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The nexus between science and industry: evidence from faculty inventions

Dirk Czarnitzki · Katrin Hussinger · Cédric Schneider

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Abstract Knowledge transfer from science to industry has been shown to be beneficial for the corporate partner. In order to get a better understanding of the reasons behind these positive effects, this study focuses on the junction of science and industry by comparing characteristics of academic inventions that are transferred to industry and those staying in the public sector. Academic inventions are identified via patent applications of German academic scientists. We find that academic patents assigned to corporations are more likely to enable firms reaping short term rather than, possibly more uncertain, long-run returns, in contrast to patents that stay in the public sector. Firms also strive for academic inventions with a high blocking potential in technology markets. Academic patents issued to corporations appear to reflect less complex inventions as compared to inventions that are patented by the public science sector.

Keywords Academic inventors · University-industry technology transfer · Intellectual property rights

D. Czarnitzki (✉) · K. Hussinger · C. Schneider
Department of Managerial Economics, Strategy and Innovation,
K.U. Leuven, Naamsestraat 69, 3000 Leuven, Belgium
e-mail: dirk.czarnitzki@econ.kuleuven.be

D. Czarnitzki
Center for R&D Monitoring (ECOOM) at K.U. Leuven, Leuven, Belgium

D. Czarnitzki · K. Hussinger
Centre for European Economic Research (ZEW), Mannheim, Germany

K. Hussinger (✉)
Department of Organization and Strategy, University of Maastricht,
Tongersestraat 53, 6211 LM Maastricht, The Netherlands
e-mail: k.hussinger@os.unimaas.nl

C. Schneider (✉)
Department of Economics, Copenhagen Business School, CEBR,
Porcelænshaven 16a, 2000 Frederiksberg, Denmark
e-mail: csc.eco@cbs.dk

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1 Introduction

The impact of public science on economic growth has been discussed among economic scholars, professionals and policy makers since decades. There are various contributions of public science including the enhancement of the knowledge stock and problem solving capacities in the economy, the education of skilled graduates, the creation of new scientific methods and instruments, and new firm formation (Salter and Martin 2001; Foray and Lissoni 2010). While the empirical literature clearly establishes a positive relationship between investment in public science and (long-term) economic returns for a variety of dimensions, such as corporate patenting (Jaffe 1989), productivity growth (Adams 1990), new product and process development in firms (Mansfield 1991, 1998; Cohen et al. 2002; Toole 2007) and even the emergence of entirely new industries (Zucker and Darby 1996, Zucker et al. 1998) this evidence is largely based on the United States and still emerging in Europe (Geuna and Nesta 2006).

It is, however, important to make a distinction between the U.S. and Europe when evaluating the impact on public science because the institutional environment for technology transfer differs significantly. For instance, the ownership of university inventions is regulated in different ways. While in the U.S. university inventions are generally owned by the university since the Bayh-Dole Act in 1980, in most European countries they were owned by the academic inventors themselves until recently (Kilger and Bartenbach 2002; Verspagen 2006). Second, many policy programs for supporting industry-science collaboration exist in Europe, while there are only few such initiatives in the U.S. (Veugelers and Cassiman 2005). Moreover, the general shift from research-focused universities towards entrepreneurial universities (Etzkowitz 1998, 2003) has only recently started in Europe while it is ongoing since the 197s in the U.S. (Mowery and Sampat 2001; Sampat 2006; Franzoni and Lissoni 2009).[1] These institutional differences define different conditions for technology transfer from universities to the business sector.

This paper focuses on the nexus between science and industry in a sample of German academic patentees. In order to improve our understanding of technology transfer we provide an empirical analysis of the assignment of patents for inventions by academic inventors in German universities. As inventions were owned by the academic inventors themselves an analysis of the characteristics of patents transferred to the business sector improves our understanding of technology transfer from science to industry.[2] Our results suggest that academic patents assigned to the corporate sector are less complex and receive more forward citations, which signals that they are more "important". Furthermore, we use

[1] Mowery and Sampat (2001) and Sampat (2006) describe the increase in patenting for U.S. universities and investigate the reasons. Franzoni and Lissoni (2009) describe the move towards more engagement in entrepreneurship for European universities and provide a comparison with the U.S.

[2] We focus on the assigneeship of academic patents rather than on other potential technology transfer modes because of the fact that the majority of European academic inventions are immediately assigned to businesses and that university licensing still occurs only occasionally in Europe. In 2006, European Technology Transfer Offices (TTOs) had, on average, only 11.2 licenses, of which only 2.3 yield licensing revenue for the university (ProTon 2006). The estimated number is based on survey evidence for 325 European TTOs. The ProTon survey is the European equivalent of the AUTM (The Association of University Technology Managers) survey for the U.S.

a measure for the blocking potential of patents and find that academic patents assigned to industry partners have a higher likelihood to block future patent applications.[3]

Our study is related to a recent investigation of patent assignee ship of university inventions by Thursby et al. (2009). While we would expect that most U.S. academic patents are assigned to universities due to the different legislation, Thursby et al. (2009) show that the share of university inventions that is patented solely by corporations accounts for 26%. They further find results which are similar to ours regarding the differences in patents assigned to corporations and academe. In particular, U.S. university patents assigned to the corporate sector are less basic than those that stay in the university.

We add to the U.S. study in two ways: first, we provide evidence for Germany as a large European country with a different institutional set-up regarding the ownership of university inventions. Private ownership of university inventions lead to a much higher percentage of university-generated patents assigned to corporations. German university professors typically commercialized their research through consultancy agreements with industry partners, through “more or less private deals” (Goddar 2005). The financial benefits for the professors either included the remuneration for the inventions made under the collaborative project if these were to be directly transferred to the industry partner or the consulting contract included licensing regulations for these inventions (Goddar 2005).[4]

A second contribution of our study is that we use a measure for the blocking potential of patents which is not available for U.S. patent data. In particular, industry partners should be interested in technologies with a potential to erect or sustain a competitive advantage vis-à-vis rivals by hindering their future patent applications. This measure adds to previous studies proposing patent indicators to investigate differences between university and corporate patents (see e.g. Trajtenberg et al. 1997; Thursby et al. 2009).

