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Non-technical summary

It is largely documented that public science has a positive impact on industrial innovation. Previous studies, for instance, provide evidence for enhanced corporate patenting and improved new product and process development in the corporate sector through scientific research results. However, most of these empirical studies focus on the U.S.

For the European Economic Area, scholars and policy makers are rather sceptical with respect to emphasizing a large impact of science on corporate innovation: it has been claimed for about a decade that a so-called "European Paradox" exists. It describes the phenomenon that EU countries play a leading global role in terms of top-level scientific output, but lag behind in the ability of converting this strength into wealth-generating innovations in the business sector.

In this paper, we investigate the nexus between science and industry in order to identify potential problems of technology transfer from academia to industry in the European area. Focusing on the "paper trail" from academia to industry in terms of patent applications, we compare academic inventions that are patented in the scientific domain with those that are directly transferred to industry and hence, although invented by an academic patented by a firm.

Our analysis of a sample of more than 4000 academic inventions by German professors suggests that there is indeed potential for improving science-industry interactions in Europe. Concretely, our results show that academic inventions assigned to corporations are rather applied and associated with short-run profits, while academic inventions patented by the academic sector are rather complex and exhibit a higher long-term value. This suggests that firms miss the opportunity to invest in basic technologies that promise higher returns in the long run. We interpret this finding as a lack of absorptive capacity by corporations that do not succeed in identifying and exploiting basic university inventions.

Das Wichtigste in Kürze (Summary in German)

Die einschlägige akademische Literatur dokumentiert weitreichend den positiven Einfluss von Universitäten und außeruniversitären Forschungseinrichtungen auf das Innovationsverhalten von Unternehmen. Dabei beziehen sich die meisten dieser Studien jedoch auf den nordamerikanischen Wirtschaftsraum.

Mit Blick auf Europa zeigen sich sowohl Wirtschaftswissenschaftler als auch politische Entscheidungsträger skeptisch, wenn es darum geht, den Technologietransfer vom öffentlichen Sektor in die Industrie zu bewerten. Oftmals ist sogar von einem „Europäischen Paradox“ die Rede. Dieser Term bezeichnet die Mutmaßung, dass in Europa zwar akademische Spitzenforschung stattfindet, diese jedoch nicht den Weg in die Industrie, und somit in kommerzielle Innovationen, findet.

Die vorliegende Studie befasst sich mit dem Technologietransfer an der Schnittstelle zwischen dem öffentlichem Wissenschaftssektor und der Industrie. Ein eingehender Vergleich von akademischen Erfindungen, die im öffentlichem Sektor patentiert werden, mit solchen, die direkt von der Wirtschaft als Patent angemeldet werden, zeigt auf, dass es sich hierbei um weitgehend verschiedene Arten von akademischen Erfindungen handelt.

Basierend auf einer Stichprobe von mehr als 4000 Erfindungen deutscher Hochschulprofessoren zeigen wir, dass das Technologietransferpotential, das der öffentlichem Wissenschaftssektor bietet, von der Industrie nicht voll ausgeschöpft wird. Konkret legen unsere Ergebnisse nahe, dass Unternehmen in der freien Wirtschaft angewandte akademische Erfindungen bevorzugen, die einen kurzfristigen Gewinn versprechen, während sie vor dem Erwerb komplexer akademischer Erfindungen, deren technologisches Potential sich erst in der langen Frist realisiert, zurückschrecken. Dies legt nahe, dass Industrieunternehmen im Europäischen Wirtschaftraum nicht über die notwendigen Kapazitäten verfügen, um solche vielversprechenden Erfindungen zu identifizieren und/oder sich das patentierte Wissen anzueignen, um es in langfristige Wettbewerbsfähigkeit, Gewinne oder Unternehmenswachstum zu transferieren.

The Nexus Between Science and Industry: Evidence From Faculty Inventions[1]

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Abstract

Against the background of the so-called "European paradox", i.e. the conjecture that EU countries lack the capability to transfer science into commercial innovations, knowledge transfer from academia to industry has been a central issue in policy debates recently. Based on a sample of German scientists we investigate which academic inventions are patented by a scientific assignee and which are owned by corporate entities. Our findings suggest that faculty patents assigned to corporations exhibit a higher short-term value in terms of forward citations and a higher potential to block property rights of competitors. Faculty patents assigned to academic inventors or to public research institutions, in contrast, are more complex, more basic and have stronger links to science. These results may suggest that European firms lack the absorptive capacity to identify and exploit academic inventions that are further away from market applications.

Keywords: academic inventors; university-industry technology transfer; intellectual property rights

JEL-Classification: O31, O32, O34

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1 Introduction

Assessing the impact of public science on industrial innovation has been discussed among economic scholars, professionals and policy makers since decades. Previous studies suggest a positive impact of research results produced in the public science sector on corporate patenting (Jaffe, 1989), productivity growth (Adams, 1990), new product and process development in firms (Cohen et al., 2002, Toole, 2007), and even the emergence of entirely new industries (Zucker and Darby, 1996, Zucker et al., 1998). While the literature clearly establishes a positive relationship between investment in public science and (long-term) economic returns for a variety of dimensions and channels through which academe contributes to welfare this evidence is largely based on the United States.

