborating with academic inventors in exploring novel domains spurs more cumulative innovation than keeping development in-house, and vice versa in case of exploiting existing technologies. When assessing the technological growth in new fields, only an effect is found for small firms, i.e. involving universities in developing new technologies enables faster growth in the new technology domains during the five-year time period after initial exploration.
At the same time, some limitations of our analysis could inspire further research. First, more robustness checks need to be done to ensure that our control sample of firm-invented patents only consists of patents developed by inventors working for the firm. An alternative control group of firm-invented patents might be created consisting of patents where the inventors appear on more than one patent, and only on patents of the same firm applicant within a particular time period. Next, the analysis could be envisaged on patent family level with family-corrected patent indicators. Our analysis on patent level does not take into account the possibility of one EPO patent and one USPTO patent within our sample protecting the same invention and thus belonging to the same patent family. Another avenue for further research would be to engage in text mining techniques for identifying exploratory technology trajectories in a more fine-grained way than the technology domain measure that we currently use.

References

Acs, Z., Audretsch, D., & Feldman, M. (1991). Real effects of academic research: Comment. *American Economic Review*, 81, 363-367.

Acs, Z., Audretsch, D., & Feldman, M. (1994). R&D spillovers and recipient firm size. *The Review of Economics and Statistics*, 76, 336-340.

Acs, Z. J. (Ed.). (2000). *Regional innovation, knowledge and global change.* London: Pinter.

Anselin, L., Varga, A., & Ács, Z. (1997). Local geographic spillovers between university research and high technology innovations. *Journal of Urban Economics*, 42(3), 422-448.

Anselin, L., Varga, A., & Ács, Z. (2000). Geographic and sectoral characteristics of academic knowledge externalities. *Papers in Regional Science*, 799, 435-445.

Autant-Bernard, C. (2001). Science and knowledge flows: Evidence from the French case. *Research Policy*, 30, 1069-1078.

Balconi, M., Breschi, S., & Lissoni, F. (2004). Networks of inventors and the role of academia: An exploration of Italian patent data. *Research Policy*, 33, 127-145.

Belderbos, R., Faems, D., Leten, B., & Van Looy, B. (2010). Technological activities and their impact on the financial performance of the firm: Exploitation and exploration within and between firms. *Journal of Product Innovation Management*, 27, 869-882.

Belderbos, R., Cassiman, B., Faems, D., Leten, B., & Van Looy, B. (2014). Co-ownership of intellectual property: Exploring the value creation and appropriation implications of co-patenting. *Research Policy*, 43, 841-852.

Belenzon, S. (2012). Cumulative innovation and market value: Evidence from patent citations. *The Economic Journal*, 122, 265-285.

Blind, K., & Grupp, H. (1999). Interdependencies between the science and technology infrastructure and innovation activities in German regions: Empirical findings and policy consequences. *Research Policy*, 28, 451-468.

Buesa, M., Heijs, J., Pellitero, M., & Baumert, T. (2006). Regional systems of innovation and the knowledge production function: the Spanish case. *Technovation*, 26, 463-472.

Callaert, J., Van Looy, B., Verbeek, A., Debackere, K., & Thijs, B. (2006). Traces of prior art: An analysis of non-patent references found in patent documents. *Scientometrics*, 69, 3-20.

Callaert, J., du Plessis, M., Van Looy, B., & Debackere, K. (2013). The impact of academic technology: Do modes of involvement matter? The Flemish case. *Industry and Innovation*, 20, 456-472.

Chesbrough, H. W. (2003). *Open Innovation: The new imperative for creating and profiting from technology.* Cambridge, MA: Harvard Business Press.

Chesbrough, H. W. (2006). The era of open innovation. *Managing Innovation* *and Change*, 127, 34-41.

Cooke, P., Gomez Uranga, M., & Extebarria, G. (1997). Regional innovation systems: Institutional and organizational dimensions. *Research Policy*, 26, 475-491.

Crespi, G. A., Geuna, A., Nomaler, Ö., & Verspagen, B. (2010). University IPRs and knowledge transfer: Is university ownership more efficient? *Economics of Innovation and New Technology*, 19, 627-648.