The remainder of the paper is organized as follows: the next section provides an overview on the institutional background for technology transfer from academe in Europe and related literature; Sect. 3 summarizes our data; Sect. 4 shows the empirical results and the final section concludes.

2 Background

2.1 Institutional background

In the U.S. as well as in Europe a change towards increased commercialization activities in science has taken place during the second half of the last century. In the U.S., this trend started earlier and was partly initiated by the postwar growth of use-oriented basic research in fields like molecular biology that spurred the demand for commercial applications (Stokes 1997; Sampat 2006). Changes in the inter-institutional allocation of public funds further increased a shift towards commercialization activities in academe (Mowery and Sampat 2001). Public funds declined for many universities which rendered patents an important alternative source for universities to generate additional income (Sampat 2006).

[3] Note that for our present research question, the sequence in which the technology transfer events happen is not of primary interest. For our purpose, it does not matter whether a scientist invents something and then sells his or her idea to the business sector that subsequently takes out a patent or whether a company requests consultancy from a scientist that eventually results in a corporate patent.

[4] An immediate implication of these practices is that the contribution of European universities to business innovation development is largely underestimated if such science-industry collaborations are not taken into account (Geuna and Nesta 2006, Verspagen 2006, van Pottelsberghe de la Potterie 2007).

These factors mitigated the prevalent aversion to patenting among university scientists (Mowery and Sampat 2001). In 1980, the Bayh-Dole Act took place as a milestone towards commercialization activities in the U.S. science sector. This change in law entitles U.S. universities to retain ownership of their inventions.[5]

In Europe, the trend towards "entrepreneurial universities" (Etzkowitz 1998, 2003) started much later, in the 1980s and 1990s. Until then, European university science was mainly financed by structural funds. Cuts in university budgets in the 1980s and 1990s increased the need to acquire complementary funding and, hence, spurred university-industry collaboration and the general interest of European academics in commercialization (Geuna and Nesta 2006). Franzoni and Lissoni (2006) describe and contrast the different steps towards an increased openness of universities towards commercializing science in Europe and the U.S.

One of the main institutional differences between the U.S. and Europe regarding the commercialization of university inventions concerns their legal ownership. In the U.S., university inventions were owned by the university since Bayh-Dole, whereas many European countries had until recently the so-called "professors' privilege" in place. This legal exception allowed university professors to retain ownership of the results from publicly financed research and development (Kilger and Bartenbach 2002; Verspagen 2006). From an economic perspective, private ownership of university inventions can be sub-optimal as individuals are generally less well positioned to exploit their knowledge in a commercial sense than a professional technology transfer office (TTO) at the university (Eisenberg, 1996, Verspagen 2006). However, private ownership still sets incentives for university inventors to approach firms in order to profit from the invention. Accordingly, European academics with an interest in commercialization did so without university involvement (Goddar 2005, for Germany). This behavior becomes visible in a very low share of academic patents being assigned to European universities (Saragossi and de la Potterie 2003; Geuna and Nesta 2006; Verspagen 2006; Lissoni et al. 2008). For Germany, France and Italy less than 1% of all patents are assigned to universities (Verspagen 2006) and university licensing is negligibly small (ProTon 2006). Lissoni et al. (2008) estimate that the share of academic patents directly assigned to corporations ranges from 60 to 80% in Europe.[6] In comparison, only 26% of U.S. university inventions are solely assigned to corporations (Thursby et al. 2009). Germany abolished the "professors' privilege" in 2002.[7] Consequently, European universities have to deal with their lack of experience in commercializing university inventions (Debackere and Veugelers 2005).

[5] Before the Bayh-Dole Act, there was no general law that decided about the ownership of U.S. university inventions. In the U.S. context, university research is often co-financed by federal resources like the National Institutes of Health or the National Science Foundation or by the corporate sector. The ownership of intellectual property rights had to be negotiated case by case before Bayh-Dole (Mowery and Sampat 2001). Empirical evaluations of the effect of Bayh-Dole on U.S. university patenting are provided by Henderson et al. (1998), Mowery et al. (2002), Mowery and Ziedonis (2002) and Sampat et al. (2003).

[6] The importance of university consulting for industry is also reflected in such endeavors as the "Berlin agreement", a collaboration between the Berlin universities, industry partners and the company Patentverwertungsagentur ipal GmbH, which aims at defining a set of rules, describing the manner in which to deal with patentable inventions ensuing from research co-operations or assignments financed by industry. From the perspective of the industry partners it is most important to ensure that universities do not only transfer patented technologies but also provide consulting service and information on related inventions even if there is no intention to publish those (Goddar 2005).

[7] This change in legislation also took place in France (Della Malva et al. 2008), in Denmark and Austria. Other European countries adopted different legislations. Italy has introduced the professor's privilege in

Another key difference between the U.S. and Europe regards technology transfer policy. While in the U.S. relatively few technology transfer programs are in place,[8] many European governments as well as the European Commission launched several programs to promote and strengthen industry-science collaboration (Veugelers and Cassiman). These initiatives have been found to increase university-collaboration in Europe for cost and risk sharing motives (Veugelers and Cassiman 2005; Capron and Cincera 2003; Mohnen and Hoareau 2003).