For the European Economic Area, in contrast, it has been claimed for about a decade that a so-called "European Paradox" exists (European Commission, 1995). Scholars argued that EU countries play a leading global role in terms of top-level scientific output, but lag behind in the ability of converting this strength into wealth-generating innovations. A highly critical review of the "paradox" and its subsequent possibly misguided policies can be found in Dosi et al. (2006). The authors claim that no overall "European Paradox" with leading science but weak downstream firms can be observed.[2] Rather significant weaknesses occur in both sectors European public science and industry.

In this paper, we focus on the nexus between science and industry and provide an in-depth analysis of academic inventions that are transferred to corporations. We compare academic inventions that remain in the scientific domain with those that are directly transferred to industry. We show that there are systematic differences between both types of academic inventions. These findings contribute to our

[2] The different conclusions about Europe's scientific performance arise from different aggregate measures used in the different studies. While the European Commission (1995) focuses on the number of publication per non-BERD (Business Enterprises Expenditure on Research and Development), Dosi et al. (2006) use scientific publications per population as well as citations and top 1% publications per population to account for publication quality. They find that in particular the quality weighted measures show a gap between Europe and the U.S. It is debatable which benchmark for the scientific outcome is the most appropriate.

understanding of academic technology transfer and potential reasons behind the European paradox.

Our analysis is based on the "paper trail" from academia to industry. As has been suggested by Thursby et al. (2009) we focus on patents that protect inventions of university faculty members. Academic patents can be assigned to corporations or to scientific entities (the academic inventor, public research institutes or universities). According to Thursby et al. (2009) academic inventions patented by the business sector represent consulting activities that did not involve university resources. For the U.S., the share of university inventions that is patented solely by corporations accounts for 26%. For Europe, this share is much higher, on average, with up to 80% for Sweden (Lissoni et al., 2008). The difference is explained by the fact that, unlike in the U.S. where universities may claim the property rights of their patented inventions since the Bayh-Dole Act of 1980, academic inventions in most European countries were owned by the faculty inventors themselves until recently. In consequence, German university professors, for instance, typically commercialized their research through consultancy agreements with industry partners, through "more or less private deals" (Goddar, 2006). The financial benefits for the professor were either already 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, 2006).[3]

The fact that the majority of European academic inventions reach industry directly is important for our study as it allows us to claim that we analyze one of the important science-industry technology transfer channels. Although there is the possibility that patents owned by academe may be licensed out to corporations, university licensing occurs only occasionally in Europe. In 2006, European TTOs had on average only

[3] 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).

11.2 licenses, only 2.3 of which yielded a licensing revenue for the university (ProTon, 2006).[4]

Focusing on patented academic inventions our analysis aims at investigating which of these inventions are issued to “scientific organizations” and which are directly owned by corporate entities.[5] We estimate probability models for patent assignment in order to investigate whether basic academic inventions which are further away from market applications are transferred to the business sector or whether firms rather focus on short-term profits and solutions to topical problems when acquiring academic inventions. The ability to identify, acquire and exploit academic knowledge in Europe’s industry sector has been claimed to be weak (Dosi et al., 2006). In the absence of a certain degree of absorptive capacity firms are not capable to benefit from complex and fundamental scientific input. Our results are in favour of this hypothesis. Our analysis suggests that firms strive for short-term profits when acquiring scientific knowledge and that they are reluctant to acquire basic technologies. We interpret this finding as a lack of absorptive capacity in the business sector, on average. Corporations do not succeed in identifying and exploiting basic university inventions.

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; section 3 summarizes our data; section 4 shows the empirical results and the final section concludes.

2 Background

2.1 Institutional Background

It has been claimed for about a decade that a so-called “European Paradox” exists. This paradox was first mentioned in a green paper on innovation published by the

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[4] 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.

[5] 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.

European Commission (1995), in which the authors argue that EU countries play a leading global role in terms of top-level scientific output, but lag behind other industrialized nations in the ability of converting this strength into wealth-generating innovations. The reasoning given by most scholars is that European academic research is lagging behind the U.S. in several areas, and that European industry is relatively weak in some key technology areas that are important for future global competitiveness (Dosi et al., 2006). For instance, Europe shows lower presence in information and communication technologies and biotechnologies, has a lower propensity to innovate, and relatively weak participation in global oligopolies.

The "European paradox" initiated significant policy initiatives towards enhancing technology transfer from science to industry. The assumption behind these policy interventions is that an increased attitude towards commercialization in public science will spur national competitiveness and wealth. The most prominent policy changes in many European countries were Bayh-Dole Act type of legislations. The Bayh-Dole Act in 1980 strengthened the patenting rights of U.S. universities (and small businesses) by granting them the right to patent and to retain ownership of their inventions even if these were financed through public resources.[6] In return, universities take over the administrative tasks associated with commercializing discoveries and they bear the financial risks of filing a patent application including patent application fees. In return, inventors get part of the licensing revenues. Recently, several European countries as for instance Germany, Denmark, and Austria followed the U.S. example and abolished the so-called professor privilege.[7] Under this exception from the law, professors were the only occupational group that had the right to claim ownership of their patented inventions, even if the underlying research was financed by the university (Kilger and Bartenbach, 2002). In consequence and as a result of a lack of professional TTOs at most European universities that would facilitate the commercialization procedure (Debackere and Veugelers, 2005), European academic inventors with an interest in commercialization did so without university involvement (Goddar, 2006, for Germany). This becomes visible in a very

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[6] Examples of studies on the effects of the U.S. Bayh-Dole Act are Henderson et al. (1998), Mowery and Ziedonis (2002), Mowery et al. (2002), and Sampat et al. (2003).

