Copenhagen
Business School
HANDELSHØJSKOLEN

Department of Economics
Copenhagen Business School

Working paper 5-2008

COMMERCIALIZING ACADEMIC RESEARCH:
The Quality of Faculty Patenting

Dirk Czarnitzki   Katrin Hussinger   Cédric Schneider

Department of Economics -Porcelænshaven 16A, 1.fl. - DK-2000 Frederiksberg

Commercializing Academic Research:
The Quality of Faculty Patenting[*]

Dirk Czarnitzki [a,b,c,d], Katrin Hussinger [e,a,c] and Cédric Schneider [a,d,f]

[a] *K.U. Leuven, Dept. of Managerial Economics, Strategy and Innovation (Belgium)*
[b] *Steunpunt O&O Indicatoren at K.U. Leuven (Belgium)*
[c] *Centre for European Economic Research (ZEW), Mannheim (Germany)*
[d] *Centre for Industrial Economics, University of Copenhagen (Denmark)*
[e] *University of Maastricht, Dept. of Organization and Strategy (The Netherlands)*
[f] *Copenhagen Business School, Dept. of Economics (Denmark)*

July 2008

Abstract

The knowledge produced by academic scientists has been identified as a potential key driver of technological progress. Recent policies in Europe aim at increasing commercially orientated activities in academe. Based on a sample of German scientists across all fields of science we investigate the importance of academic patenting. Our findings suggest that academic involvement in patenting results in greater knowledge externalities, as academic patents appear to generate more forward citations. We also find that in the European context of changing research objectives and funding sources since the mid-90's, the "importance" of academic patents declines over time. We show that academic entrants have patents of lower "quality" than academic incumbents but they did not cause the decline, since the relative importance of patents involving academics with an existing patenting history declined over time as well. Moreover, a preliminary evaluation of the effects of the abolishment of the "professor privilege" (the German counterpart of the U.S. Bayh-Dole Act) reveals that this legal disposition led to an acceleration of this apparent decline.

Keywords: academic inventors; faculty patenting; patent quality

JEL-Classification: O31, O32, O34

---

[*] The authors thank seminar participants at the Georgia Institute of Technology, the Haas Business School at UC Berkeley, the University of Notre-Dame, and the University of Helsinki (HECER) for useful comments.

1 Introduction

Assessing the economic impact of public science has been discussed among economic scholars, professionals and policy makers since decades. The most obvious contribution of public science towards economic growth is the education of the future high-skilled labor force. Possibly equally important, however, is the fact that public science provides research results for the public domain, and their insights can be picked up by the business sector so that research results from public institutions can be translated into new production processes and products. Third, more active ways to promote the knowledge and technology transfer from academe to industry are, among other channels, collaborations in R&D projects, faculty consulting, spin-off creation by universities, university patenting and licensing of technologies. Those activities are typically summarized as industry-science interactions.

Several scholars have shown positive economic benefits of research results produced in public science. For instance, Jaffe (1989) has shown that university research contributes to state-level corporate patenting. Adams (1990) found that cumulative stocks of academic research stimulate productivity growth in industry. Lichtenberg (1996, 2001, 2003) links pharmaceutical innovation to lower hospital costs and increased life expectancy, and Toole (2007) concludes that university research makes significant contribution to drug innovation in pharmaceutical industry. Mansfield (1991) concludes from a survey of 76 US firms that 11% of product inventions and 9% of process inventions would not have been made in the absence of recent academic research. This picture is supported by the Yale survey and the Carnegy Mellon survey. Both surveys have shown that universities deliver a significant impact for new product and process development in firms (Cohen et al., 2002). Further studies have shown that academic scientists significantly contributed to the birth of the U.S. biotechnology industry (Zucker and Darby, 1996, Zucker et al., 1998), and that academic scientists significantly contribute to firm performance when they venture from academe to industry (Zucker et al., 2002, Toole and Czarnitzki, 2007, 2008).

On the background of the ongoing transformation of economies towards "modern knowledge societies", many governments increased their attention towards industry-science interactions, and, hence, those have been the subject of innovation policy in most industrialized countries recently. Such policies aim at increasing industry-science interactions in the future as it is assumed that an increased attitude towards commercialization in public science will result in even higher economic benefits. Despite the presumably positive effect of increased commercialization of academic inventions on technological progress, there are some serious threats. Most important is the peril of the "culture of open science" at universities through a shift in content of academic research from basic to applied research that focuses on subsequent commercialization (Verspagen, 2006). Many scholars see the relatively open nature of science progress at universities, which is characterized by sharing of knowledge, data and research results as opposed to corporate research and development, as a key determinant of the success of university research (Dasgupta and David, 1994).

These controversial arguments gave rise to several studies on the commercialization of academic research in response to policy changes. Among other policies, the most prominent or most studied example is the U.S. Bayh-Dole Act from 1980. The Bayh-Dole Act strengthened the patenting rights of US universities (and small businesses) by granting them the right to patent and to retain the ownership of inventions even if these were financed through public resources. Examples of studies on the potential effects of the Bayh-Dole Act are Henderson et al. (1998), Mowery and Ziedonis (2002), Mowery et al. (2002), and Sampat et al. (2003).

While most of the literature on the quality of academic commercialization is based on the Bayh-Dole Act in the U.S., little attention has been paid to the commercial value of science more generally. We exploit institutional differences between the U.S. and Europe, and suggest that even without a Bayh-Dole Act, the increasing orientation towards commercialization results in diminishing quality of academic commercialization. We argue that declining public budgets for Higher Education R&D and increased policy orientation towards technology transfer result in more industry-science interactions. However, as can be expected from neoclassical theory, more commercialization activities are subject to decreasing marginal returns.

We use patent data on German professors as we are able to identify individual academic inventors. Unlike most other studies for the U.S., we do not rely on assigneeship of a university, as academics may also collaborate with industry without university involvement. Our results show that "professor patents" are, on average, more valuable than a corporate patent without faculty involvement. However, we observe a stark decline of quality over time. First, the quality of corporate and academic patents converge, but in the most recent period in our data, academic quality even falls behind corporate quality. Interestingly, this last period corresponds to the introduction of a Bayh-Dole-type policy in Germany. In further steps, we show that academic entrants that enter commercialization channels possibly due to budget constraints in the public sector account for a larger share of the decline than do experienced inventors.

The remainder of the paper is organized as follows: first we outline the literature and our hypotheses to be tested. The third section presents the construction of the database, and some descriptive evidence. Section 4 presents econometric evidence from count data models. The final section concludes and suggests further research on the topic.

2 Commercializing Academic Research

2.1 The difference between public and private research

Public sector science in form of discoveries and inventions produced at universities or other public research institutions has some features that distinguish it from research financed and produced in the business sector. Typically, public knowledge production happens in an open regime that facilitates disclosure and diffusion of inventions and discoveries (Dasgupta and David, 1994). Science has priority over commercialization of inventions and the incentives for inventors are significantly determined by peer recognition and career rewards such as tenure, and not only by monetary rewards (Merton, 1973).[1] This incentive structure strongly supports the openness of public science and leverages effective cumulative innovation through a sharing of knowledge, data and research results. In contrast, science produced in the private sector aims at commercialization and the profit from an invention largely depends on the degree to which others can be excluded (Arrow, 1962).

As the focus of private science is often on short and medium-term profits from inventions, the private sector is likely to systematically “underfund” inventions that are rather basic in nature (Agrawal and Henderson, 2002). As opposed to applied

---

[1] This is strongly supported by a recent survey among European inventors (Giuri et al., 2007).

inventions that are strongly linked to their commercial success basic inventions and the results of fundamental research are more difficult to appropriate, especially in the short run. This is one of the main arguments for publicly sponsored science. A systematic difference in the nature of public and private science has been empirically approved (Trajtenberg et al., 1997). A related argument for public science is that fundamental research might have much broader applications, i.e. their social value should be higher than that of private science. Hence, the "shoulders" of inventions and discoveries produced at universities are supposed to be much broader than those of private inventions. Beyond break-through inventions and industry-science collaborations, publicly sponsored science at universities provides codified ways of solving problems that can be useful beyond a specific content and universities borders (Dasgupta and David, 1994). Further, public science provides a structured picture of interdependencies in science, which can help uncovering the relevant technology areas of a particular problem. This can save research efforts as it can help avoiding unnecessary (costly and time consuming) experiments and maximize the probability of discovery (Fleming and Sorensen, 2004).

These distinctive features of public science suggest a significant contribution to technological progress and growth: the basicness of university science increases the potential for its use and the open culture at universities positively affects the diffusion of research results. Griliches (1984) and Adams (1990) document a significant contribution of university research and science produced at public research centres to economic growth in their seminal studies.

On top of that there are arguments that support that the knowledge produced in the public science sector should even exceed private sector knowledge. For instance, in order to justify publicly financed science, we should see that discoveries made in the public sector have a higher social value than inventions produced by the private sector (Agrawal and Henderson, 2002).

What happens if academic scientists engage in commercialization, though? While we expect that academic inventions will be socially more valuable, it does not necessarily imply that the private value is also high. However, in the case of spin-off creation or patenting, for example, we can follow the logic of a theoretical model of Lacetera (2008). Suppose an industrial research and an academic scientist face the same time constraint for their activity (e.g. 12 working hours per day), and suppose both have certain ideas for research projects. The industrial researcher would start a project if the expected profits are larger than zero. The academic scientist, however, has to decide to which extent he or she splits the time between academic tasks, e.g. publications, and commercial tasks. Thus, the academic has opportunity cost of foregone academic merits if he or she decides to engage in commercialization. The academic scientist would only self-select into commercialization if the expected utility gain, that is, monetary profits, is larger than the lost utility of non-published papers due to time constraints. Hence, we can still conclude that academic patents, for instance, should be more valuable than private sector patents due to the incurred positive opportunity cost for the academic scientist which induces a self-selection into commercialization.[2]

Taking these different arguments together, we arrive at a first hypothesis which will be tested with patent data:

- **Hypothesis 1:**
  Faculty involvement in the commercialization of inventions should, on average, lead to higher quality than inventions produced by non-academics.