2.2 Technology transfer modes in Europe

There are a number of empirical studies that analyze different university-industry transfer modes for the U.S. and Europe. Rothaermel et al. (2007) present an extensive survey on the state of the art surveying a number of empirical studies. A more recent survey is provided by Lissoni and Foray (2010).[9] Both reviews indicate that a majority of studies focuses on the U.S.

The technology transfer literature for Europe has a different focus due to the different institutional set-up. For instance, industry-science collaborations receive more attention in the European context than in the U.S. The determinants of such collaborations are, for instance, studied by Belderbos et al. (2004a) and Veugelers and Cassiman (2005). It has been shown that such industry-science linkages are beneficial for innovation product sales of German and Dutch manufacturing firms (Beise and Stahl 1999; Belderbos et al. 2004b).

Another important technology transfer channel in Europe are academic spin-offs (e.g. Mustar 1997; Clarysse et al. 2005). The empirical studies on academic spin-offs are difficult to compare as they are mostly based on very specific samples, e.g. they focus on spin-offs from one specific academic institution, in a specific region or industry. However, there is some evidence that academic spin-offs have a higher R&D intensity than other new technology based firms (Mustar 1997) and that they contribute significantly to the growth of regions (Mueller 2006).

Another topic that deserves attention in the European context is the variety of different types of universities and public research institutions. In countries like Germany and France, public research institutions contribute significantly to knowledge transfer to the business sector (Franzoni and Lissoni 2009).

Many U.S. studies focus on university patenting (see Rothaermel et al. 2007, for a survey). As pointed out in the previous section, scholars considered university patenting as a less important technology transfer channel for Europe as there were only a few patents assigned to European universities in the past (Verspagen 2006; Geuna and Nesta 2006). The inventive activity of academics in form of patents assigned to other entities was often neglected. In the European context, however, it is actually more instructive to focus on university-invented patents than on university-owned patents because of the different institutional settings in the U.S. and Europe. A large stream of the recent empirical

Footnote 7 continued
2001 ("Legge Finanziaria") and Sweden maintained the professors' privilege (see van Pottelsberghe de la Potterie 2007, for a more detailed discussion).

[8] The major U.S. initiatives are the Small Business Technology Transfer (SSTR) that fosters collaboration between universities and small firms, the Small Business Innovation Research (SBIR) that allows academic scientists to commercialize their inventions (Toole and Czarnitzki 2007, 2009, 2010), and, formerly, the Advanced Technology Program (ATP) program for encouraging university industry collaborations (Hall et al. 2003).

[9] Complementary surveys are provided by Verspagen (2006) and Geuna and Nesta (2006).

literature for Europe therefore focuses on academic inventors and studies which the characteristics and motives of scientists engaging in patenting. The overall finding is that successful research and patenting activities go together (van Looy et al. 2004; Gulbrandsen and Smedy 2005; Meyer 2006; Breschi et al. 2005, 2007, 2008; Calderini and Franzoni 2004; Czarnitzki et al. 2007). These results confirm the findings for the U.S., where scholars have found that "star scientists" are more likely to engage in commercialization (e.g. Zucker and Darby 1996; Zucker et al. 1998; Azoulay et al. 2009). In a recent study for Germany, Czarnitzki et al. (2009a) show that there is substantial heterogeneity in academic patenting. Scientists engaged in patenting with research institutes and other non-profit organizations show a high scientific publication outcome. If a university scientist files patents with corporations, however, her scientific publication record is below average both in quantity and quality.

This finding suggests that there might also be differences between technologies transferred to the business sector and those that remain in academe or go to non-profit organizations. This assertion is supported by previous evidence on differences between academic and corporate patents. Trajtenberg et al. (1997), for instance, find that university patents capture more basic inventions indicating that industry R&D is directed at commercial success, while university research rather focuses on solving scientific questions. This is also reflected in lower patent opposition rates for patented academic inventions compared to corporate patents in Europe (Czarnitzki et al. 2009b). The fact that academic patents assigned to corporations are opposed more frequently suggests that they are more likely to capture applied inventions with a higher market potential. The contribution of our study is to investigate the difference between academic patents assigned to corporations and others. Evidence on these differences increases our understanding of the nature of technology transfer from universities to industry.

From the firm's perspective, previous studies have shown scientific research to be beneficial in terms of increased R&D productivity (Henderson et al. 1998), enhanced patent quality (Cassiman et al. 2008) and reduced labor cost (Stern 2004). The beneficial effects of science in industry have been explained by the fact that science provides substantial guidance for industrial research by pointing out promising avenues for future technology development leading to efficiency enhancement and avoidance of wasteful R&D investments and experimentations (Fleming and Sorenson 2004; Dasgupta and Paul 1994; Hall et al. 2003; Crespi et al. 2006) and that university research has a higher importance for future technological development (Henderson et al. 1998). Our analysis of the characteristics of academic patents assigned to firms provides insights into further reasons for the beneficial effect of academic science in industry.

3 Data and variables

3.1 Data and sample selection

Our analysis is based on a database issued by the European Patent Office (EPO) and the OECD. The "EPO/OECD patent citations database" covers all patents applied for at the EPO since its foundation in 1978 and up to October 2006 as well as all patents applied for under the Patent Cooperation Treaty (PCT) in which the EPO is designated, so-called "Euro-PCT applications". In addition to detailed information on all patents and their citations, the dataset contains other information for each patent (technology classes, date of application and title) and each applicant and inventor (name and place of residence). An earlier version of this database is fully described and analyzed in Webb et al. (2005).