[7] Similar changes in legislation took place in the UK and Belgium (van Pottelsberghe de la Potterie, 2007) and France (della Malva et al., 2008).

low share of academic patents being assigned to European universities (Geuna and Nesta, 2006, Verspagen, 2006). For Germany, France and Italy, for instance, less than 1% of all patents are assigned to universities. The share of corporate patents with faculty involvement is, however, much higher with 2.5% for each of the countries (Verspagen, 2006). Lissoni et al. (2008) estimate that the share of academic patents directly assigned to corporations ranges from 60% to 80% in Europe, whereas licensing activities of European universities as reported by ProTon (2006) is negligibly small.[8]

The significance of these direct science-industry knowledge transfers through faculty-inventorship in combination with corporate-assigneeship notwithstanding, they have received little attention in the previous academic literature (van Pottelsberghe de la Potterie, 2007). The few previous studies on that topic are based on surveys of faculty and/or industry personnel.[9] In a recent study, Thursby et al. (2009) suggest to use academic inventions that are patented solely by corporations as a method of making such informal science-industry links visible. The authors find that about 26% of faculty patents in the U.S. are assigned to the corporate sector. Against the legal background in the U.S., one would expect that only very few academic patents are filed without the involvement of universities. In search for explanations for the high share of firm-owned faculty patents, Thursby et al. (2009) conducted interviews with TTO employees, faculty members and industry partners. The main reason given by all three groups of interview partners was that these patents are an outcome of faculty

[8] 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 invention to publish those (Goddar, 2006).

[9] The results of the Carnegie Mellon Survey show, for instance, that university consulting is very important and even relatively more important than patents and licenses from the viewpoint of industrial R&D personnel (Cohen et al., 1998). A correspondingly high share of U.S. university scientists engages in industry consulting (18%), in joint publication (16%) and commercialization activities with industry (15%) (Link et al., 2007, for university scientists and engineers with a Ph.D. at the 150 Carnegie Extensive Doctoral/Research Universities in 2004/2005). First evidence for the importance of informal links for Germany shows that informal contacts increase the effectiveness of formal industry-science links with respect to firms’ innovation performance (Grimpe and Hussinger, 2008a, based on the German Community Innovation Survey).

consulting activities, in which no university resources were used.[10] Interviews with TTO personnel further revealed that presumably less than 50% of the inventions made at universities are not commercialized through university TTOs but directly with an industry partner (Thursby et al., 2001). In their investigation of potential differences between academic inventions patented by universities themselves and those assigned to the business sector, Thursby et al. (2009) find that the university-owned academic patents correspond to rather basic inventions. They further find that inventor revenue schemes at universities impact their incentives to patent outside the university. Lastly, there are differences across scientific fields and the type of the university, i.e. whether it is public or private.

In this paper, we follow Thursby et al. (2009) by investigating differences in academic patents assigned to science and corporations. Academic inventions are considered to be among the most important sources of knowledge for innovation activities in the U.S. (Cohen et al., 2002) and Europe (Arundel and Geuna, 2004). Against the background of Europe's presumed difficulties of transferring knowledge into commercially successful innovation, our analysis contributes to the understanding of the reasons for the European paradox.

2.2 Technological complexity of academic patents and absorptive capacity of industry partners

Previous literature has documented that the nature of inventions produced in academia differs significantly from corporate inventions. While industry R&D is directed at commercial success, university research focuses on solving fundamental science questions (Trajtenberg et al., 1997). Scientific research aims at developing and testing theories in order to understand why certain phenomena occur. The results enable predictions for untried experiments. Also, the research process in both sectors differs. Academic research relies on a vivid discussion of earlier research results including a careful documentation of trial and error of the experiments taken out. Industry

[10] A different reasoning for the high percentage of university-invented patents that are assigned to the corporate sector is given by Herzfeld et al. (2006). The authors interviewed the responsible persons for negotiating intellectual property of 54 R&D intensive U.S. firms. The results show that firms have great difficulties in dealing with TTOs on intellectual property issues arising from inexperience and a lack of business knowledge of TTO employees as well as from their tendency to inflate the commercial potential of their patents. Herzfeld et al. (2006) conclude that firms would try to by-pass the TTO if possible and engage directly with the university scientist or engineer.

research is mainly focused on exploitation of existing technologies in order to increase profits, e.g. by altering one component of an existing invention (Fleming and Sorensen, 2004).

Previous studies have shown that acquisition of scientific research is beneficial for firms, as becomes for instance visible in increased R&D productivity (Henderson and Cockburn, 1998), enhanced patent quality (Cassiman et al., 2008) and reduced labor cost (Stern, 1999). Explanations for these beneficial effects of science in industry include 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 Sorensen, 2004, Dasgupta and David, 1994, Hall et al., 2003, Crespi et al., 2006) or that university research has a higher importance for future technological development (Henderson et al., 1998).