Furthermore, we will also test if academic inventors are more likely to produce break-through inventions. While one expects that the average quality is higher, it can also be expected that block-buster patents are produced in academe, as they may require highly complex processes and approaches. Academics who are usually assumed to be at the forefront of research in their field may have a comparative advantage over industrial researchers, as they, for instance, shape their human capital within a small group of initial discoverers of new technology field. See Zucker et al. (1998) for the example of academic discoveries in the biotechnology sector and how their commercialization activities linked to a few star scientists led to a diffusion of knowledge that is nowadays commonly used in the U.S. or to a large extent even in the global biotechnology industry.

---

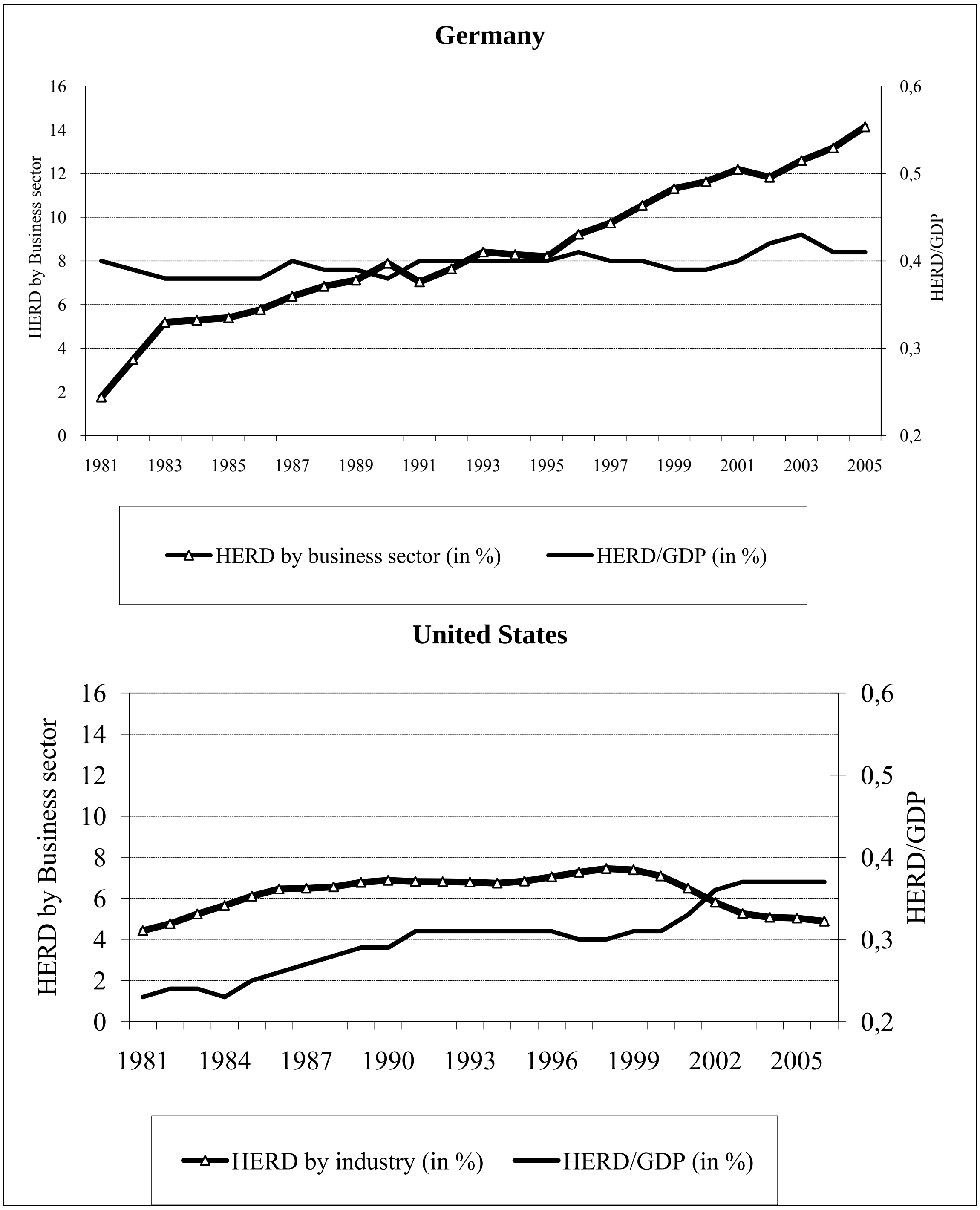
[2] Lacetera (2008) originally built his model to argue that studies comparing academic spin-off performance with other newly founded firms are suffering from such self-selection bias. Researchers typically found that academic spin-offs perform better, but Lacetera argues that this is a self-selection effect than rather superior average performance in the population of academics.

- **Hypothesis 2:**
  Faculty involvement in the commercialization of inventions does not only lead to higher quality, on average, but faculty patents are especially more valuable in the upper tail of the quality distribution of inventions.

2.2 Public budgets and implications for public research

The recent past has seen significant changes in the European public science sector. First of all, public budgets spent on science and technology decreased significantly all over Europe (Geuna and Nesta, 2006). Figure 1 shows the development of higher education R&D expenditures (HERD) in Germany and the united States over the past decades. The solid line shows that the investment in higher education is almost constant over time in terms of GDP in Germany at about 0.4%. In the United States, HERD/GDP grew over time, but is still below 0.4% in the mid 2000s. In contrast, the share of HERD financed by the business sector increased significantly in Germany. It rose from a share of about 2% in 1981 to 14% in 2005. Thus the contribution of private funding sources gradually substituted public funding sources. Interestingly, we do not see such a trend in the United States. The share of HERD financed by the business sector peaks at about 8% at the end of the nineties, but declines to about 4% by 2005.

Figure 1: Higher education R&D expenditure over time



Source: OECD – Main Science and Technology Indicators; own calculations.

Furthermore, in the presence of public budget constraints the structure of public financing of research changed towards competitive funds (Geuna, 2001). Examples are the “elite university” in Germany, where universities compete against each other for “elite” funding by the government.

The decreasing public funding forced universities to more and more reach out for different sources of financing (Geuna and Nesta, 2006). Besides an increased financing by non-profit organizations, most of the funding gap was bridged through increased collaborations with the private sector (Geuna, 2001). The increased dependence on industry funds might have significant consequences for academic research. On the one hand, close links between academia and industry have many positive aspects not only for the business partner (e.g. Zucker and Darby, 2000, Hall et al., 2001) but also for the academic sector, as for instance the realization of complementarities between applied and basic research (Azoulay et al., 2006) and the generation of new research ideas (Rosenberg, 1998). However, there are also some potential negative implications. Most serious, the content of academic research might shift from rather basic to applied inventions that aim at immediate commercialization (Azoulay et al., 2006), which would have negative implications for long-term fundamental research. A shift in content towards commercialization would partly explain the increased engagement of academics in patenting that was documented by a number of scholars for different European countries (Meyer et al., 2003, Lissoni et al., 2006, Czarnitzki et al., 2007a, 2007b).[3]

However, scientists face an increasing pressure to patent from changing rules in the public science sector. The competition for funding from the government is not based on scientific publications only but also evaluates the scientists or the university department in terms of their patent outcome. Furthermore, career rewards as tenure are increasingly dependent on patents and industry-science collaboration rather than on scientific publications only. These developments gradually changed the incentive structure for scientists and put them under increased pressure to transfer their knowledge into marketable products.

---

[3] Another important threat concerns the number and the quality of scientific publications. Geuna and Nesta (2006) survey the existing literature for Europe on the effect of increased patenting on publication outcome. Most of the studies for Europe find no empirical evidence for university patenting to reduce the number of scientific publications or their quality (e.g. Czarnitzki et al. 2007a, for Germany, Breschi et al., 2006, for Italy). For the US, the results are similar (e.g. Stephan et al., 2006, Azoulay et al., 2006, Fabrizio and DiMinin, 2005). Distinguishing between university and corporate patents of professors in Germany, Czarnitzki et al. (2007b) conclude that corporate patenting by academics has a negative impact on their scientific performance, while patents in collaboration with nor-profit organizations spur their publication outcome and quality .