From this database we extracted all applications involving at least one inventor residing in Germany, resulting in a total of 346,892 patent applications. We identified all patents invented by German professors by using the persons' title "Prof. Dr." and variations of that. The professor title is protected by the German criminal code (article 132a) against misuse by unauthorized persons. Although not compulsory, it is common practice in Germany to use academic titles in official communications. Czarnitzki et al. (2007) conducted a test on the accuracy of this identification strategy at the German Patent and Trademark Office (GPTO) and the EPO. They checked whether the names of professors appeared in the patent database without the title but with the same address in order to verify that the title field is always filled in the data. The verification of a sample of persons had shown that university professors (or professors at other higher education facilities such as polytechnical colleges) can be identified by their title with high precision. Czarnitzki et al. (2007) conclude that it basically never happens that inventor names appear sometimes with "Prof. Dr." (or similar title) and sometimes without on other patents. Thus, we can safely argue that with focus on Germany this procedure delivers an exhaustive listing of patents where professors are recorded as inventors. In total, we found 4,841 (granted) patents that list at least one faculty member between 1978 and 2000.[10]

In the next step, we manually identified the ownership type of all academic patents in our sample. More specifically, we categorized the academic patents depending on whether they were assigned to a corporate entity, a university, a public research institute or to the professor who was listed as inventor. We distinguish between universities and "public research institutes" because of some special format of the German public science landscape. Major research institutions in Germany are not only universities but also public research institutions, such as the Max-Planck Society, the Helmholtz Society, and the Fraunhofer Society. These are large public research institutions that have many branches in a variety of different scientific disciplines. For instance, the Fraunhofer Society has 59 institutes in Germany with about 17,000 employees, the Max-Planck Society has 76 institutes with about 12,000 employees plus about 10,000 other affiliated researchers such as post-docs, doctoral students and student assistants. The Helmholtz Society is the largest institution in German public science. It has about 30,000 employees in 16 research centres. University professors are frequently heads of research groups at all of these institutions. We keep the public research institutions as a separate category since part of their mission in the German public science landscape is clearly active engagement in technology transfer.

We deleted some patents that did not fit into the above mentioned groups. First, we found 113 patents that were assigned to other types of applicants. These are mainly individuals without a professor title[11] or government agencies. As we are interested in comparing patents of corporate assignees to scientific assignees, we omit this category

[10] To further check the completeness of our sample of academic patents, we compared the outcome with a similar search in the data from the GPTO. We used the data collected by Czarnitzki et al. (2007) which covered the time period 1990–2001. Using the GPTO data, we searched for all patents that have an EPO equivalent and that list professors as inventors in the EPO database. We found only 112 applications in which the GPTO patent listed a professor, but not the equivalent EPO patent. As we could not perform this search for the whole time period considered in this paper, we decided not to add these 112 patents to our sample.

[11] These will most likely be researchers at the labs that do not have a professor title. As we cannot be sure, however, we prefer to drop such patents.

from the subsequent analysis.[12] Second, we found 89 patents which listed more than one type of assignee. As we could not clearly determine whether these should be classified as corporate or scientific patents, we preferred to delete them from our sample. Our final sample for this study contains 4,752 observations.

3.2 Variables

Similarly to Thursby et al. (2009), the aim of our multivariate analysis is to uncover partial correlations between assignment of academic patents to a specific type of organization and a set of patent characteristics. The patent-based variables we use in our multivariate analysis are usually determined after the assignment of the patent. Therefore, we do not hypothesize causality between assignment and patent characteristics; instead, we posit that patent characteristics provide information about the type of research that led to the invention, which in turn can explain the type of assignment.

We use two different models in our multivariate analysis. The first one is a binary model, for which the dependent variable is a dummy that takes on the value one if the focal patent was assigned to a corporate entity (the most frequent outcome), and zero if it was assigned to a "scientific" assignee, broadly speaking. As discussed above, the latter type of organizations may be universities, public research institutes, the scientist who is also listed as inventor, or the residual category.

Next, we estimate a series of probability models of assignment, where the dependent variables are categorical and take on different values according to the type of organization that owns the patent.

Following the literature on patent quality and previous empirical studies, we use several patent characteristics that may be correlated with the likelihood of assignment to the one or the other type of organization.

3.2.1 The number of backward citations

The search report published by the EPO yields information on the state of the art relevant for a given patent application. Backward citations determine the legal boundaries of an invention by citing a related body of work. Thus, one could hypothesize that applications containing references to a large number of related inventions are of more incremental nature. However, empirical evidence tends to uncover a positive effect of backward citations on the value of a patent (Harhoff et al. 2003), which suggests that the number of cited patents is more likely to refer to the extent of patenting in a given technological area (Lanjouw and Schankerman 2001) and hence to the potential profitability of inventions falling into that domain.

3.2.2 Share of X and Y backward citations

Backward citations at the EPO are classified into different categories by the examiner during the search procedure, according to their relevance for the evaluation of patentability of the invention. Two interesting categories for our purpose are:

[12] Including these patents as a separate group does not alter any of the reported results.

- "Type X" citations. References classified in this category indicate material that is potentially harmful to the novelty or inventive step requirements of the claimed invention, when the referenced document is taken alone.
- "Type Y" citations indicate material that is potentially harmful to the inventive step requirement of the claimed invention, when the referenced document is combined with one or more other documents of the same category, such a combination being obvious to a person skilled in the art.

We include the sum of X and Y citations, relative to the total number of backward citations. This measure is presumably (inversely) correlated with the degree of novelty and/or inventive step of the claimed invention.

When a patent has no backward citations, we set the share of X and Y citations to zero and add a dummy variable that takes the value one when the focal patent has no backward citations. This captures the arising bias from the missing value imputation. As a consequence, we do not have to discard these observations.[13]

The number of forward citations is defined as the number of citations received by a focal patent from any subsequent patent application and measures the "importance", the "quality" or the "significance" of a patented invention. Previous studies have shown that forward citations are highly correlated with the social value of the patented invention (Trajtenberg 1990, for the computer tomography industry) as well as with its private value (Harhoff et al. 1999; Hall et al. 2005). Furthermore, forward citations reflect the economic and technological "importance" as perceived by the inventors themselves (Jaffe et al. 2000) and knowledgeable peers in the technology field (Albert et al. 1991). The high correlation between the number of forward citations to EPO patents with patent value has been documented by Gambardella et al. (2008).