Scientific knowledge, however, cannot be absorbed by the firms without efforts. In order to benefit from science firms need to be able to identify, assimilate and exploit the relevant knowledge. In other words, a certain degree of "absorptive capacity" (Cohen and Levinthal, 1989) is crucial for the transformation of scientific knowledge into innovations and higher firm performance (Hall et al., 2003, Fabrizio, 2009). The appropriation and exploitation of scientific results is not trivial as research is typically presented in a codified way so that the reader might not be provided with enough knowledge to utilize the research in the absence of related tacit knowledge (Dasgupta and David, 1994). Furthermore, research-related knowledge often resides with the researcher and is difficult to be transferred (von Hippel, 1994). Hence, industry partners need a certain level of in-house scientific competence in order to be able to successfully adapt scientific know-how (Fabrizio, 2009).

In the European context, where industry is considered to be weak as compared to the U.S. (Dosi et al., 2006), corporations might lack the absorptive capacity that is necessary for the identification and exploitation of basic and science-intensive academic inventions although those have been found to exhibit a higher monetary value (Harhoff et al., 2003). Hence, we hypothesize that European firms are reluctant to acquire complex and science-intense university inventions and rather focus on technologies with an immediate commercialization potential and the power to block rivals. Patents can be used to block competitors' innovation activities as they grant the holder the right to exclude third parties from using the protected technology (Cohen et al., 2000, Blind et al., 2009). Accordingly, control over key patents can be an essential factor to maintain or enhance a firm's position in technology markets. In the context of firm acquisitions, acquiring firms pay a significant premium for a patent portfolio which has the potential to deter entry into technology markets (Grimpe and Hussinger, 2008b). In fact, the blocking potential of a patent portfolio is at least as important for acquiring firms as its "building potential"[11], especially if the acquired patents are technologically related to the acquirer's patent portfolio (Grimpe and Hussinger, 2008c).

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 for 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

[11] The building potential is defined as the contribution of the patent portfolio to the state of the art in a certain technology field.

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 a 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.

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. More precisely, we searched all patent applications that have an EPO equivalent at the GPTO and that list professors as inventors. We found only 112 applications in which the GPTO patent listed a professor, but not the equivalent EPO patent over the period 1990-2001.

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 also created a residual category for patents that were assigned to any other party than the aforementioned ones (mainly individuals without a professor title or government agencies). Finally, we deleted 89 patents which listed more than one type of assignee, leaving us with 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. In doing so, 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.

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 patent 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.

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:

- "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.

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). In this paper we use citation data from the EPO that has been made recently available in machine readable format by the EPO and the OECD. The high correlation between the number of forward citations to EPO patents with patent value has been documented by Gambardella et al. (2008).

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, 2008b,c), 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 five years after publication. Second, we also include the number of citations received from the fifth year onward. The reason is that we expect the patents assigned to corporations to have different citation patterns than patents that 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 five 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.

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 complexity of 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. This type of research is expected to increase the 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 fundamental research and thus further away from market applications, which suggests increasing probability of assignment to "science".

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, 2006). Thus, the broader the scope of a patent is, the higher the expected likelihood of assignment to "science".

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.

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.

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

Tables 1 and 2 provide an overview 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 five years has elapsed. This pattern is in line with the interpretation of late citation 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.

Table 1: Descriptive statistics: academic patent applications (1978-2000)

	Mean	S.D.	Min.	Max.
# backward citations	3.671	2.378	0	19
share of X&Y backward citations	0.268	0.360	0	1
# forward citations (<5 years)	1.045	1.875	0	30
# forward citations (>5 years)	1.804	2.793	0	45
Share of forward X&Y citations (<5 years)	0.167	0.330	0	1
Share of forward X&Y citations (>5 years)	0.055	0.178	0	1
NPR	0.361	0.480	0	1
# IPC assignments	1.670	0.862	1	11
Grant lag	4.350	1.673	1	15
# inventors	3.435	2.104	1	21
# observations		4737		

Table 2: Descriptive statistics: academic patents by type of assignee

	Corporate assignee		Academic appl.		PRI		Others	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
# backward citations	3,556	2,312	4,315	2,574	3,603	2,432	4,345	2,780
share of X&Y backward citations	0,268	0,363	0,286	0,359	0,233	0,338	0,280	0,357
# forward citations (<5 years)	1,140	2,001	0,662	1,159	0,702	1,212	0,938	1,734
# forward citations (>5 years)	1.755	2.807	2.280	3.038	1.612	2.262	1.628	2.184
Share of forward X&Y citations (<5 years)	0,183	0,339	0,110	0,291	0,093	0,263	0,146	0,318
Share of forward X&Y citations (>5 years)	0.053	0.176	0.063	0.196	0.053	0.171	0.062	0.173
Non-patent refernce	0,369	0,483	0,279	0,449	0,434	0,496	0,327	0,471
# IPC assignments	1,679	0,847	1,567	0,875	1,738	0,976	1,708	0,942
Grant lag	4,303	1,657	4,639	1,702	4,431	1,651	4,381	1,988
# inventors	3,709	2,147	1,868	1,305	3,193	1,583	2,832	1,546
# observations	3740		559		325		113	

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, by a university or by any other type of organization. Panels A and C in Table 3 includes the residual category “other assignee types”, while it is excluded in Panels B and D, so that the dummy takes on the value zero if the patent was assigned to a PRI, to the academic inventor or to a university. In addition, we add the number of citations received after five years in panels C and D.