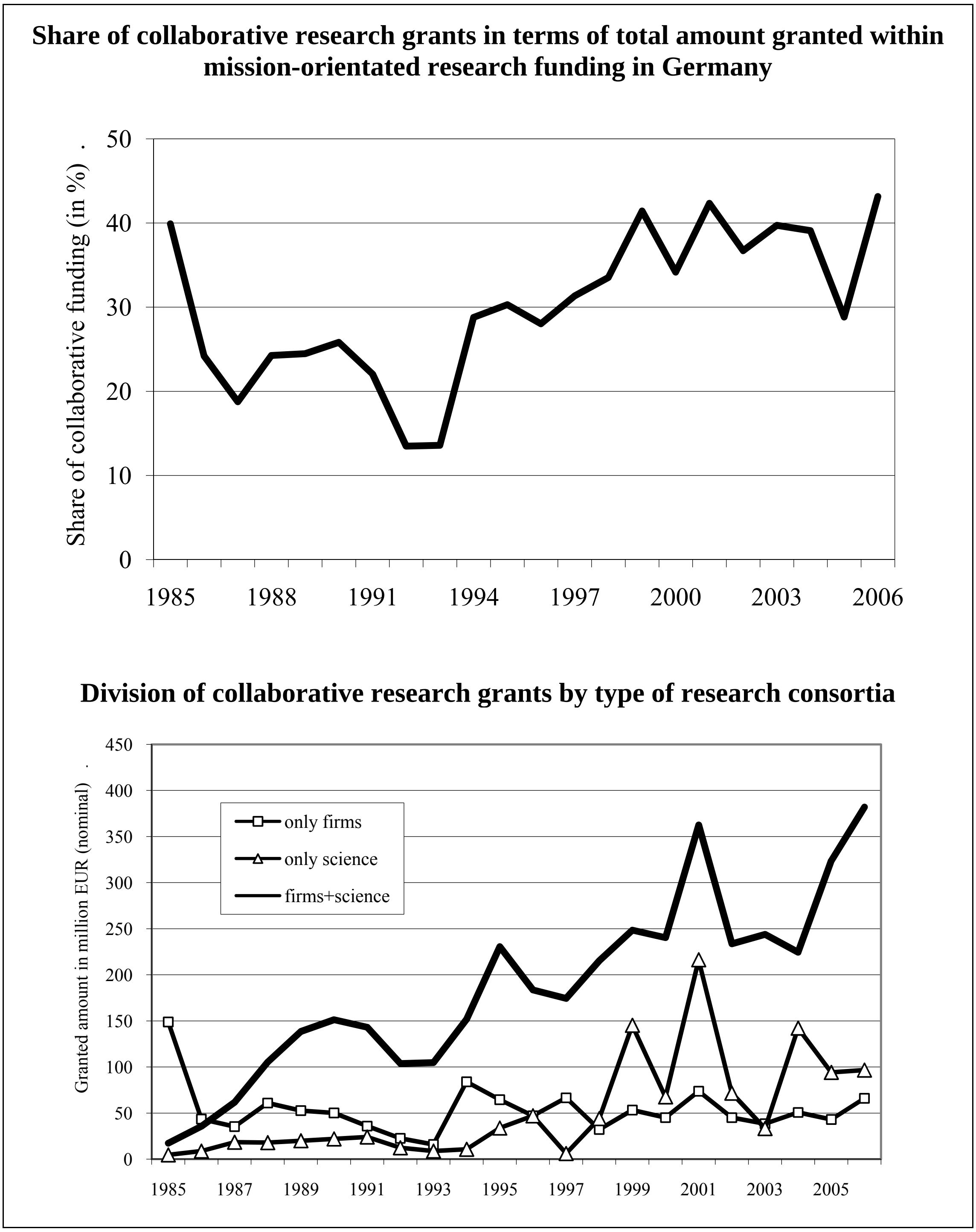
Extending Lacetera's (2008) and Jensen et al.'s (2007) arguments, suppose that an academic scientist has the opportunity to complete either an economically valuable project or to do basic science in each of two periods. The scientist can do pre-commercial research in the first period and use this new knowledge to engage in commercial activity in the second period. Alternatively, the scientist can engage in commercial activity right away, building on his current stock of knowledge solely. In the first scenario, the scientist applies his new research results to innovate. In the second scenario, the scientist will innovate, based on the current state of knowledge. Therefore, the quality of these innovations will differ substantially, as the innovation based on novel scientific achievements will have a higher value than the innovation based on existing knowledge. Due to the increased pressure to patent they face, scientists will therefore be more likely to shift toward immediate commercialization without performing pre-commercial research, which will result in innovations of lower quality.

In addition, incentives for the corporate sector to collaborate with academia have also evolved. Many European governments, as well as the European Commission, have launched several public programs to promote and strengthen industry-science links, by financially supporting collaboration between academia and the private sector (Veugelers and Cassiman, 2005). There is ample evidence that these financial incentives increase the propensity of firms of engaging in cooperative agreements with academia in order to benefit from government-sponsored cost sharing of innovation (Veugelers and Cassiman, 2005, Capron and Cincera, 2003, Mohnen and Hoareau, 2003).

Figure 2 shows some evidence from German subsidy data taken from the PROFI database. The graph shows annual statistics of civilian "direct project funding" of the German Federal Government. The "direct project funding" is the most important project-orientated policy instrument for funding R&D projects in Germany. Applicants for public R&D money can submit proposals which are evaluated according to technological feasibility and expected economic returns. An application may either be filed by a single firm or research institution, or by a research consortium of firms and/or research institutions. The upper chart shows that grants given out to consortia rather than single firms or institutions oscillates around 40% of total grants in the 2000s. The lower graph clearly shows the change of policy in

Germany. Within several sub-programs of the “direct project funding” the German Government promoted industry-science interactions. This becomes evident when we separate the collaborative research grants by type of consortium. Since the mid 1980s, we find a clear trend towards promoting industry-science consortia, while there is little growth of grants given to pure firm research consortia or pure science consortia.

Figure 2: Civilian mission-orientated research funding by German Federal Government



Share of collaborative research grants in terms of total amount granted within mission-orientated research funding in Germany

Division of collaborative research grants by type of research consortia

Source: PROFI database from Germany’s Federal Ministry of Education and Research; own calculations.

However, cooperation with academia requires a critical level of prior knowledge or "absorptive capacity" (Cohen and Levinthal, 1989) to effectively recognize, assimilate and utilize external information flows stemming from academia, which are by nature more basic. This suggests that the growing public support of cooperative agreements between the private sector and academia led many firms that do not have this critical level of internal knowledge to engage in partnerships with academia.

Thus, we arrive at our third hypothesis on a possible decline of patent quality.

- **Hypothesis 3:**
  The quality of faculty patents declines with the increasing shift towards commercialization in academe (compared to a control group of corporate patents).

Mowery et al. (2006) find that in the US, inexperienced universities initially adopted an indiscriminate policy toward patenting as they entered into this activity after passage of the Bayh-Dole Act and patented inventions with little evaluation of the market within their industry. Furthermore, they find that the decline quality of university patents in the U.S. is largely due to these academic entrants. Provided Hypothesis 3 is fulfilled, the decline in quality of faculty patents might as well be driven by academic entrants. Therefore we will test whether the decrease in quality of faculty patents should be attributed to academics with no historical experience in patenting, or if there is a more secular decline.

We argue that even if academic entrants patent inventions of lower importance than academic incumbents, they are not causing the decline, since the new "research culture" induced by the changing objectives and funding sources affect all potential academic inventor.

- **Hypothesis 4:**
  Academic entrants have patents of lower quality than academic incumbents, but they do not drive the decline in quality.

2.3 The abolishment of the professor's privilege in Germany

As outlined above, the shift to entrepreneurial universities (Etzkowitz et al., 2000) may reduce the difference between academic and industrial research due to an orientation towards commercialization in public science. Studies for the U.S. that have investigated the consequences of the Bayh-Dole Act find mixed evidence on this hypothesis (among others, Henderson et al., 1998, Mowery and Ziedonis, 2002, Mowery et al., 2002, and Sampat et al., 2003). Researchers have studied patent quality before and after the Act in 1980. However, the after-Bayh-Dole Act phase was also characterized by a general trend towards the entrepreneurial university in the U.S. that cannot be purely attributed to strengthening universities' patent rights. For instance, it can also be observed that the number of spin-off companies is constantly growing in the U.S., from about 200 in the mid 1990s per year to about 400 in the early 2000s (Source: AUTM U.S. Licensing Survey: FY 2004).

We make use of institutional differences between the U.S. and Germany to uncover differences of the generally increasing commercialization trend and the impact of a Bayh-Dole Act-type policy change in February 2002. Until then, German universities had a weak position in terms of their rights to use the inventions of their employees. The "professors' privilege" determined that professors were the only occupational group in Germany that had the right to use their scientific results for private commercialization even if the underlying research was financed by the university. This explains why the majority of inventions (that were taken out as patents) made in German universities were not assigned to universities but to the professors themselves or to corporations (Verspagen, 2006, Geuna and Nesta, 2006, Czarnitzki et al., 2007a,b).

Once derived from Article 5 of the German constitution, which pertains to the freedom of science and research, the German Federal Ministry of Education and Research (BMBF) decided to abandon the professor's privilege in 2002 because it was suspected to inhibit science and technology transfer (Kilger and Bartenbach, 2002). Under the old law, the professor bore all the financial risk of filing a patent application (including patent application fees and potential infringement costs). As the distribution of the value of patents is known to be very skew university professors faced the risk that the costs of patenting would increase the profits thereof by far, which significantly decreased their incentives to patent. Under the new law, the university takes over the financial risk and the patent application procedure and the professor receives 30% of the revenues from exploiting his invention. Hence, the threshold for professors to patent is even reduced as the opportunity cost of patenting were decreased through the abolishment of the "professor's privilege" in 2002.

We expect that the abolishment of the “professor’s privilege” will have two effects: for one, the number of patents assigned to universities is expected to increase. Second, we suspect a decline in quality of patents taken out by professors. As a result of the change in law the self selection effect into commercial activities that resulted in higher quality of academic patents is supposed to be significantly reduced. Hence, a potential decline of patent quality due to an increasing commercial orientation in academe is expected to be accelerated trough the change in law, i.e. after 2002. The investigation of the effect of the abolishment of the professors’ privilege should, however, be taken cautiously, since we only observe academic patents for a short period after the law change. Our results should be taken as indicative of the effect that the abolishment of the Professors’ privilege had in the short run, but should not be taken as a definitive evaluation.