Czarnitzki, D., Hussinger, K., & Schneider, C. (2009). Why challenge the ivory tower? New evidence on the basicness of academic patents. *Kyklos*, 62, 488-499.

Czarnitzki, D., Hussinger, K., & Schneider, C. (2011). Commercializing academic research: The quality of faculty patenting. *Industrial and Corporate Change*, 20, 1403-1437.

Czarnitzki, D., Hussinger, K., & Schneider, C. (2012). The nexus between science and industry: Evidence from faculty inventions. *The Journal of Technology Transfer*, 37, 755-776.

Debackere, K., & Veugelers, R.(2005). The role of academic technology transfer organizations in improving industry science links. *Research Policy*¸ 34, 321-342.

Del Barrio-Castro, T., & Garcia-Quevedo, J. (2005). Effects of university research on the geography of innovation. *Regional Studies*, 39, 1217-1229.

Dornbusch, F., Schmoch, U., Schulze, N., & Bethke, N. (2013). Identification of university-based patents: A new large-scale approach. *Research Evaluation*, 22, 52-63.

Etzkowitz, H., & Leydesdorff, L. (1997). Introduction to special issue on science policy dimensions of the Triple Helix of university-industry-government relations. *Science and Public Policy*, 24, 2-5.

Etzkowitz, H., & Leydesdorff, L. (1998). The endless transition: A Triple Helix of university industry government relations. *Minerva*, 36, 203-208.

Faems, D., Van Looy, B., & Debackere, K. (2005). Interorganizational collaboration and innovation: Toward a portfolio approach. *Journal of Product Innovation Management*, 22, 238-250.

Feldman, M., & Florida, R. (1994). The geographic sources of innovation: Technological infrastructure and product innovation in the United States. *Annals of the Association of American Geographers*, 84, 210-229.

Fischer, M., & Varga, A. (2003). Spatial knowledge spillovers and university research: Evidence from Austria. *The Annals of Regional Science*, 37, 303-322.

Freeman, C. (1987). *Technology policy and economic performance*. London: Pinter.

Henderson, R., Jaffe, A. B., & Trajtenberg, M. (1998). Universities as a source of commercial technology: A detailed analysis of university patenting, 1965-1988. *Review of Economics and Statistics*, 80, 119-127.

Jaffe, A. (1989). Real effects of academic research. *American Economic Review*, 79, 957-970.

Lanjouw, J. O., & Schankerman, M. (2004). Patent quality and research

productivity: Measuring innovation with multiple indicators. *The Economic Journal*, 114, 441-465.
Leten, B., Landoni, P., & Van Looy, B. (2011). Developing technology in the vicinity of science: Do firms benefit? An overview and empirical assessment on the level of Italian provinces. In M. G. Colombo, L. Grilli, & L. Piscitello (Eds.), *Science and innovation policies for the new knowledge economy*: 160-133. Northampton, MA: Edward Elgar Publishing.
Leten, B., Landoni, P., & Van Looy, B. (2014). Science or graduates: How do firms benefit from the proximity of universities? *Research Policy*, 43, 1398-1412.
Leydesdorff, L., & Etzkowitz, H. (1996). Emergence of a Triple Helix of university-industry-government relations. *Science and Public Policy*, 23, 279-286.
Leydesdorff, L., & Etzkowitz, H. (1998). The Triple Helix as a model for innovation studies. *Science and Public Policy*, 25, 195-203.
Lissoni, F., Llerena, P., McKelvey, M., & Sanditov, B. (2008). Academic patenting in Europe: New evidence from the KEINS database. *Research Evaluation*, 17, 87-102.
Ljungberg, D. (2011, April). *Academic inventors and firm inventiveness: A quasi-experimental analysis of firms' patents*. Paper presented at the DIME Final Conference, Maastricht, Netherlands.
Ljungberg, D., & McKelvey, M. (2012). What characterizes firms' academic patents? Academic involvement in industrial inventions in Sweden. *Industry and Innovation*, 19, 585-606.
Ljungberg, D., Bourelos, E., & McKelvey, M. (2013). Academic inventors, technological profiles and patent value: An analysis of academic patents owned by Swedish-based firms. *Industry and Innovation*, 20, 473-487.
Lundvall, B. A. (Ed.). (2010). *National systems of innovation: Toward a theory of innovation and interactive learning*. London: Anthem Press.
Magerman, T., Van Looy, B., & Song, X. (2006). *Data production methods for harmonized patent statistics: Patentee name harmonization* (Working Paper No. 0605). Retrieved from K.U. Leuven FETEW MSI website: https://lirias.kuleuven.be/handle/123456789/228567
Mowery, D. C., & Ziedonis, A. A. (2002). Academic patent quality and quantity before and after the Bayh-Dole act in the United States, *Research Policy*, 31, 399-418.
Nelson, R. R. (1993). *National Innovation Systems: A comparative study.* Oxford: Oxford University Press.
Piergiovanni, R., Santarelli, E., & Vivarelli, M. (1997). From which source do small firms derive their innovative inputs? Some evidence from Italian industry. *Review of Industrial Organization*, 12, 243-258.
Piergiovanni, R., & Santarelli, E. (2001). Patents and the geographic localization of R&D spillovers in French manufacturing. *Regional Studies*, 35, 697-702.
Podolny, J. M., & Stuart T. E. (1995). A role-based ecology of technological change. *American Journal of Sociology*, 100, 1224-1260.
Quillen, C. D., & Webster, O. H. (2001). Continuing patent applications and