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 five years after publication), are more likely to be assigned to corporations, at least when the residual category is excluded (Panel B).

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 likely to reflect the fact that these inventions result from fundamental 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 and fundamental research.

In Panels C and D we introduce the number of forward citations received after five years. The results reveal that patents that are cited later (i.e. after five 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.

Table 3: Binary probit model of assignment

	(A)				(B)			
	Coeff.		S.E.	Marg. Eff.	Coeff.		S.E.	Marg. Eff.
log # backward citations	-0.026		0.042	-0.006	-0.018		0.046	-0.003
Share of X&Y backward citations	-0.017		0.068	-0.004	0.004		0.076	0.001
# backward citations = 0	0.014		0.119	0.003	-0.037		0.129	-0.007
log # forward citations (≤ 5 years)	0.079		0.110	0.019	0.259	**	0.134	0.049
Share of forward X&Y citations (≤ 5 years)	0.206	**	0.095	0.050	0.214	**	0.104	0.041
# forward citations= 0	-0.118	**	0.055	-0.029	-0.063		0.060	-0.012
NPR	-0.080		0.056	-0.020	-0.035		0.062	-0.007
# IPC assignments	-0.105	***	0.027	-0.025	-0.107	***	0.030	-0.020
Grant lag	-0.054	***	0.015	-0.013	-0.065	***	0.016	-0.012
# inventors	0.189	***	0.015	0.046	0.222	***	0.017	0.042
Constant	0.955	**	0.42		0.754	*	0.424	
Appl. Years - test of joint significance	χ2 (22) = 53.51***				X2 (22) = 43.81***			
Tech. Classes -test of joint significance	χ2 (28) = 401.82 ***				χ2 (28) = 310.51***			
	(C)				(D)			
	Coeff.		S.E.	Marg. Eff.	Coeff.		S.E.	Marg. Eff.
log # backward citations	-0.016		0.042	0.010	-0.010		0.046	0.009
Share of X&Y backward citations	-0.004		0.068	0.017	0.014		0.076	0.014
# backward citations = 0	0.008		0.119	0.029	-0.043		0.129	0.026
log # forward citations (≤ 5 years)	0.138		0.111	0.027	0.315	**	0.135	0.025
log # forward citations (> 5 years)	-0.120	***	0.042	0.010	-0.128	***	0.047	0.009
Share of forward X&Y citations (≤ 5 years)	0.314	***	0.087	0.021	0.268	***	0.097	0.018
Share of forward X&Y citations (> 5 years)	-0.109		0.130	0.032	-0.062		0.147	0.028
# forward citations= 0	0.002		0.069	0.017	-0.051		0.076	0.015
NPR	-0.071		0.056	0.014	-0.026		0.062	0.012
# IPC assignments	-0.098	***	0.027	0.007	-0.102	***	0.030	0.006
Grant lag	-0.051	***	0.015	0.004	-0.063	***	0.016	0.003
# inventors	0.190	***	0.015	0.003	0.223	***	0.017	0.003
Constant	0.967	**	0.424		0.813	*	0.427	
Appl. Years - test of joint significance	χ2 (22) = 57.03***				X2 (22) = 44.22***			
Tech. Classes -test of joint significance	χ2 (28) = 282.14 ***				χ2 (28) = 221.41***			
# observations	4737				4624			

Note: *** (**, *) 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

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 Tables 4 and 5 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 Tables 4 and 5 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. In Table 5 and 7, patents from the residual category are excluded from the analysis, while they constitute a separate category in Table 4 and 6.

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 citations have a negative impact on firm assignment and a positive one with academic ownership. Theses 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 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 Section 2. Overall, patents with short-run value as proxied by the number of forward citations received within five 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". We interpret this result as an indication of lack of absorptive capacity from the corporate sector, as firms do not seem to utilize more fundamental academic knowledge. This situation might be detrimental to their 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.

Table 4: Multinomial logit model on type of assignee

	Corporation			Acad. Appl.			PRI			Other		
	Marg. Eff.		S.E.	Marg. Eff.		S.E.	Marg. Eff.		S.E.	Marg. Eff.		S.E.
log # backward citations	-0.011		0.008	0.007		0.005	-0.001		0.006	0.004		0.004
share of X&Y backward citations	0.006		0.014	0.006		0.008	-0.014		0.010	0.002		0.006
# backward citations = 0	0.009		0.024	-0.018		0.012	0.007		0.017	0.003		0.013
log # forward citations (<5 years)	0.041	*	0.024	-0.011		0.014	-0.043	*	0.022	0.013	*	0.008
Share of forward X&Y citations (<5 years)	0.039	*	0.020	-0.006		0.011	-0.031	**	0.016	-0.002		0.008
# forward citations= 0	-0.022	**	0.011	0.011	*	0.006	0.006		0.008	0.005		0.005
NPR	-0.029	**	0.012	-0.006		0.006	0.030	***	0.009	0.005		0.005
# IPC assignments	-0.017	***	0.006	0.006	**	0.003	0.007	*	0.004	0.004	*	0.002
Grant lag	-0.014	***	0.003	0.007	***	0.002	0.006	***	0.002	0.001		0.001
# inventors	0.047	***	0.003	-0.042	***	0.002	-0.003		0.002	-0.003	**	0.001
Appl. year dummies	Included			Included			Included			Included		
Tech. class dummies	Included			Included			Included			Included		
# observations	4737											