3 Data and Methodology

3.1 Data and sample selection

Our analysis is based on a dataset 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 cited patents, 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. (2007a) did a test on the accuracy of this identification strategy for a sample of patents of German scientists at the German Patent and Trade Mark Office and the European Patent Office. 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. (2007a) 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 4,973 (granted) patents that list at least one faculty member between 1980 and 2003. Our data turned out to contain "only" 22 university patents (i.e. patents owned by universities), roughly 0.45% of the total of academic patents.

To further check the completeness of our sample of academic patents, we compared the outcome with a similar search in the data from the German Patent and Trademark Office (GPTO). More precisely, we searched all patents that have an EPO equivalent at the GPTO and that list professors as inventors. We found only 112 cases in which the GPTO patent listed a professor, but not the equivalent EPO patent over the period 1990-2001.

In order to evaluate the "importance" of our "academic patents", we constructed a control group that include one non-academic patent for each academic patent. The non-academic patents were randomly drawn based on the date of applications and on 30 patent technology classes as defined in the OST-INPI/FhG-ISI classification also often referred to as the Fraunhofer classification, which is based on a concordance with IPC assignments. For a detailed description see OECD (1994, p.77-78 for the definition).

In order to ensure that no academic patent would end up in our control group, we deleted patents granted to non-German universities and public non-university research institutions[4] from the pool of non-academic patents. In total, 6,758 patents were taken out of the pool from which the control group was drawn.

---

[4] This required a manual search in all assignee names. Most prominent examples of German public research institutions are the Max-Planck Society, the Fraunhofer Society and the Helmholtz Society. However, the search was not limited to those. We excluded all public non-profit research institutions from the control group.

3.2 Variables

We use the number of citations received by a focal patent from any subsequent patent application in order to establish potential differences between academic patents and the control group. Our purpose in this paper is to evaluate the involvement of academics in terms of the quality of patents. In particular, we want to know whether applications involving academic inventors have a stronger technological impact, and are therefore more frequently cited. Patent forward citations are a well established measure for the "importance", the "quality" or the "significance" of a patented invention and have been used in different contexts in the literature on technological change (see Trajtenberg, 1990, Henderson et al., 1998, Harhoff et al., 1999, Trajtenberg, 2001, or Hall et al., 2001). 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). Hence, we can safely argue that forward citations reflect the "importance" of the cited patent.

Previous U.S. studies on patent citations paid particular attention to "self-citations", i.e. cited and citing patents are owned by the same entity (e.g. Jaffe et al., 1993, Jaffe and Trajtenberg, 2002). Self-citations differ from external citations in that they cannot be regarded as representing spillovers to another patentee, they might be affected by the patentee's differential knowledge and they might provide different signals than other citations regarding the value to the patentee with respect to future cumulative inventions (Hall et al., 2005). Contrary to the well-known "NBER Patent Database", the "EPO/OECD patent citations database" does not indicate self-citations. Hence, we cannot control for them. However, we do not expect any significant impact on the results from self-citations for two reasons. First, previous studies have found little effects from the exclusion of self-citation on forward citations in different contexts. Hall et al. (2005), for instance, found a real but limited effect of the exclusion of self-citation on the relationship between forward citations and the market value of firms for U.S. patents (see also Hall et al., 2007). For Europe, Sapsalis and Van Pottelsberghe de la Potterie (2007) found that removing self-citations does not affect the relationship between forward citations and the explanatory variables for EPO patents of Belgian universities. Second, unlike at the USPTO, patent applicants at the EPO do not have the "duty of candor", which means that there is no legal requirement to disclose prior art. In order to check whether an EPO patent application fulfills the necessary criteria to be granted, a patent examiner researches prior. The results of this investigation are summarized in the so-called "search report". Descriptive statistics show that more than 95% of the citations in EPO patents are added by the examiner. In contrast, USPTO applicants have to provide a full list of prior art, including their own work. This suggests that the "self-bias" in EPO patents is presumably very low and would carry a weak informational content. The fact that the allocation of citations follows a standardized procedure at the EPO is likely to reduce the noise contained in the forward citations as a measure of the "importance" of patents.

Turning to the explanatory variables of our analysis, our main variable is a binary indicator that takes the value 1 if the inventor is an academic (see description in section 3.1). We will test whether patents that involve academic inventors are more "important" than those of the controls.

Following the literature on patent quality, intrinsic attributes of the patent that may lead to a higher expected count of forward citations need to be controlled for. Consequently, we include the following control variables:

Number of references to the patent literature (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 (Lanjouw and Schankerman, 2001). 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 crowdedness of the technological area (Lanjouw and Schankerman, 2001). Everything else equal, patents in more crowded areas should generate more forward citations. An alternative interpretation is that backward citations are a measure of the scope of the patents. Since patent citations always refer to a claim (or a set of claims), patents with more backward citations should be more cited, everything else equal (Harhoff et al., 2003).

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 extent of monopoly power a patent grants. Thus the broader the scope of a patent, the higher the probability to be cited by other patents.

References to the non-patent literature: We include a binary variable that takes the value 1 if the patent application cites at least one non-patent reference (NPR). We hypothesize that NPRs capture the invention's science linkage. This measure should be taken cautiously, since NPRs do not necessarily represent a linkage to prior scientific work (Harhoff et al., 2003).[5] However, Callaert et al. (2004) show that roughly 65% of NPRs in EPO patents refer to scientific publications and there is some recognition of their use as an indicator of science-technology linkages (Meyer, 2000, Schmoch, 1997).

Finally, we control for systematic year and technology effects by including dummies for application years and technology fields (see below).

3.3 Descriptive analysis

3.3.1 Summary statistics

Table 1 displays descriptive statistics of the variables used in the analysis. These figures show that academic patents receive, on average, more citations than the control group and have more NPRs. In addition, academic patents appear to be broader, as measured by the number of IPC assignments and to be in less crowded technology fields as indicated by the number of backward citations.

---

[5] Non-patent references can also be made to trade journals, firm publications or standard classifications in a technology field as classifications of chemical substances or mechanical designs.

Table 1: Descriptive statistics

	Academic patents				**Control group**			
	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
Number of forward citations	2.702	3.792	0	58	2.242	3.122	0	48
Number of IPC assignments	1.663	0.861	1	11	1.556	0.770	1	8
Non-patent references	0.364	0.481	0	1	0.245	0.430	0	1
Number of backward citations	3.700	2.370	0	19	3.909	2.230	0	18
Number of observations	4,973				4,973			

Table 2 tabulates the number of academic patents in each of the technology areas from the OST classification. The Table shows that most academic patents are granted in chemicals and pharmaceuticals, which contains more than 40% of all academic patents, notably in the field of organic fine chemicals.

3.3.2 Citation lags

Forward citations are by nature truncated, since earlier patents have more time to garner citations than later ones (Hall et al., 2001). Sampat et al. (2003) compare university and corporate patents in the U.S. and find that the resulting difference in citation counts is sensitive to the length of the time period taken into account. They argue that citations to universities occur on average later than citations to the controls. We test the hypothesis of different citation lags between academic patents and the control group by plotting the kernel density of the citation lag distribution for both groups. Figure 2 reveals that there are no systematic differences between academic patents and the controls. Moreover, the Kolmogorov-Smirnov test does not reject equality of the citation lag distributions (p-value: 0.678). Hence, we can safely argue that our empirical findings are not driven by systematic differences in citation lags for academic and control patents.

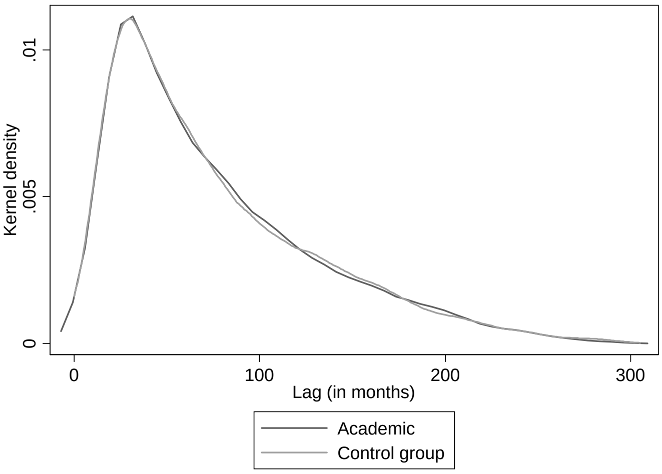
Table 2: Technology classification of academic patents

Field	OST technology class	Total academic patents	% of total
	I Electricity – Electronics	**390**	**7.8**
1	Electrical devices - electrical engineering	168	
2	Audiovisual technology	49	
3	Telecommunications	103	
4	Information technology	37	
5	Semiconductors	33	
	II Instruments	**882**	**17.7**
6	Optics	87	
7	Analysis, measurement, control	377	
8	Medical engineering	418	
	III Chemicals, pharmaceuticals	**2153**	**43.3**
9	Organic fine chemicals	997	
10	Macromolecular chemistry, polymers	201	
11	Pharmaceuticals, cosmetics	323	
12	Biotechnology	296	
13	Materials, metallurgy	288	
14	Agriculture, food	48	
	IV Process engineering	**829**	**16.7**
15	General technological processes	45	
16	Surfaces, coatings	130	
17	Material processing	201	
18	Thermal techniques	88	
19	Basic chemical processing, petrol	193	
20	Environment, pollution	172	
	V Mechanical engineering	**565**	**11.4**
21	Mechanical tools	119	
22	Engines, pumps, turbines	64	
23	Mechanical elements	136	
24	Handling, printing	68	
25	Agriculture & food machinery	34	
26	Transport	105	
27	Nuclear engineering	23	
28	Space technology, weapons	16	
	VI Other	**154**	**3.1**
29	Consumer goods & equipment	61	
30	Civil engineering, building, mining	92	
99	Misc or unclassified	1	
	Total	4973	**100.0**

The finding that there is no significant difference in citation lags for European patents might be due to different procedures at the EPO and USPTO. As pointed out in section 3.2 already, contrary to practices at the USPTO, inventors applying for an EPO patent do not have the “duty of candor” and are not required to provide a list of prior art. The patent application is examined by the patent office and even references made by the applicant have to be approved by the patent examiner. Bacchiocchi and

Montobbio (2004) find that these institutional differences imply that USPTO patents contain on average more citations than EPO patents and that the median citation lag is twice as large at the USPTO than at the EPO.