Patent citations have also been used to measure the value of academic or university patents (see e.g. Henderson et al. 1998; Sapsalis et al. 2006; Czarnitzki et al. 2009).[14]

We also include the *share of forward X and Y citations*, which accounts for the potential blocking power of a given patent. If a patent is listed as an X or Y reference in subsequent patents, it means that the owner of the original patent can potentially block the development of follow-on research by (potential) competitors (Hall and Harhoff 2001; Guellec et al. 2008). This type of patents have been found to be of particular interest for firms (Grimpe and Hussinger 2008a, b), but we would not expect that the blocking potential of technologies is important for universities, public research institutes or academic applicants.

For both types of citations, we employ two different measures. First, we use the number of citations received up to 5 years after publication. Second, we also include the number of citations received from the fifth year onward.[15] The reason is that we expect the patents assigned to corporations to have different citation patterns than patents that

[13] Note that the estimated coefficient of this dummy has no interpretation in itself. Instead of zero, we could also have imputed a different number than zero, and the estimate of the slope coefficient of the share of X and Y citations would be numerically identical. Then the dummy variable would just have a different coefficient due to the arbitrary choice of the imputation value.

[14] Note that it might appear as a conceptual problem that forward citations only occur chronologically after the assignment of a patent. However, this potential conceptual problem is common to all studies using such measures. Therefore, scholars typically do not claim investigating causality but only analyze multivariate correlations as we do here.

[15] There is no obvious cut-off point for forward citations. However, most citations at the EPO are garnered before the fifth year (see e.g. Webb et al. 2005).

remain in the scientific sector. More precisely, we expect patents in the scientific sector to be cited later than corporate patents (Sampat et al. 2003). The nature of early and late citations has been found to be different (Lanjouw and Schankerman 2004). While early citations (in the first 5 years after the patent application) correlate with the importance and economic value of patents, later citations are only weakly correlated with economic value but can be seen as an indication for the science-basedness of patents (Sampat et al. 2003). The more basic the patented invention is the longer it takes to be understood and used by others.

When a patent does not have any forward citations, we set the ratio to zero, and add a dummy that takes the value one for patents with no forward citations and zero otherwise. This is analogous to the procedure done for the backward citations.

The grant lag (in years) measures the time elapsed between the dates of grant and application of a focal patent. The duration of the examination procedure is, among other things, influenced by the inherent complexityof the invention and the novelty of the technology (Harhoff and Wagner 2005).

Patents in emerging technologies will therefore have a greater grant lag, and longer pendencies will then presumably reflect patents in nascent technology fields. For example, Popp et al. (2004) find that applications in newer, more complex technologies take significantly longer than other patent applications in the examination procedure. With increasing complexity (and thus longer grant lags), we would expect a higher probability of assignment to "science".

Non-patent references (NPR) indicate that the examiner (or in rare cases the inventor) inserted at least one citation to the non-patent literature into the search report. While the meaning of NPRs is not unambiguous, there is some recognition of their use as an indicator of science-technology linkages (Callaert et al. 2004; Meyer 2000; Schmoch 1997). Therefore, patents containing NPRs may reflect inventions resulting from scientific research and thus further away from market applications. Thus, the probability of patents assigned to "science" should be higher if the references include NPRs.

3.2.3 Patent scope

Following Lerner (1994), we use the number of international patent classes (IPC), at the 4-digit level, assigned to the patent as a measure of patent scope. The number of IPC assignments is a proxy for the complexity of the invention (Harhoff and Wagner 2009). Trajtenberg et al. (1997) argue that the synthesis of divergent ideas is characteristic of research that is highly original and therefore more basic. Thus, the broader the scope of a patent is, the higher the expected likelihood of assignment to "science".

3.2.4 Number of inventors

We also include the number of inventors listed on the patent application in order to control for the scope of the project.

3.2.5 Technology classes

We include 30 technology class dummies since some technologies, especially in emerging fields, might by nature be more likely to be assigned to the one or the other type of organization. We use the so-called OST-INPI/FhG-ISI classification, which is based on a concordance with IPC assignments.

3.2.6 Application years

Finally, we also include dummies for each application year, to control for any remaining unobserved economic fluctuation over time.

3.3 Descriptive statistics

Table 1 provides descriptive statistics of the variables used in the multivariate analysis. Several patterns stand out from the comparison of academic patents by type of assignee. Academic patents assigned to corporations receive, on average, more forward citations than patents assigned to any other type of assignee up to five years after their publication. However, academic applicants receive more citations than the corporate ones after this period of 5 years has elapsed. This pattern is in line with the interpretation of late citations as an indication for the science intensity of patented technologies. In addition, corporate patents seem to have a higher “blocking potential” as measured by the share of forward X and Y citations. Academic patents assigned to Public Research Institutes (PRI) are more likely to cite non-patent references than patents assigned to other assignees, suggesting stronger scientific ties. The measures of complexity (grant lag and number of IPC assignments), have a higher average value for non-corporate organizations. Patents assigned to universities are included in the group of academic applicants, as there are only 18 of such cases over the period we study. Finally, patents assigned to corporations list more inventors; this was expected as firms have more resources than academic assignee to devote to a given project. In the appendix, we also present results of tests on mean differences of all variables as well as a correlation matrix.