performance of the US patent and trademark office. *Fed. Cir. BJ*¸ 11, 1-21.
Sampat, B. N., Mowery, D. C., & Ziedonis, A. A. (2003). Changes in university patent quality after the Bayh-Dole act: A re-examination. *International Journal of Industrial Organization*, 21, 1371-1390.
Sapsalis, E., van Pottelsberghe de la Potterie, B., & Navon, R. (2006). Academic versus industry patenting: An in-depth analysis of what determines patent value. *Research Policy*, 35, 1631-1645.
Saxenian, A. (1994). *Regional advantage: Culture and competition in Silicon Valley and Route 128.* Cambridge, MA: Harvard University Press.
Schumpeter, J. A. (1934). *The theory of economic development: An inquiry into profits, capital, credit interest, and the business cycle.* New Brunswick, NJ: Transaction Publishers.
Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics*, 39, 312-320.
Sterzi, V. (2013). Patent quality and ownership: An analysis of UK faculty patenting. *Research Policy*, 42, 564-576.
Thursby, J., Fuller, A. W., & Thursby, M. (2009). US faculty patenting: Inside and outside the university. *Research Policy*, 38, 14-25.
Trajtenberg, M. (1990). A penny for your quotes: Patent citations and the value of innovations. *The Rand Journal of Economics*, 21, 172-187.
Trajtenberg, M., Henderson, R., & Jaffe, A. (1997). University versus corporate patents: A window on the basicness of invention. *Economics of Innovation and New Technology*, 5, 19-50.
Van Looy, B., du Plessis, M., & Magerman, T. (2006). *Data production methods for harmonized patent statistics: Assignee sector allocation* (Working Paper). Retrieved from Eurostat website: http://ec.europa.eu/eurostat/documents/3888793/5835901/KS-AV-06-001-EN.PDF
van Pottelsberghe de la Potterie, B., & François, D. (2009). The cost factor in patent systems. *Journal of Industry, Competition and Trade*, 9, 329-355.
Vervenne, J., Callaert, J., & Van Looy, B. (2014). Patent statistics at Eurostat: Mapping the contribution of SMEs in EU patenting, 2014 edition, retrieved from http://ec.europa.eu/eurostat/documents/3859598/6064260/KS-GQ-14-009-EN-N.pdf/caa6f467-11f8-43f9-ba76-eb3ccb6fab6d
Veugelers, R., Callaert, J., Song, X., & Van Looy, B. (2012). The participation of universities in technology development: Do creation and use coincide? An empirical investigation on the level of national innovation systems. *Economics of Innovation and New Technology*, 21, 445-472.
Von Hippel, E. (1988). *The sources of innovation.* Oxford, England: Oxford University Press.