Figure 3: Citation lags of academic patents and controls



3.4 Methodology

Since our variable of interest, the number of forward citations contains only positive integers, we use count models. The specification of our baseline regression follows a well established literature in the area (see for example Henderson et al., 1998 or Mowery et al., 2002). More specifically, we estimate negative binomial and Poisson models with conditional mean:

$$E\left[C \mid X\right]T = \exp\left[\beta ACAD + \sum_t \alpha_t APY_t + \sum_c \lambda_c TECH_c + \sum_i \delta_i Z_i + \log(T) + \varepsilon\right], \quad (1)$$

where C is the number of forward citations to the focal patent and X is the vector of explanatory variables containing: *ACAD,* a dummy that equals 1 for all academic patents in our sample; *APY*, a set of dummy variables for different patent application years *t*, and *TECH*, a set of dummy variables for the different technology classes *c* a patent application is attributed to. In addition, the vector *Z* contains the control variables outlined in Section 3.2. The dependent variable, the number of forward citations, is truncated since later patents have less time to garner citations than earlier ones, which is why we estimate the model with "exposure" (Cameron and Trivedi, 1998). The variable *T* is the age of the patent in 2006 (the last year recorded in our data) since its publication, or exposure during which citations occur. Thus, the natural log of T enters as an offset in the conditional mean. The Poisson model is estimated by Quasi-Maximum Likelihood, since estimates of this model will be consistent, provided the mean is correctly specified, even if the true distribution is not Poisson (Gouriéroux et al., 1984). However, it is possible to improve efficiency by making more restrictive assumptions about the way the variance differs from the mean, which is why we also report results of Negative Binomial regressions.

Two robustness checks are reported in the Appendix. First, we repeat all regressions using only those academic patents that involve corporate assignees. We also repeat all regressions using all academic patent applications (instead of granted patents only). This enables us to verify that our data is not affected by the end of the sample truncation in patent grants. Sampat et al. (2003) show that U.S. university patents are on average granted later than corporate patents. Since the results of the estimations in which we use all patent applications go into the same direction as the results from our baseline sample, we argue that this problem is not severe for European patents.

4 Results

4.1 Are academic patents more "important" than corporate patents?

Table 3 displays the results of the Negative Binomial and Poisson regressions for equation (1). Confirming our findings on the comparison of means, patents involving an academic inventor have a higher technological impact. According to the Negative Binomial regression results, academic patents receive on average about *17%* (*=exp(0.161)-1*) more citations than their counterparts in the control group. This confirms our first hypothesis that academics are involved in more valuable inventions. This suggests that university patenting per se is not the only channel through which academics can generate knowledge externalities. Overall, the results support our assumption that academic patents are, on average, more "important" than purely corporate patents.

With respect to the control variables, our results show that, everything else equal, applications with more backward citations receive, on average, more citations. In the same way, broader applications, as measured by the number of IPC assignments (at the 4-digit level), show a higher expected citations count. Finally, NPRs do not exhibit a higher citation impact in the Poisson model, but turn out to be positively and significantly related to the number of citations received in the Negative Binomial model.

Table 3: QMLE Poisson and Negative Binomial regressions for patent forward citations: academics patents versus controls

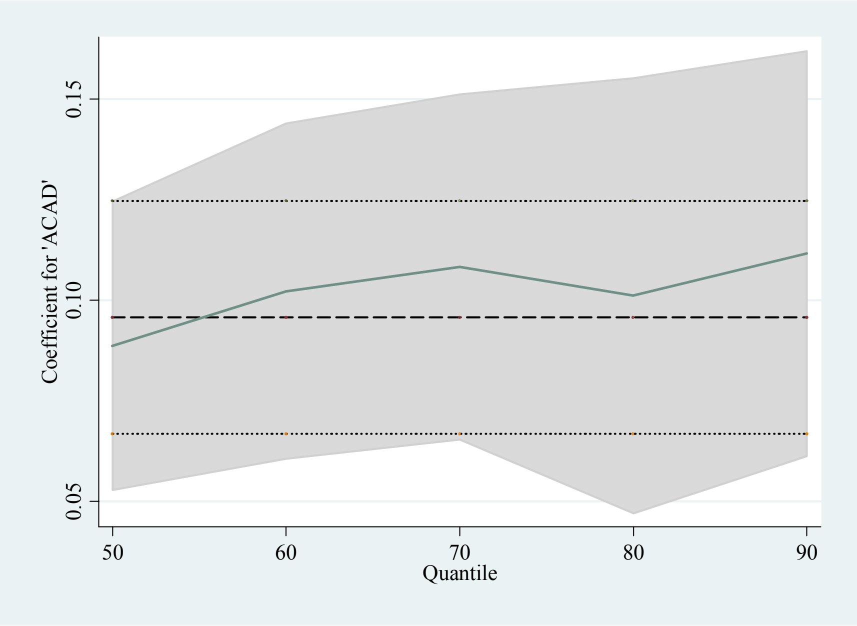
	QMLE Poisson			Negative Binomial		
Variables	Coef.		S.E.	Coef.		S.E.
ACAD	0.169	***	0.027	0.161	***	0.024
# backward citations	0.046	***	0.006	0.049	***	0.006
NPR	0.048		0.034	0.057	**	0.029
# IPC assignments	0.128	***	0.018	0.135	***	0.016
log(T)	1			1		
Constant	-4.403	***	0.335	-4.429	***	0.432
App. years – test of joint significance	$\chi^2(23)$=201.99***			$\chi^2(23)$=252.23***		
Tech. Classes – test of joint significance	$\chi^2(30)$=358.10***			$\chi^2(30)$=365.25***		
Overdispersion parameter				0.968		0.022
LR test of equidispersion (p-value)				0.000		
Log-likelihood	-25393.463			-19957.302		

4.2 Are academic patents more "important" in the upper tail of the quality distribution of inventions?

In order to test our second hypothesis we estimate quantile regressions. For simplicity we use a log-linear specification instead of count models, where the dependent variable is the log of (one plus) the number of forward citations. Figure 4 displays the results. The solid curve represents the coefficient of the quantile regression, the shaded area indicates the confidence interval of this regression and the dotted lines the OLS coefficient and the corresponding confidence interval. The results are only shown from the 50th quantile since there are more than 30% of patents with no citation, so that the coefficient for the academic dummy would always be zero at lower quantiles.

We find that, academic patents have a quite uniform effect over the whole range of the distribution. Thus, the quantile regressions are quite consistent with the OLS results, since their coefficient is always contained in the OLS confidence interval. Therefore, we do not confirm our second hypothesis. The results suggest that academics are not more likely to be found in the upper tail of the quality distribution of patented inventions.

Figure 4: Quantile regression results



4.3 Did the "quality" of academic patents decline over time?

Given the changing conditions for academics in terms of research agendas, funding sources, as well as legal structures, we test whether the "quality" of academic patents has evolved over time. To do so, we repeat the baseline regression by interacting the application years with the "academic patent" dummy. The estimated model becomes:

$$E\left[C \mid X\right]T = \exp\left[\sum_t \gamma_t (ACAD * APY_t) + \sum_t \alpha_t APY_t + \sum_c \lambda_c TECH_c + \sum_i \delta_i Z_i + \log(T) + \varepsilon\right] \quad (2)$$

The results are reported in Table 4. The signs and magnitude of the interaction terms suggest that the quality of academic and corporate patents tends to converge over time, which supports our hypothesis 3 of greater pressure put on faculty members to patent, leading to academic patents of lower "importance". The results reveal a decreasing trend in academic patent quality, even without a Bayh-Dole act type of legislation.

Interestingly, the interaction terms of application years and the academic inventor dummy becomes negative and significant after 2001, which corresponds to the period of the abolishment of the "professor privilege". These preliminary estimations suggest that the law change has accelerated the decline in "importance" of academic patents, confirming hypothesis 4; however, we are not able to assess the long-term impact of this policy change for two reasons. First, in order to effectively assess the effect of this new measure, we would need to perform the analysis using a longer time window of the citations. The current result only includes data for two years after the policy change entered into play and we only have three years of citations data for the latest period in our sample. Second, it is not clear whether universities already started to enforce this policy since we only observe four patents granted to universities in the post 2002 period. The present results are therefore only indicative of a negative relationship in the short run. Moreover, as demonstrated by Mowery et al. (2003), universities (and academics) can learn to patent, through experience in patenting and therefore our results might well be different in the long run, once universities start to enforce the new policy by claiming ownership of the patents and establishing efficient technology transfer offices, which does not seem to be the case so far.