Table 1 Descriptive statistics: academic patents by type of assignee

	Corporate assignee		Academic appl.		PRI	
	Mean	SD	Mean	SD	Mean	SD
# Backward citations	3.556	2.312	4.315	2.574	3.603	2.432
Share of X&Y backward citations	0.268	0.363	0.286	0.359	0.233	0.338
# Backward citations = 0	0.053	0.224	0.023	0.151	0.068	0.252
# Forward citations (≤5 years)	1.140	2.001	0.662	1.159	0.702	1.212
# Forward citations (>5 years)	1.755	2.807	2.280	3.038	1.612	2.262
Share of forward X&Y citations (≤5 years)	0.183	0.339	0.110	0.291	0.093	0.263
Share of forward X&Y citations (>5 years)	0.053	0.176	0.063	0.196	0.053	0.171
# Forward citations = 0	0.265	0.441	0.252	0.435	0.283	0.451
Non-patent reference	0.369	0.483	0.279	0.449	0.,434	0.496
# IPC assignments	1.679	0.847	1.567	0.875	1.738	0.976
Grant lag	4.303	1.657	4.639	1.702	4.431	1.651
# Inventors	3.709	2.147	1.868	1.305	3.193	1.583
# Observations	3,740		559		325	

4 Empirical results

4.1 Binary model of patent assignment

As a first step in our analysis, we regress patent characteristics on a binary variable of assignment that takes on the value one if the patent was assigned to a corporation and zero if the patent is owned by a PRI, by the academic inventor, or by a university. We first estimate the model once without the measures referring to forward citations received after 5 years, and then include these measures in a modified specification (see Table 2). As the distinction between short term citations (less than 6 years) and long term citations (more than 5 years) is not standard in the literature, we thought it is interesting to compare the two specifications.

The results reveal that backward citation measures have a poor predictive power, as none of the three backward looking measures is significant. However, forward looking measures have a higher explanatory power; "important" patents, those with a high number of forward citations (up to 5 years after publication), are more likely to be assigned to corporations.

Patents with potential "blocking power", those with a high share of forward X and Y citations, are more likely to be assigned to corporations, too. This result was expected as corporate entities might be more interested in blocking the development of similar technologies by potential rivals. Patents with stronger scientific ties, as measured by the presence of at least one reference to the non-patent literature, are less likely to be assigned to corporations and more likely to be assigned to the group of scientific assignees. This is

Table 2 Binary probit model of assignment to a corporation (4,624 obs.)

	A			B		
	Coeff.	SE	Marg. Eff.	Coeff.	SE	Marg. Eff.
Log # backward citations	−0.018	0.046	−0.003	−0.010	0.046	0.009
Share of X&Y backward citations	0.004	0.076	0.001	0.014	0.076	0.014
# Backward citations = 0	−0.037	0.129	−0.007	−0.043	0.129	0.026
Log # forward citations (≤5 years)	0.259**	0.134	0.049	0.315**	0.135	0.025
Log # forward citations (>5 years)				−0.128***	0.047	0.009
Share of forward X&Y citations (≤5 years)	0.214**	0.104	0.041	0.268***	0.097	0.018
Share of forward X&Y citations (>5 years)				−0.062	0.147	0.028
# Forward citations = 0	−0.063	0.060	−0.012	−0.051	0.076	0.015
NPR	−0.035	0.062	−0.007	−0.026	0.062	0.012
# IPC assignments	−0.107***	0.030	−0.020	−0.102***	0.030	0.006
Grant lag	−0.065***	0.016	−0.012	−0.063***	0.016	0.003
# Inventors	0.222***	0.017	0.042	0.223***	0.017	0.003
Constant	0.754*	0.424		0.813*	0.427	
Appl. years—test of joint significance	$\chi2$ (22) = 43.81***			$\chi2$ (22) = 44.22***		
Tech. classes—test of joint significance	$\chi2$ (28) = 310.51***			$\chi2$ (28) = 221.41***		

*** (**, *) indicate a significance level of 1% (5%, 10%). Marginal effects are computed by holding all other variables constant at their mean. For dummy variables, we show the change in probability of each outcome type induced by a one-unit change in the right-hand side dummy variable likely to reflect the fact that these inventions result from scientific research and are thus further away from market applications and therefore of lower immediate interest to corporations. Finally, both measures of complexity (number of IPC assignments and the grant lag), exhibit a negative effect on the probability of corporate assignment. Similarly to the references to the non-patent literature, these variables are likely to proxy for more basic research.

In Panel B, we introduce the number of forward citations received after 5 years. The results reveal that patents that are cited later (i.e. after 5 years) are more likely to be assigned to "science" rather than corporations. This confirms our presumption that corporations tend to source knowledge which yields immediate returns and tend to ignore more basic patents that result in later applications.

4.2 Multinomial model of patent assignment

Next, we estimate the probability of academic patent assignment using a multinomial logit model. The aim is to distinguish between the different types of scientific assignees versus firm assignees. In Table 3, we show the change in probability of assignment for each type of organization induced by marginal changes in each of the right-hand side variables, such that the rows in the table sum up to zero. Technology classes are aggregated in six broader areas and application years are included biennially to account for the low number of observations in some of the categories. As before, university assignment is included in the "academic applicant" type of assignment. Table 4 is analogous to the previous regression, but includes the measures accounting for forward citations received after 5 years.