Note: *** (**, *) 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 5: Multinomial logit model on type of assignee (excl. the category "others")

	Corporation			Acad. Appl.			PRI		
	Marg. Eff.		S.E.	Marg. Eff.		S.E.	Marg. Eff.		S.E.
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				4624					

Note: *** (**, *) 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 6: Multinomial logit model on type of assignee

	Corporation			Acad. Appl.			PRI			Other		
	Marg. Eff.		S.E.	Marg. Eff.		S.E.	Marg. Eff.		S.E.	Marg. Eff.		S.E.
log # backward citations	-0.008		0.008	0.005		0.005	-0.001		0.006	0.004		0.004
share of X&Y backward citations	0.008		0.014	0.004		0.008	-0.014		0.011	0.002		0.006
# backward citations = 0	0.008		0.024	-0.018		0.012	0.007		0.017	0.003		0.013
log # forward citations (>5 years)	0.052	**	0.026	-0.020		0.014	-0.046	**	0.022	0.013	*	0.008
log # forward citations (<5 years)	-0.025	***	0.009	0.024	***	0.005	0.004		0.006	-0.003		0.004
Share of forward X&Y citations (<5 years)	0.061	***	0.019	-0.016		0.010	-0.039	***	0.015	-0.006		0.008
Share of forward X&Y citations (>5 years)	-0.006		0.027	0.015		0.014	-0.016		0.021	0.007		0.010
# forward citations= 0	-0.006		0.014	0.011		0.009	-0.003		0.010	-0.002		0.006
NPR	-0.028	**	0.012	-0.007		0.006	0.030	***	0.009	0.005		0.005
# IPC assignments	-0.015	***	0.006	0.005	*	0.003	0.007	*	0.004	0.003		0.002
Grant lag	-0.013	***	0.003	0.007	***	0.002	0.005	**	0.002	0.001		0.001
# inventors	0.046	***	0.003	-0.041	***	0.002	-0.003		0.002	-0.003	**	0.001
Appl. year dummies	Included			Included			Included			Included		
Tech. class dummies	Included			Included			Included			Included		
# observations	4737											

Note: *** (**, *) 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 7: Multinomial logit model on type of assignee (excl. the category "others")

	Corporation		Acad. Appl.		PRI	
	Marg. Eff.	S.E.	Marg. Eff.	S.E.	Marg. Eff.	S.E.
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			4624			

Note: *** (**, *) 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

5 Conclusion

Knowledge transfer from science to industry has been an important issue for European innovation policy during the last decades. Against the background of a European paradox, which describes the fact that top-level research in the European science sector does not translate into successful commercial exploitation, many initiatives to foster industry-science interaction have been launched. In a critical review, however, economic scholars suggest that a European paradox does not exist and that Europe's backwardness if compared to the U.S. is explained by a relatively weak performance of both science and industry in certain fields (Dosi et al., 2006). In this study we focus on the junction of science and industry and investigate which academic inventions go directly to industry. The results shed new light on technology transfer from academe to industry and support our understanding of a potential European Paradox.

Based on an empirical analysis of German academic patents we find that corporations favor collaborative agreements with academia that enable them to reap short term rather than, possibly more uncertain, long term returns. Our results further show that, in the European context, firms strive for academic inventions with a high blocking potential in technology markets. Academic patents issued to corporations appear to reflect less complex and fundamental inventions as compared to inventions that are patented by the science sector as is reflected by their forward citation pattern. The results support the argument that a weak corporate sector explains part of the European paradox. Firms seem to lack the necessary absorptive capacity that would enable them to identify and acquire the most promising scientific inventions possibly enhancing long term growth and competitiveness. As this is a necessary first step before commercialization can take place, firms and policy makers should pay attention to strengthening this stage of science-industry knowledge transfer. It is questionable whether it is a successful long-term strategy to focus on rather short-term benefits from science than aiming for the adoption of more complex and more basic university technologies.

Finally, our results raise concerns whether the increased science-industry interactions and policy efforts to support those are effective. In another study, we show that the trend towards increased commercialization in the public science sector is accompanied by a decrease in the average quality of academic inventions and that the abolishment of the German professors' privilege coincides with an acceleration of this patent quality decline (Czarnitzki et al., 2008). The fact that the average quality of academic inventions decreases over time makes it potentially more difficult for industry to identify valuable inventions. Further, the novel fact that academic scientists are ought to patent through their universities rather than directly negotiating with business partners, as inferred by the abolishment of the German professors' privilege, might have a further negative impact on science-industry collaborations. It has been argued in the U.S. context that firms face significant difficulties when dealing with TTO staff and that they prefer dealing with the scientists directly when possible (Herzfeld et al., 2006). In contrast to the U.S., professional TTOs were basically not existent in Germany and emerged only recently after the abolishment of the professors' privilege. Hence, the effects of the abolishment of the professors' privilege in the absence of a functioning system of technology transfer to industry via the university might slow down technology transfers.[12]

Our analysis is not without limitations. We do not claim that the identified relationship between the patent characteristics and assigneeship are causal. Instead, we just 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.