Table 4: QMLE Poisson and Negative Binomial regressions for patent forward citations: the "importance" of academic patents over time

	Poisson QMLE			Negative Binomial		
Variables	Coef.		S.E.	Coef.		S.E.
1980-1983*ACAD	0.248	***	0.066	0.264	***	0.060
1984-1987*ACAD	0.159	***	0.056	0.164	***	0.050
1988-1991*ACAD	0.151	***	0.052	0.159	***	0.049
1992-1995*ACAD	0.271	***	0.061	0.282	***	0.056
1996-1998*ACAD	0.037		0.080	0.031		0.072
1999-2001*ACAD	-0.116		0.150	-0.094		0.096
2002-2003*ACAD	-1.004	***	0.341	-0.987	***	0.284
# backward citations	0.046	***	0.006	0.049	***	0.006
NPR	0.048		0.035	0.057	**	0.029
# IPC assignments	0.127	***	0.018	0.134	***	0.015
log(T)	1			1		
Constant	-2.766	***	0.089	-2.816	***	0.086
App. years – test of joint significance	$\chi^2(6)=106.93$***			$\chi^2(6)=135.38$***		
Tech. Classes – test of joint significance	$\chi^2(30)=366.91$***			$\chi^2(30)=362.68$***		
Overdispersion parameter				0.968		0.022
LR test of equidispersion (p-value)				0.000		
Log-likelihood	-25408.794			-19958.754		

4.4 Is the decline driven by academic entry?

Mowery et al. (2006) find that in the U.S., inexperienced universities initially adopted an indiscriminate policy toward patenting as they entered into this activity after passage of the Bayh-Dole Act and patented inventions with little evaluation of the market within their industry. Furthermore, they find that the decline quality of

university patents in the U.S. is largely due to these academic entrants. In order to complement our previous findings we test whether the decline in the quality of faculty patents can be attributed to academics with no historical experience in patenting.
The estimated model becomes:

$$E\left[C \mid X\right]T = [\exp \sum_t \gamma_t (APY_t * ACAD\_INCUM) + \sum_t \omega_t (APY_t * ACAD\_ENT) \\ + \sum_t \alpha_t APY_t + \sum_c \lambda_c TECH_c + \sum_i \delta_i Z_i + \log(T) + \varepsilon], \tag{3}$$

where *ACAD_ENT* equals 1 for all entrant faculty members and 0 for all incumbent Faculty inventors and the control group. Entrants are defined as academic inventors who have never patented before the focal patent. Similarly, *ACAD_INCUM* stands for academic incumbents, who are faculty members that have at least patented once before the focal patent. For a given time period *t*, *exp(ω)* will be indicative of the quality of patents issued to academic entrants relative to those granted to the control group. Similarly, the comparison of ω and γ will measure the difference in quality between academic entrants and academic incumbents.

In the previous section, we identified three periods: the period 1980-1995, in which the academic patents were more important than those of the controls; the period 1996-2001, where this relationship became insignificant, and the period 2002-2003, after the abolishment of the professor privilege, where the relationship became negative. We are going to use these three time windows in order to identify whether entry of new academic inventors played a role in this apparent decline in quality of academic patents.

The results in Table 5 suggest that academic entrants performed better than the controls until 1995. The relationship becomes negative in the 1996-2001 period. The negative effect is even stronger in the post 2001 period (after the abolishment of the professors' privilege).

The results of formal tests for the relative performance of academic entrants and incumbents are presented in Table 6. One-sided χ^2-tests for the null hypothesis $\omega \geq \gamma$ reveal that academic entrants always performed worse than incumbents. However, our previous finding on the decline in quality still holds for academic incumbents, even when controlling for academic entry. This suggests that academic entrants are not causing the decline but that seems to be more secular.

Table 5: Estimation results (3)

	Poisson QMLE			Negative Binomial		
Variables	Coef.		S.E.	Coef.		S.E.
1980-1995*ACAD_ENT	0.161	***	0.039	0.178	***	0.035
1996-2001*ACAD_ENT	-0.102		0.093	-0.115		0.076
2001-2003*ACAD_ENT	-1.399	***	0.418	-1.371	***	0.415
1980-1995*ACAD_INCUM	0.221	***	0.034	0.233	***	0.032
1996-2001*ACAD_INCUM	0.050		0.082	0.051		0.067
2001-2003*ACAD_INCUM	-0.709	*	0.386	-0.696	**	0.340
# backward citations	0.045	***	0.005	0.049	***	0.006
NPR	0.066	*	0.035	0.072	**	0.029
# IPC assignments	0.120	***	0.019	0.131	***	0.015
log(T)	1			1		
Constant	-2.452	***	0.081	-2.464	***	0.076
App. years – test of joint significance	$\chi^2(2)$=38.91***			$\chi^2(2)$=50.01***		
Tech. Classes – test of joint significance	$\chi^2(30)$=365.54***			$\chi^2(30)$=357.39***		
Overdispersion parameter				0.998		0.026
LR test of equidispersion (p-value)				0.000		
Log-likelihood	-25345.270			-20040.445		

Table 6: Test of $\omega \geq \gamma$

	P-value of one-sided χ^2-test	
	Poisson QMLE	Negative Binomial
1980-1995	0.080	0.081
1996-2001	0.065	0.023
2002-2003	0.057	0.080

5 Conclusion

As a major source of knowledge creation the public science sector and universities in particular have attracted considerable attention by policy makers and economic scholars in the recent past. Their main interest is to access the full potential of science and knowledge produces at universities (and other public science institutions) and to identify and facilitate effective ways to improve exploitation of these inventions for the benefit of the economy. In consequence, recent policy endeavors aimed at enhancing knowledge transfer from science to industry. Most prominent and also most significant actions taken by governments of industrialized countries were Bayh-Dole act type of legislation changes to strengthen universities' patenting rights.

Addressing the importance of university inventions as opposed to business inventions previous studies focused on patents as a way to make inventions and their importance (in terms of citations they receive) visible. It is found that university patents outperform patents in the business sector in terms of citations they receive (e.g. Henderson et al., 1998). Not all inventions by university professors are, however, patented through the university (Thursby et al., 2007). The present paper takes an initial step in focusing on the whole landscape of inventions taken out by academic scientists independent of assigneeship on patent documents. By comparing patents with at least one academic on the inventor list to a control group of pure business patents we find that academic involvement in patenting results in greater knowledge externalities as measured by forward citations. Hence, our results confirm the findings by previous studies that focus on university patents only. However, our analysis also suggests that the contribution of academics is underestimated if only patents assigned to universities are taken into account. Indeed, a major channel of knowledge transfer from science to business takes place through consulting and other forms of collaborative research in between academics and firms that become visible in co-invented patents assigned to the private sector. Taking these patents into account is especially important for Europe where Bayh-Dole act type of legislations took place only recently in many countries, which implies that universities claim the right on academics' inventions only in recent years.

Further, we find that in the European context of changing public sector research environments and increasingly competitive funding sources, the "importance" of academic patents declines over time since the mid-90's. This is partly due to inexperienced academics that engage in patenting without any thorough evaluation of the relevant market as is suggested by the low number of citations their patents receive. However, also the relative importance of patents involving experienced academics declined over time. Hence, the quality of corporate and academic patents converge and in the most recent period in our data, academic quality even falls behind corporate quality. This last period corresponds to the introduction of a Bayh-Dole-type policy in Germany, which suggests that this legal disposition led to an acceleration of the patent quality decline. The latter result has to be taken with caution though as it only maps the effects in the immediate years after the abolishment of the professors' privilege and might be a transitory effect.

These results have some interesting implications. In showing that academic and business patents converge over the past decades in terms of importance we find a similar pattern as has been found for the U.S. (e.g. Henderson et al., 1998). The relative quality decline of university patents in the U.S. is typically attributed at least in part to the Bayh-Dole act that led university to increased patenting, though. The fact that we observe the same development for Germany, where the "German Bayh-Dole act" took only place recently, suggests, however, that the convergence between academic and business patents is rather attributable to a reorientation of the public science sector towards marketable research projects, funding sources in the private sector and through industry-science collaborations.

References

Adams, J.D. (1998). *The Industrial Scientific Labor Force since World War II. Proceedings of the Business and Economics Section of the American Statistical Association*. Alexandria, Va.: American Statis. Assoc.

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

Agrawal, A., Henderson, R. (2002). Putting Patents in Context: Exploring Knowledge Transfer from MIT. *Management Science* 48(1): 44-60.

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.

Arrow, K. (1962). Economic Welfare and the Allocation of Resources for Invention. in: Nelson, R.R. (Ed.): *The Rate and Direction of Inventive Activity*. Princeton, NJ: Princeton University Press: 609-25.

Azoulay, P., Ding W., Stuart, T. (2006). *The Impact of Academic Patenting on the Rate, Quality and Direction of (Public) Research*. NBER working paper 11917, Cambridge, MA.

Bacchiocchi, E. and Montobbio, F. (2004). *EPO vs. USPTO Citation Lags*. CESPRI working paper 161.

Breschi, S., Lissoni, F., Montobbio F. (2006). *University Patenting and Scientific Productivity. A quantitative study of Italian academic inventors*. CESPRI working paper n.189, Milan.

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.

Cameron, A.C., Trivedi, P.K. (1998). *Regression Analysis of Count Data*. Cambridge University Press, NY.

Capron, H., Cincera, M. (2003). Industry–University S&T Transfers, Belgian Evidence on CIS data. *Brussels Economic Review* 46 (3): 58– 85.

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

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.