Similarly to the probit model, there is no significant correlation between backward looking citation measures and assignment. The number of forward citations correlates positively with corporate assignment and negatively with PRI ownership. However, later

Table 3 Multinomial logit model on type of assignee

	Corporation		Acad. Appl.		PRI	
	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE
Log # backward citations	−0.007	0.008	0.007	0.005	0.000	0.006
Share of X&Y backward citations	0.008	0.013	0.006	0.008	−0.014	0.011
# Backward citations = 0	0.011	0.021	−0.019	0.012	0.008	0.017
Log # forward citations (≤5 years)	0.052**	0.026	−0.010	0.014	−0.042*	0.023
Share of forward X&Y citations (≤5 years)	0.039**	0.019	−0.007	0.012	−0.032**	0.016
# Forward citations = 0	−0.018*	0.010	0.012*	0.007	0.007	0.008
NPR	−0.024**	0.011	−0.006	0.006	0.030***	0.009
# IPC assignments	−0.014***	0.005	0.007**	0.003	0.007*	0.004
Grant lag	−0.014***	0.003	0.008***	0.002	0.006***	0.002
# Inventors	0.045***	0.003	−0.042***	0.002	−0.003	0.002
Appl. year dummies	Included		Included		Included	
Tech. class dummies	Included		Included		Included	
# Observations	4,624					

*** (**, *) indicate a significance level of 1% (5%, 10%). Marginal effects are computed by holding all other variables constant at their mean. For dummy variables, we show the change in probability of each outcome type induced by a discrete change from zero to one in the right-hand side dummy variable

Table 4 Multinomial logit model on type of assignee (incl. forward citations received after 5 years as regressor)

	Corporation		Acad. Appl.		PRI	
	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE
Log # backward citations	−0.005	0.008	0.005	0.005	0.000	0.006
Share of X&Y backward citations	0.010	0.013	0.004	0.008	−0.014	0.011
# Backward citations = 0	0.010	0.021	−0.018	0.012	0.008	0.018
Log # forward citations (≤5 years)	0.064**	0.026	−0.019	0.014	−0.045**	0.023
Log # forward citations (>5 years)	−0.028***	0.008	0.024***	0.005	0.004	0.007
Share of forward X&Y citations (≤5 years)	0.058***	0.018	−0.017*	0.010	−0.040***	0.015
Share of forward X&Y citations (>5 years)	0.001	0.025	0.015	0.014	−0.016	0.021
# Forward citations = 0	−0.008	0.013	0.010	0.009	−0.002	0.010
NPR	−0.023**	0.011	−0.007	0.006	0.030***	0.009
# IPC assignments	−0.013**	0.005	0.006*	0.003	0.007*	0.004
Grant lag	−0.013***	0.003	0.008***	0.002	0.006***	0.002
# Inventors	0.044***	0.003	−0.041***	0.002	−0.003*	0.002
Appl. year dummies	Included		Included		Included	
Tech. class dummies	Included		Included		Included	
# Observations	4,624					

*** (**, *) indicate a significance level of 1% (5%, 10%). Marginal effects are computed by holding all other variables constant at their mean. For dummy variables, we show the change in probability of each outcome type induced by a discrete change from zero to one in the right-hand side dummy variable

citations have a negative impact on firm assignment and a positive one on academic ownership. These results confirm that patents that are further away from the market are less likely to be assigned to corporate entities, and more likely to be assigned to one of the scientific assignees. This result is confirmed by the effect of the complexity measures. Patents with NPRs or those that embed more complex technologies (measured by the grant lag and the number of IPC assignments) are negatively correlated with corporate assignment.

Our results confirm the set of predictions outlined in Sect. 3. Overall, patents with short-run value as proxied by the number of forward citations received within 5 years are more likely to be assigned to corporations as do patents with high blocking potential, as measured by the share of X and Y forward citations. On the other hand, inventions that are further away from market applications are more likely to be assigned to “science”. This situation might be detrimental to firms’ global competitiveness, since these patents might be highly valuable in the long run. Basic and complex knowledge may unlock and open new technological paths with potential applications that are far away from market applications. The underlying patents are therefore likely to be cited later. Hall et al. (2005) find that “unexpected” late citations (those not predicted by early citations) are strongly correlated with the market value of firms. Our result confirms that corporations tend to source (patented) knowledge from academia that is likely to yield immediate and more likely returns and tend to shy away from applications that are still further away from market applications.

It is assumed in the multinomial logit model that the disturbances for each category are independent. We tested the Irrelevance of Independent Alternatives (IIA) assumption using the Hausman-McFadden (1984) and the Small-Hsiao (1985) tests. The Hausman test was inconclusive in most cases whereas the Small-Hsiao test does not reject independence across categories, supporting the IIA assumption. To complement these results, we also performed Likelihood-Ratio (LR) tests of combing alternatives in order to determine whether certain categories can be collapsed. In both models, the LR tests (for all pairs of outcome categories) strongly reject the hypothesis that alternatives can be collapsed.

5 Conclusion

Knowledge transfer from science to industry has been shown to be beneficial for the corporate partner in terms of increased R&D productivity (Henderson et al. 1998), enhanced patent quality (Cassiman et al. 2008) and reduced labor cost (Stern 2004). In order to get a better understanding of the reasons behind these positive effects, this study focuses on the junction of science and industry and investigates the characteristics of academic inventions that go directly to industry.

Based on an empirical analysis of German academic patents the results show that academic patents that enable firms to reap short-term returns rather than possibly more uncertain long-term returns are most likely to be assigned to corporations. Firms also strive for academic inventions with a high blocking potential in technology markets. Academic patents issued to corporations appear to reflect less complex inventions as compared to inventions that are patented by the science sector.

These findings are of interest for European policy makers and technology transfer managers. Since the abolishment of the “professors’ privilege” European universities are responsible for technology transfer from science to industry. Most universities in Europe had therefore no experience and no professional TTO. Our results can inform universities and their TTOs on the technological needs or preferences of industry partners. In a similar vein, our findings can be interesting for European policy makers that define programs to support industry-science collaborations. It should be questioned whether current policy practices support collaborations involving more basic and generic research between universities and corporations, or whether current programs for technology transfer are mainly targeted at projects which are similar to pure corporate R&D. In the latter case, the policies might not capture the basic research for transfer that is conducted in public science.