Table 1: Second stage of name harmonization of firm assignees: Number of name variants in PATSTAT

Nr. of firm assignees	Mean nr. of name variants per assignee	Std.Dev.	Min	Max
144	22.18	51.77	1	370

Table 2: University-invented firm-owned versus firm-invented firm-owned patents, broken down by technology domain

IPC (1-digit)	University-invented firm-owned	Firm-invented firm-owned
A. Human necessities	150.83 (31.16%)	24216.83 (19.59%)
B. Performing operations, transporting	40.67 (8.40%)	2905.51 (2.35%)
C. Chemistry, metallurgy	167.50 (34.61%)	25160.33 (20.35%)
D. Textiles, paper	0 (0%)	0 (0%)
E. Fixed constructions	0 (0%)	0 (0%)
F. Mechanical engineering, lighting, heating, weapons, blasting	1 (0.21%)	28.50 (0.02%)
G. Physics	68.83 (14.22%)	49574.33 (40.10%)
H. Electricity	55.17 (11.40%)	21751.50 (17.59%)
Total	484 (100%)	123637 (100%)

Table 3: University-invented firm-owned versus firm-invented firm-owned patents, broken down by patent office

	University-invented firm-owned	Firm-invented firm-owned
EPO grants	139 (28.72%)	29349 (23.74%)
USPTO grants	345 (71.28%)	94288 (76.26%)
Total	484 (100%)	123637 (100%)

Table 4: University-invented firm-owned versus firm-invented firm-owned patents: exploratory or exploitative technological activities

	University-invented firm-owned	Firm-invented firm-owned	Total
Exploitative	375 (77.48%)	122979 (99.47%)	123354
Exploratory	109 (22.52%)	658 (0.53%)	767
Total	484 (100%)	123637 (100%)	124121

Table 5: University-invented firm-owned versus firm-invented firm-owned patents: summary statistics

		N	Mean	Std.Dev.	Min	Max
Forward self-citations (10Y)	University-invented firm-owned	484	.80	2.34	0	20
	Firm-invented firm-owned	123637	1.26	3.50	0	175
Forward net citations (10Y)	University-invented firm-owned	484	4.31	8.35	0	79
	Firm-invented firm-owned	123637	5.68	11.98	0	380
Backward patent references	University-invented firm-owned	484	9.60	11.86	0	93
	Firm-invented firm-owned	123637	11.90	16.04	0	194
Non-patent references	University-invented firm-owned	484	10.85	22.60	0	110
	Firm-invented firm-owned	123637	3.58	10.37	0	144
Originality	University-invented firm-owned	386	.54	.21	0	.90
	Firm-invented firm-owned	107421	.40	.25	0	.93
Number of inventors	University-invented firm-owned	484	4.51	2.85	1	14
	Firm-invented firm-owned	123637	3.00	2.03	1	30
Technology scope (IPC 3-digit)	University-invented firm-owned	484	1.89	.90	1	7
	Firm-invented firm-owned	123637	1.19	.45	1	5

Table 6: University-invented firm-owned versus firm-invented firm-owned patents: correlations

	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Forward net citations (10Y)	.402***	.066***	.025***	-.067***	-.204***	-.106***	-.033***	-.007**	-.001
2. Forward self-citations (10Y)		.097***	.054***	-.056***	-.134***	-.031***	.050***	-.008***	-.018***
3. Backward patent references			.306***	.085***	-.319***	-.029***	.065***	-.009***	-.010***
4. Non-patent references				.159***	-.123***	.217***	.110***	.043***	.005*
5. Originality					-.105***	.258***	.102***	.036***	.036***
6. Patent system (EPO = 1)						.121***	.025***	.007**	.021***
7. Technology scope							.238***	.096***	.053***
8. Number of inventors								.046***	-.010***
9. University-invented (= 1)									.175***
10. Exploration (= 1)									

Notes: standard errors in parentheses.