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

Czarnitzki, D., Glänzel, W., Hussinger, K. (2007b). *Heterogeneity of Patenting Activity and Implications for Scientific Research.* ZEW Discussion Paper No. 07-028, Mannheim.

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

Eyzkowitz, H., Webster, A., Gebhardt, C., Cantisano Terra, B.R. (2000). The Future of the University and the University of the Future: Evolution of Ivory Tower to Entrepreneurial Paradigm. *Research Policy* 29: 313-330.

Fabrizio, K.R., DiMinin, A. (2005). *Commercializing the Laboratory: Faculty Patenting and the Open Science Environment*. Working Paper, University of California.

Fleming, L., Sorenson, O. (2004). Science as a Map in Technological Search. *Strategic Management Journal* 25: 909-9280.

Gambardella, A., Harhoff, D., Verspagen, B. (2008). The Value of European Patents, *European Management Review*, forthcoming

Geuna, A. (2001). The Changing Rationale for European University Research Funding: Are there Negative Unintended Consequences. *Journal of Economic Issues* 35: 607–632.

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

Giuri P., Mariani, M., Brusoni, S., Crespi, G., Francoz, D., Gambardella, A., Garcia-Fontes, W., Geuna, A., Gonzales, R., Harhoff, D., Hoisl, K., Lebas, C., Luzzi, A., Magazzini, L., Nesta, L., Nomaler, O., Palomeras, N., Patel, P., Romanelli, M., Verspagen, B. (2006). Inventors and Invention Processes in Europe Results from the PatVal-EU Survey. *Research Policy* 36(8): 1107-1127.

Gourieroux, C., Monfort, A., Trognon, A. (1984). Pseudo Maximum Likelihood Methods: Applications to Poisson Models, *Econometrica* 52(3): 701-20

Griliches, Z. (1984). *R&D, Patents, and Productivity*. Chicago: Univ. Chicago Press.

Hall, B.H., Jaffe, A., Trajtenberg, M. (2001). *The NBER Patent Citations Data File: Lessons, Insights, and Methodological Tools*. NBER Working Paper No. 8498.

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. (2001). Barriers Inhibiting Industry from Partnering with Universities: Evidence from the Advanced Technology Program. *Journal of Technology Transfer* 26: 87-98.

Hall, B.H., Thoma, G., Torrisi, S. (2007). *The Market Value of Patents and R&D: Evidence from European firms*, NBER Working Paper No. 13426.

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

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.

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

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

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., Trajtenberg, M. (2002). *Patents, Citations and Innovation: A Window on the Knowledge Economy*. Cambridge: MIT Press.

Jaffe, A., Trajtenberg, M., Henderson, R. (1993). Geographical Localization of Knowledge Spilloevers as Evidenced by Patent Citations. *Quarterly Journal of Economics* 108: 577-598.

Jensen, R., Thursby, J., Thursby, M. (2007). In or Out: Faculty Research and Consulting, *mimeo*.

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

Lacetera, N. (2008). Multiple Missions and Academic Entrepreneurship*, mimeo*.

Lanjouw, J.O., Schankerman, M. (2001). Characteristics of Patent Litigation: A Window on Competition. *RAND Journal of Economics* 32(1): 129–151.

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

Lichtenberg, F. (1996). Do (More and Better) Drugs Keep People Out of Hospitals? *American Economic Review* 86(2): 384-388.

Lichtenberg, F. (2001). Are the Benefits of Newer Drugs Worth their Cost? Evidence from the 1996 MEPS. *Health Affairs* 20(5): 241-252.

Lichtenberg, F. (2003). Pharmaceutical Innovation, Mortality Reduction, and Economic Growth. In: Murphy, K.M., Topel, R.H. (eds.), *Measuring the Gains from Medical Research: An Economic Approach*. University of Chicago Press, Chicago.

Lissoni F., Sanditov B., Tarasconi G. (2006). *The KEINS Database on Academic Inventors: Methodology and Contents*. CESPRI working paper n.181, Milan.

Mansfield, E. (1991). Academic Research and Industrial Innovation. *Research Policy*, 20(1): 1-12.

Merton, R.K. (1973). The Normative Structure of Science, in: Merton R.K. (ed.), *The Sociology of Science: Theoretical and Empirical Investigations*. Chicago, IL: The University of Chicago Press.

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

Meyer M., Sinilainen T., Utecht J.T. (2003). Towards Hybrid Triple Helix Indicators: A Study of University-related Patents and a Survey of Academic Inventors. *Scientometrics* 58(2): 321- 350.

Mohnen, P., Hoareau, C. (2003). What Type of Enterprises Forges Close Links with Universities and Government Labs? Evidence from CIS2. *Managerial and Decision Economics* 24: 133– 146.

Mowery, D., Nelson, R., Sampat, B., Ziedonis A. (2002). The Growth of Patenting and Licensing by U.S. Universities: An Assessment of the Effects of the Bayh-Dole Act of 1980. *Research Policy* 30: 99-119.

Mowery, D., Sampat B., Ziedonis A. (2002). Learning to Patent: Institutional Experience, Learning abd 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.

OECD (1994). *The Measurement of Scientific and Technological Activities: Using Patent Data as Science and Technology Indicators, Patent Manual*. OECD/GD(94)114, Paris.

Rosenberg, N. (1998). Chemical Engineering as a General Purpose Technology, in: Helpman E. (ed.), *General Purpose Technologies and Economic Growth*. Cambridge: MIT Press, 167-192.

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

Sapsalis, E., van Pottelsberghe de la Potterie, B. (2007). The Institutional Sources of Knowledge and the Value of Academic Patents. *Economics of Innovation and New Technology* 16(2):139-157.

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

Stephan, P., Gurmu, S., Sumell, A.J., Black, G. (2006). Who's Patenting in the University? *Economics of Innovation and New Technology* 16(2): 71-99.

Thursby, J., Fuller, A., Thursby, M. (2007). US Faculty Patenting: Inside and Outside the University, *mimeo*.

Thursby, J.G., Thursby, M.C. (2002). Who is Selling the Ivory Tower? Sources of Growth in University Licensing. *Management Science* 48(1): 90-104.

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.

Toole, A.A., Czarnitzki, D. (2007). Biomedical Academic Entrepreneurship through the SBIR Program. *Journal of Economic Behavior and Organization* 63: 716-738.

Toole, A.A., Czarnitzki, D. (2008). Exploring the Relationship Between Scientist Human Capital and Firm Performance: The Case of Biomedical Academic Entrepreneurs in the SBIR Program, *Management Science*, forthcoming.

Trajtenberg, M. (1990). A Penny for Your Quotes: Patent Citations and the Value of Innovations. *RAND Journal of Economics* 21(1): 172-187.

Trajtenberg, M. (2001). Innovation in Israel 1968-97: A Comparative Analysis Using Patent Data. *Research Policy* 30: 363-389.

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.

Veugelers, R., Cassiman, B. (2005). R&D Cooperation between Firms and Universities. Some Empirical Evidence from Belgian Manufacturing. *International Journal of Industrial Organization* 23: 355-379.

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. (2000). Capturing Technological Opportunities via Japan's Star Scientists. *Journal of Technology Transfer* 26: 37-58.

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

Zucker, L.G., Darby M.R., Armstrong, J.S. (2002). Commercializing Knowledge: University Science, Knowledge Capture, and Firm Performance in Biotechnology, *Management Science* 48(1): 138-153.

Appendix

In this Appendix we report robustness checks for the results found in the text, using alternative sample specifications.

A. Academic patents with corporate assignees.

In this Section, we repeat all regressions made in the text using only those academic patents with corporate assignees. The construction of the control group follows the strategy described in Section 3. Descriptive statistics for the new sample are provided in Table 1a.

Table 1a: Descriptive statistics

	Academic patents				**Control group**			
	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
Number of forward citations	2.754	3.925	0	58	2.228	3.108	0	48
Number of IPC assignments	1.675	0.846	1	11	1.576	0.778	1	8
Non-patent references	0.368	0.482	0	1	0.260	0.438	0	1
Number of backward citations	3.591	2.311	0	19	3.821	2.238	0	18
Number of observations	3,901				3,901			

Table 2a repeats the regression made in Table 2. The results are consistent with those discussed in the text and the coefficient for the academic dummy is close to the one previously found.

Table 2a: QMLE Poisson and Negative Binomial regressions for patent forward citations: academics patents versus controls

	QMLE Poisson			Negative Binomial		
Variables	Coef.		S.E.	Coef.		S.E.
ACAD	0.190	***	0.030	0.187	***	0.027
# backward citations	0.043	***	0.006	0.047	***	0.006
NPR	0.043		0.039	0.055	*	0.032
# IPC assignments	0.134	***	0.020	0.144	***	0.018
log(T)	1			1		
Constant	-2.818	***	0.125	-2.874	***	0.114
App. years – test of joint significance	$\chi^2(23)=149.02$***			$\chi^2(23)=194.12$***		
Tech. Classes – test of joint significance	$\chi^2(30)=294.62$***			$\chi^2(30)=303.31$***		
Overdispersion parameter				0.988		0.025
LR test of equidispersion (p-value)				0.000		
Log-likelihood	-20129.568			-15675.812		

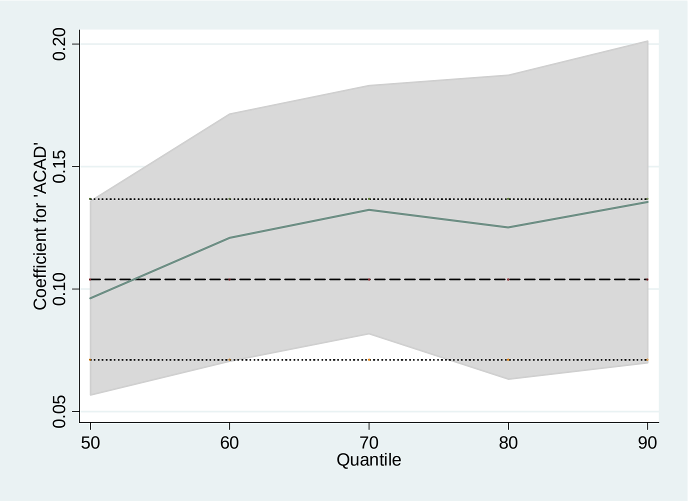
Table 4a repeats the regression from Table 4 by interacting the academic dummy with year dummies. The results are again consistent with those from our baseline sample and exhibit the same trend.