[12] In Germany, the Federal Ministry for Education and Research launched a large study on technology transfer in Germany in 1998/1999. Among other issues, the report found that most university TTOs have many tasks, but that they are largely understaffed to fulfill these in a professional manner. Most TTOs are only run by a single person or even on part-time basis (50% of a full-time equivalent person). See Schmoch et al. (2000) for the detailed report.

References

Adams, J.D. (1990). Fundamental Stocks of Knowledge and Productivity Growth, *Journal of Political Economy*, 98: 673-702.

Albert, M.B., Avery, D., Narin, F., and McAllister, P. (1991). Direct Validation of Citation Counts as Indicators of Industrially Important Patents. *Research Policy* 20: 251-259.

Arundel, A., Geuna, A. (2004), Proximity and the Use of Public Science by Innovative European Firms, *Economics of Innovation and New Technologies* 13 (6), 559-580.

Blind, K., Cremers, K., Müller, E (2009), The Influence of Strategic Patenting on Companies' Patent Portfolios, *Research Policy*, forthcoming.

Callaert, J., Van Looy, B., Verbeek, A., Debackere, K. Thijs, B. (2004). Traces of Prior Art: An Analysis of Non-patent References Found in Patent Documents. *Scientometrics* 69(18): 3-20.

Cassiman, B., Veugelers, R., Zuniga, M.P. (2008). In Search of Performance Effects of (in)Direct Industry Science Links. *Industrial & Corporate Change* 17(4): 611-646.

Cohen, W., Goto, A., Nagata, A., Nelson, R., Walsh, J. (2002). R&D Spillovers, Patents and the Incentives to Innovate in Japan and the United States. *Research Policy* 31: 8-41.

Cohen, W., Levinthal, D. (1989). Innovation and Learning: The two Faces of R&D. *Economic Journal* 99: 569–596.

Crespi, G.A., Geuna, A., Verspagen, B. (2006). *University IPRs and Knowledge Transfer. Is the IPR Ownership Model More Efficient?* SEWPS (SPRU Electronic Working Paper Series) No. 154, Brighton.

Czarnitzki, D., Glänzel, W., Hussinger, K. (2007). Patent and Publication Activities of German Professors: An Empirical Assessment of their Co-activity. *Research Evaluation* 16(4): 311-319.

Czarnitzki, D., Hussinger, K., Schneider, C. (2008). *Commercializing Academic Research: The Quality of Faculty Patenting*. ZEW Discussion Paper No. 08-069, Mannheim.

Dasgupta, P., David P. (1994). Towards a New Economics of Science. *Research Policy* 23: 487-521.

Dosi, G., Llerena, P., Labini, M.S. (2006). The Relationship Between Science, Technologies and their Industrial Exploitation: An Illustration Through the Myths and Realities of the So-called 'European Paradox'. *Research Policy* 35: 1450-1464.

European Commission (2005). Green Paper on Innovation. EC, Brussels.

Fabrizio, K. (2009). Absorptive Capacity and the Search for Innovation. *Research Policy*, forthcoming.

Fleming, L. and O. Sorensen (2004). Science as a Map in Technological Search. *Strategic Management Journal* 25: 909-928.

Gambardella, A., Harhoff, D., Verspagen, B. (2008). The Value of European Patents. *European Management Review* 5: 69-84.

Geuna, A., Nesta, L.J.J. (2006). University Patenting and its Effects on Academic Research: The Emerging European Evidence. *Research Policy* 35: 790–807.

Goddar, H. (2005). Recent Development in the Business of Patent Licensing – Technology Transfer from Universities and Research Institutions to Industry in Germany. *International Journal of Intellectual Property – Law, Economy and Management* 1: 19-25.

Grimpe, C., Hussinger, K. (2008a). *Formal and Informal Technology Transfer from Academia to Industry: Complementarity Effects and Innovation Performance*. ZEW Discussion Paper No. 08-080, Mannheim.

Grimpe, C., Hussinger, K. (2008b). *Building and Blocking: The Two Faces of Technology Acquisitions*. ZEW Discussion Paper No. 08-069, Mannheim.

Grimpe, C., Hussinger, K. (2008c). Pre-empting Technology Competition through Firm Acquisitions. *Economics Letters* 100: 189-191.

Guellec, D., Martinez, C., Zuniga, P. (2008). More Exclusion than Invention: Blocking Patents at Work. *mimeo*. OECD, Paris.

Hall, B.H., Harhoff, D. (2001). Intellectual Property Strategy in the Global Cosmetics Industry: A Soap Opera. *mimeo*. University of Munich.

Hall B.H., Jaffe, A., Trajtenberg, M. (2005). Market Value and Patent Citations. *RAND Journal of Economics*, 36: 16-38.

Hall, B.H., Link, A.N., Scott, J.T. (2003). Universities as Research Partners. *Journal of Economic Studies* 85: 485-491.

Harhoff, D., Narin, F., Scherer, F.M., Vopel, K. (1999). Citation Frequency and the Value of Patented Innovation. *Review of Economics and Statistics* 81(3): 511-515.

Harhoff, D., Scherer, F.M., Vopel, K. (2003). Citations, Family Size, Opposition and the Value of Patent Rights - Evidence from Germany. *Research Policy* 32: 1343-1363

Harhoff, D., Wagner, S. (2006). *Modeling the Duration of Patent Examination at the European Patent Office*. CEPR Discussion Paper No. 5283, London.