Lastly, the fact that academic inventions assigned to corporations differ significantly from other academic inventions in many perspectives raises the question to which extent increased commercialization activities of universities will shift the academic research directions towards industry needs. In combination with the reasoning on current policy instruments mentioned above, it may lead to dramatic changes in university research if technology transfer is further intensified (see also Azoulay et al. 2009). It is questionable whether it is a successful long-term strategy to focus on short-term benefits from science rather than aiming for the adoption of more complex and more basic university technologies within technology transfer policies.

Related to the arguments above, it would certainly be interesting to extend our study towards the characteristics of the academic inventor and his or her associated institution. As most academic patents were not assigned to universities until recently, we could not trace the employers of the academic scientists. However, it would be instructive for policy which type of academic inventor engages in technology transfer and which institutions transfer which type of inventions to industry in Europe.[16] For instance, it could be the case that lower quality universities or less professionally managed institutions assign inventions more frequently to corporations whereas others exploit the economic value of inventions themselves.

Our analysis is not without limitations. We do not claim that the identified relationship between the patent characteristics and assigneeship are causal. Instead, we identify multivariate correlations. In order to infer causality we would, first, have to know at which stage of the academic R&D process firms and professors contact each other, and second, find instrumental variables to account for a potential reverse causality between assigneeship and patent characteristics. Given the data at hand this is unfortunately not possible. It would require in-depth knowledge about the negotiation process between corporations and the TTOs and/or academic inventors as well as insights into the contractual agreements among parties.

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Appendix

See Tables 5, 6, and 7.

Table 5 Technology classes

Field	OST technology class	# Academic patents	% of total
	I Electricity—electronics	370	7,81
1	Electrical devices—electrical engineering	160	
2	Audiovisual technology	48	
3	Telecommunications	95	
4	Information technology	36	
5	Semiconductors	31	
	II Instruments	841	17,75
6	Optics	87	
7	Analysis, measurement, control	350	
8	Medical engineering	404	
	III Chemicals, pharmaceuticals	2.102	44,37
9	Organic fine chemicals	1.013	
10	Macromolecular chemistry, polymers	194	
11	Pharmaceuticals, cosmetics	321	
12	Biotechnology	261	
13	Materials, metallurgy	269	
14	Agriculture, food	44	
	IV Process engineering	788	16,64
15	General technological processes	45	

[16] For the U.S., Link et al. (2007) show that in particular tenured and research-grant active university scientists engage in technology transfer without involvement of the U.S. TTOs.

Table 5 continued

Field	OST technology class	# Academic patents	% of total
16	Surfaces, coatings	110	
17	Material processing	191	
18	Thermal techniques	84	
19	Basic chemical processing, petrol	187	
20	Environment, pollution	171	
	V Mechanical engineering	502	10,60
21	Mechanical tools	108	
22	Engines, pumps, turbines	59	
23	Mechanical elements	126	
24	Handling, printing	62	
25	Agriculture and food machinery	29	
26	Transport	96	
27	Nuclear engineering	22	
28	Space technology, weapons	0	
	VI Other	134	2,83
29	Consumer goods and equipment	56	
30	Civil engineering, building, mining	78	
	Total	4737	100

Table 6 *t*-Tests on mean differences

	Corp. vs. acad.	Corp. vs. PRI	PRI vs. acad
# Backward citations	−0.759***	−0.047	−0.712***
Share of X&Y backward citations	−0.018	0.035*	−0.053**
# Backward citations = 0	0.030***	−0.015	0.044***
# Forward citations (≤5 years)	0.478***	0.438***	0.040
# Forward citations (>5 years)	−0.525***	0.143	−0.669***
Share of forward X&Y citations (≤5 years)	0.073***	0.090***	−0.017
Share of forward X&Y citations (>5 years)	−0.010	0.000	−0.010
# Forward citations = 0	0.012	−0.018	0.031
Non-patent reference	0.090***	−0.065**	0.155***
# IPC assignments	0.112***	−0.059	0.171***
Grant lag	−0.336***	−0.128	−0.208*
# Inventors	1.841***	0.515***	1.326***

The numbers in the table reflect the mean differences between the respective assignee types (compare to Table 1)

The asterisks *** (**, *) denote a 1% (5%, 10%) significance level of *t* tests on mean differences

Table 7 Bivariate correlations

		1	2	3	4	5	6	7	8	9	10	11
1	# Backward citations	1										
2	Share of X&Y backward citations	0.127*	1									
3	# Backward citations = 0	−0.354*	−0.170*	1								
4	# Forward citations (≤5 years)	0.010	0.015	−0.014	1							
5	# Forward citations (>5 years)	0.040*	0.020	−0.020	0.344*	1						
6	Share of forward X&Y citations (≤ 5 years)	0.019	0.069*	−0.003	0.353*	0.146*	1					
7	Share of forward X&Y citations (>5 years)	0.019	0.020	0.009	−0.086*	0.079*	−0.144*	1				
8	# Forward citations = 0	−0.029	−0.033*	0.003	−0.319*	−0.388*	−0.283*	−0.185*	1			
9	Non-patent reference	−0.295*	0.030*	0.275*	0.027	0.023	0.034*	0.019	−0.016	1		
10	# IPC assignments	−0.035*	−0.005	0.021	0.114*	0.049*	0.058*	0.004	−0.040*	0.077*	1	
11	Grant lag	0.062*	0.180*	0.036*	0.050*	0.049*	0.058*	−0.022	−0.011	0.113*	0.061*	1
12	# Inventors	−0.081*	0.015	−0.001	0.188*	0.017	0.119*	0.001	−0.042*	0.005	0.180*	0.036*

* Indicates significance at the 5% level

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