Table 4a: QMLE Poisson and Negative Binomial regressions for patent forward citations: the "importance" of academic patents over time

	Poisson QMLE			Negative Binomial		
Variables	Coef.		S.E.	Coef.		S.E.
1980-1983*ACAD	0.307	***	0.078	0.324	***	0.069
1984-1987*ACAD	0.143	**	0.064	0.153	***	0.057
1988-1991*ACAD	0.148	***	0.058	0.159	***	0.055
1992-1995*ACAD	0.310	***	0.068	0.319	***	0.063
1996-1998*ACAD	0.088		0.095	0.083		0.085
1999-2001*ACAD	-0.020		0.168	-0.007		0.114
2002-2003*ACAD	-0.931	**	0.374	-0.996	***	0.308
# backward citations	0.043	***	0.006	0.047	***	0.006
NPR	0.046		0.039	0.057	*	0.032
# IPC assignments	0.133	***	0.021	0.142	***	0.018
log(T)	1			1		
Constant	-2.804	***	0.101	-2.861	***	0.076
App. years – test of joint significance	$\chi^2(6)=79.31$***			$\chi^2(6)=104.13$***		
Tech. Classes – test of joint significance	$\chi^2(30)=298.95$***			$\chi^2(30)=301.97$***		
Overdispersion parameter				0.988		0.025
LR test of equidispersion (p-value)				0.000		
Log-likelihood	-20131.941			-15675.261		

The quantile regression gives identical results as the ones found in the text, as the coefficient for the academic dummy remains within the boundaries of the OLS confidence interval.

Figure 3a: Quantile regression



Finally, the estimation that interacts application years with academic entrants and incumbents supports the results found in the text.

Table 5a: Estimation results (3)

	Poisson QMLE			Negative Binomial		
Variables	Coef.		S.E.	Coef.		S.E.
1980-1995*ACAD_ENT	0.196	***	0.045	0.213	***	0.041
1996-2001*ACAD_ENT	-0.027		0.113	-0.056		0.092
2001-2003*ACAD_ENT	-1.263	***	0.454	-1.206	***	0.454
1980-1995*ACAD_INCUM	0.219	***	0.038	0.236	***	0.036
1996-2001*ACAD_INCUM	0.099		0.094	0.109		0.077
2001-2003*ACAD_INCUM	-0.719	*	0.419	-0.689	**	0.362
# backward citations	0.044	***	0.006	0.049	***	0.006
NPR	0.069	*	0.039	0.075	**	0.033
# IPC assignments	0.126	***	0.021	0.139	***	0.018
log(T)	1			1		
Constant	-2.485	***	0.090	-2.507	***	0.085
App. years – test of joint significance	$\chi^2(2)=27.47$***			$\chi^2(2)=33.32$***		
Tech. Classes – test of joint significance	$\chi^2(30)=288.21$***			$\chi^2(30)=283.91$***		
Overdispersion parameter				1.019		0.026
LR test of equidispersion (p-value)				0.000		
Log-likelihood	-20387.441			-15743.745		

B. All patent applications.

In this Section, we repeat all regressions made in the text using all patent applications instead of the granted ones only, and by constructing an adequate control group as before. Descriptive statistics for the new sample are provided in Table 1b.

Table 1b: Descriptive statistics

	Academic patents				**Control group**			
	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
Number of forward citations	2.128	3.284	0	58	1.861	2.728	0	48
Number of IPC assignments	1.681	0.882	1	11	1.590	0.818	1	8
Non-patent references	0.378	0.485	0	1	0.184	0.388	0	1
Number of backward citations	3.646	2.457	0	21	3.941	2.359	0	23
Number of observations	8,396				3,977			

Table 2b shows that the coefficient on the academic dummy is slightly lower, as can be expected, when we take all applications into account. However, the effect is still positive and significant.

Table 2b: QMLE Poisson and Negative Binomial regressions for patent forward citations: academics patents versus controls

	QMLE Poisson			Negative Binomial		
Variables	Coef.		S.E.	Coef.		S.E.
ACAD	0.120	***	0.022	0.111	***	0.021
# backward citations	0.046	***	0.004	0.048	***	0.005
NPR	0.039		0.027	0.022		0.024
# IPC assignments	0.112	***	0.014	0.123	***	0.013
log(T)	1			1		
Constant	-2.884	***	0.088	-2.921	***	0.087
App. years – test of joint significance	$\chi^2(23)$=290.75***			$\chi^2(23)$=344.30***		
Tech. Classes – test of joint significance	$\chi^2(30)$=431.75***			$\chi^2(30)$=473.84***		
Overdispersion parameter				1.053		0.087
LR test of equidispersion (p-value)				0.000		
Log-likelihood	-37756.242			-30214.231		

The quantile regression gives the same results as before, i.e., the academic dummy remains within the boundaries of the OLS confidence interval.

Figure 3b: Quantile regression

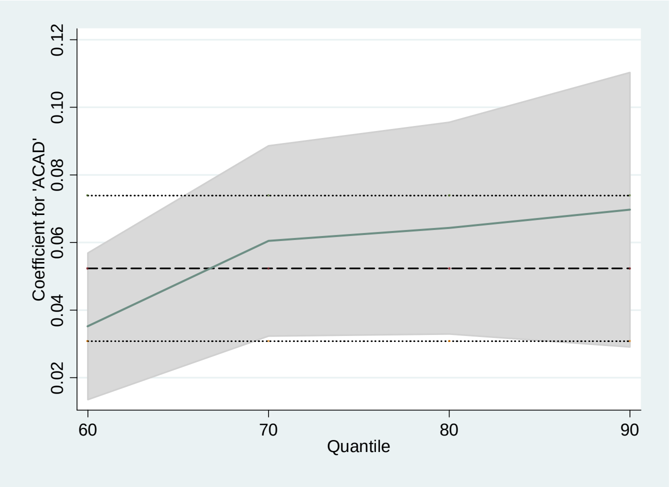


Table 4b is consistent with our previous results in showing the decline of the quality of academic patents over time.

Table 4b: QMLE Poisson and Negative Binomial regressions for patent forward citations: the "importance" of academic patents over time

	Poisson QMLE			Negative Binomial		
Variables	Coef.		S.E.	Coef.		S.E.
1980-1983*ACAD	0.262	***	0.059	0.276	***	0.056
1984-1987*ACAD	0.099	**	0.046	0.112	***	0.044
1988-1991*ACAD	0.113	***	0.044	0.121	***	0.041
1992-1995*ACAD	0.169	***	0.051	0.183	***	0.048
1996-1998*ACAD	0.061		0.064	0.073		0.057
1999-2001*ACAD	-0.112		0.086	-0.092		0.054
2002-2003*ACAD	-0.609	**	0.084	-0.580	***	0.149
# backward citations	0.045	***	0.004	0.048	***	0.004
NPR	0.046	*	0.027	0.028		0.024
# IPC assignments	0.110	***	0.014	0.121	***	0.013
log(T)	1			1		
Constant	-2.868	***	0.073	-2.911	***	0.072
App. years – test of joint significance	$\chi^2(6)=121.19$***			$\chi^2(6)=149.35$***		
Tech. Classes – test of joint significance	$\chi^2(30)=433.57$***			$\chi^2(30)=471.70$***		
Overdispersion parameter				1.055		0.020
LR test of equidispersion (p-value)				0.000		
Log-likelihood	-37785.295			-30230.821		

Finally, the results reported in Table 5b confirm our previous findings concerning the decline of quality for academic entrants and incumbents.

Table 5b: Estimation results (3)

	Poisson QMLE			Negative Binomial		
Variables	Coef.		S.E.	Coef.		S.E.
1980-1995*ACAD_ENT	0.126	***	0.033	0.143	***	0.031
1996-2001*ACAD_ENT	-0.099		0.066	-0.087		0.055
2001-2003*ACAD_ENT	-0.901	***	0.228	-0.874	***	0.198
1980-1995*ACAD_INCUM	0.163	***	0.029	0.168	***	0.028
1996-2001*ACAD_INCUM	0.063		0.060	0.067		0.050
2001-2003*ACAD_INCUM	-0.336		0.219	-0.303	*	0.181
# backward citations	0.045	***	0.004	0.048	***	0.004
NPR	0.053	*	0.027	0.033		0.025
# IPC assignments	0.105	***	0.014	0.118	***	0.013
log(T)	1			1		
Constant	-2.580	***	0.060	-2.588	***	0.062
App. years – test of joint significance	$\chi^2(2)=9.04$***			$\chi^2(2)=56.26$***		
Tech. Classes – test of joint significance	$\chi^2(30)=428.06$***			$X^2(30)=460.94$***		
Overdispersion parameter				1.076		0.020
LR test of equidispersion (p-value)				0.000		
Log-likelihood	-38056.274			-30310.459		