* $p \leq 0.10$; ** $p \leq 0.05$; *** $p \leq 0.01$

Table 7: University-invented versus firm-invented firm-owned patents: prior art

University-invented (= 1)	
Backward patent references	-.013***
	(.003)
Non-patent references	.011***
	(.002)
Originality	.418***
	(.137)
Patent system (EPO = 1)	-.304***
	(.078)
Technology scope	.955***
	(.319)
Number of inventors	.140***
	(.011)
Constant	-3.633***
	(.516)
Application year dummies	yes
Applicant dummies	yes
Technology domain dummies	yes
N	70452
LR	$\chi^2(150)$
	= 1754.33***

Notes: standard errors in parentheses.

* $p \leq 0.10$; ** $p \leq 0.05$; *** $p \leq 0.01$

Table 8: University-invented firm-owned versus firm-invented firm-owned patents: impact

	Forward net citations (10Y)	Forward self-citations (10Y)
University-invented (= 1)	-.169**	-.138
	(.076)	(.121)
Backward patent references	.004***	.010***
	(.000)	(.000)
Non-patent references	.005***	.005***
	(.000)	(.001)
Originality	.097***	-.183***
	(.018)	(.027)
Patent system (EPO = 1)	-.955***	-.348***
	(.014)	(.020)
Technology scope	.525***	.646***
	(.062)	(.092)
Number of inventors	.044***	.084***
	(.002)	(.003)
Constant	-5.420***	-6.124***
	(.715)	(1.013)
Application year dummies	yes	yes
Applicant dummies	yes	yes
Technology domain dummies	yes	yes
N	107807	107807
LR	$\chi^2(197)$	$\chi^2(197)$
	= 54071.97***	= 20042.29***

Notes: standard errors in parentheses.

* $p \leq 0.10$; ** $p \leq 0.05$; *** $p \leq 0.01$

Table 9: University-invented firm-owned versus firm-invented firm-owned patents: impact of exploration versus exploitation

	Forward net citations (10Y)	Forward self-citations (10Y)
University-invented (= 1)	-.158**	-.186
	(.080)	(.125)
Exploration (= 1)	.074	-.437***
	(.058)	(.103)
University-invented X exploration	-.134	.748*
	(.236)	(.400)
Backward patent references	.004***	.010***
	(.000)	(.000)
Non-patent references	.005***	.005***
	(.000)	(.001)
Originality	.096***	-.181***
	(.018)	(.027)
Patent system (EPO = 1)	-.955***	-.348***
	(.014)	(.020)
Technology scope	.523***	.652***
	(.062)	(.092)
Number of inventors	.044***	.084***
	(.002)	(.003)
Constant	-5.419***	-6.125***
	(.715)	(1.013)
Application year dummies	yes	yes
Applicant dummies	yes	yes
Technology domain dummies	yes	yes
N	107807	107807
LR	$\chi^2(199)$	$\chi^2(199)$
	= 54073.73***	= 20060.56***

Notes: standard errors in parentheses.

* $p \leq 0.10$; ** $p \leq 0.05$; *** $p \leq 0.01$

Table 10: University-invented firm-owned versus firm-invented firm-owned patents: technological growth in exploratory trajectories

	N	Mean	Std.Dev.	Min	Max
University-invented firm-owned	199	1.12	2.61	0	17
Firm-invented firm-owned	617	10.05	22.14	0	161
Total	816	7.87	19.67	0	161

Table 11: Exploratory technology trajectories: technological growth

Technological growth	(Total sample)	(Small firms)	(Large and medium firms)
University-invented	-.241	2.171**	-.342
(= 1)	(.263)	(1.064)	(.277)
Patent system	-.773***	-.085	-.760***
(EPO = 1)	(.129)	(.418)	(.140)
Application year dummies	yes	yes	yes
Applicant dummies	yes	yes	yes
Technology domain dummies	yes	yes	yes
N	816	179	637
LR	$\chi^2(144)$	$\chi^2(65)$	$\chi^2(102)$
	= 797.49***	= 187.84***	= 551.19***

Notes: standard errors in parentheses.

* $p \leq 0.10$; ** $p \leq 0.05$; *** $p \leq 0.01$