Hausman, J. And McFadden, D. (1984), “Specification tests for the Multinomial Logit Model”. *Econometrica*, 52:1219-40

Henderson R., Jaffe, A., Trajtenberg, M. (1998). Universities as a Source of Commercial Technology. *Review of Economics and Statistics* 80(1): 119-127.

Hertzfeld, H.R., Link, A.N., Vonortas, N.S. (2006). Intellectual Property Protection Mechanisms in Research Partnerships. *Research Policy* 35: 825-838.

Hippel, E. von (1994). “Sticky Information” and the Locus of Problem Solving: Implications for Innovation. *Management Science* 40(4): 429-439.

Jaffe, A., Fogarty, M.S., Trajtenberg, M. (2000). Knowledge Spillovers and Patent Citations: Evidence from a Survey of Inventors. *American Economic Review* 90: 215-218.

Jaffe, A. (1989). The Real Effects of Academic Research. *American Economic Review* 97(5): 957-907.

Kilger, C., Bartenbach, K. (2002). New Rules for German Professors. *Science* 298(8): 1173-1175.

Lanjouw, J.O., Schankerman, M. (2004). Patent Quality and Research Productivity: Measuring Innovation with Multiple Indicators. Economic Journal 114 (495): 441-465.

Lerner, J. (1994). The Importance of Patent Scope: an Empirical Analysis. *RAND Journal of Economics* 25(2): 319-333.

Link, A.N., Siegel, D.S., Bozeman, B. (2007). An Empirical Analysis of the Propensity of Academics to Engage in Informal University Technology Transfer. *Industrial & Corporate Change* 16 (4): 641-655.

Lissoni, F., Llerena, P., McKelvey, M., Sanditov, B. (2008). Academic Patenting in Europe: New Evidence from the KEINS Database. *Research Evaluation* 16: 87-102.

della Malva, A., Lissoni, F., Llerena, P. (2008). *Institutional Change and Academic Patenting: French Universities and the Innovation Act of 1999*. Document de Travail No 2008-9, BETA, Strasbourg.

Meyer, M. (2000). Does Science Push Technology? Patents Citing Scientific Literature. *Research Policy* 29: 409–434.

Mowery, D., Sampat B., Ziedonis A. (2002). Learning to Patent: Institutional Experience, Learning and the Characteristics of U.S. University Patents after the Bayh-Dole Act, 1981-1992. *Management Science* 48(1): 73-89.

Mowery, D., Ziedonis A. (2002). Academic Patenting Quality and Quantity Before and After the Bayh-Dole Act in the United States. *Research Policy* 31: 399-418.

van Pottelsberghe de la Potterie, B. (2007). Hot Patent Issues: Quantitative Evidence. In Guellec, D., van Pottelsberghe de la Potterie, B. (eds.): *The Economics of the European Patent System – IP Policy for Innovation and Competition*, Oxford: Oxford University Press: 184-215.

ProTon (2006). *The Proton Europe. Fourth Annaual Survey Report (fiscal year 2006)*: http://www.protoneurope.org/news/PatentPolicyStatement

Sampat, B., Mowery, D., Ziedonis, A. (2003). Changes in University Patent Quality after the Bayh-Dole Act: A Re-examination. *International Journal of Industrial Organization* 21(3): 1371-1390.

Schmoch, U. (1997). Indicators and the Relation between Science and Technology. *Scientometrics* 38(1): 103-116.

Schmoch, U., Licht, G., Reinhard, M. (2000). Wissens- und Technologietransfer in Deutschland, Stuttgart: Fraunhofer IRB Verlag.

Small, K. A. and Hsiao, C. (1985). Multinomial Logit Specification Tests. *International Economic Review*, 26:619-27.

Thursby, J.G., Jensen, R., Thursby, M.C. (2001). Objectives, Characteristics and Outcomes of University Licensing: A Survey of Major U.S. Universities. *Journal of Technology Transfer* 26: 59-72.

Thursby, J.G., Fuller, A., Thursby, M.C. (2009). U.S. Faculty Patenting: Inside and Outside the University. *Research Policy* 38: 14-25.

Toole, A.A. (2007). The Impact of Public Basic Research on Industrial Innovation: Evidence from the Pharmaceutical Industry, *mimeo*, Rutgers University, earlier version available as Stanford University (SIEPR) Discussion Paper 00-07.

Trajtenberg, M., Henderson, R., Jaffe, A.B. (1997). University versus Corporate Patents: A Window on the Basicness of Invention. *Economics of Innovation and New Technologies* 5(19), 19-50.

Verspagen, B. (2006). University Research, Intellectual Property Rights and European Innovation Systems. *Journal of Economic Survey* 20(4): 607-632.

Webb C., Dernis, H., Harhoff, D., Hoisl K. (2005). *Analyzing European and International Patent Citations: A Set of EPO Database Building Blocks*. STI Working Paper 2005/9, OECD.

Zucker, L.G., Darby, M.R. (1996). Star Scientists and Institutional Transformation: Patterns of Invention and Innovation in the Formation of the Biotechnology Industry. *Proceedings of the National Academies of Science* 93: 12709-12716.

Zucker, L.G., Darby, M.R., Brewer, M.B. (1998). Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises. *American Economic Review* 88(1): 290-306.