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Industry Funding of University Research and Scientific Productivity*

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Abstract

University research provides valuable inputs to industrial innovation. It is therefore not surprising that private sector firms increasingly seek direct access through funding public R&D. This development, however, spurred concerns about possible negative long-run effects on scientific performance. While previous research mainly focused on a potential crowding-out of scientific publications through commercialization activities such as patenting or the formation of spin-off companies, we study the effects of direct funding from industry on professors' publication and patenting efforts. Our analysis on a sample of 678 professors at 46 higher education institutions in Germany shows that a higher share of industry funding of a professor's research budget results in a lower publication outcome both in terms of quantity and quality in subsequent years. For patents, we find that industry funding increases their quality measured by patent citations.

Keywords: Scientific Productivity, Research Funding, Academic Patents, Technology Transfer

JEL-Classification: O31, O32, O33

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1 Introduction

Over the past decades, universities have widened their activities beyond teaching and academic research. In particular, university research provides knowledge inputs to private-sector innovation (Jaffe 1989; Salter and Martin 2001 for a review). One of the main channels through which knowledge and technology are transferred from science to the private sector is research conducted by university researchers for industry. The value of such inputs for the innovation performance of firms has been found to be considerable (Mansfield 1991, 1995, 1998; Zucker et al. 2002; Cohen et al. 2002; Cassiman et al. 2008).

It is therefore not surprising that firms increasingly seek direct access to university knowledge through sponsoring research projects. A recent OECD study shows a rise in industry funding for public sector R&D in most OECD countries. In Europe, Germany experienced the most significant increase. From 1997 to 2007, industry funding for public R&D in Germany doubled from 6.2% to 12.5% of R&D expenditure in higher education. Likewise in other continental European countries such as Italy (0.6% in 1997 and 3.2% in 2007), and Austria (2% in 1998 and 4.5% in 2007) private sector funding for public R&D is growing (OECD 2009).

While some policy makers argue that the potential of universities to foster and accelerate industrial innovations is not yet fully exploited and thus believe that there is still room for improving the (social) returns from academic research (European Commission 2003a,b; OECD 2007; Dosi et al. 2006), others are concerned with the distraction of academics from their actual research mission. From a private-sector perspective, the benefits of collaborating with academia are found to be unambiguously positive, whereas the effects on the scientific sector are not as clear cut. On the one hand, science may benefit from the initiation of new ideas from industry or the use of industry funds for hiring additional researchers or investment in lab equipment (Rosenberg 1998; Siegel et al. 1999). On the other hand, traditional incentives in scientific research characterized by knowledge sharing and rapid disclosure of research outcomes may be distorted (Blumenthal et al. 1996a,b; Campbell et al. 2002). Moreover, commercial interests may induce scientists to select research projects on the basis of their perceived value in the private sector and not solely on the basis of scientific progress. Increased funding from industry may thus be accompanied by a shift in scientists' research agendas and in the incentives for disclosure that leads to a lower number of academic publications and to less effort devoted to basic research. Further, inventions that address market demand may not necessarily be close to the academic research frontier (Trajtenberg et al. 1997).

Previous research focused to great extent on the productivity effects of increased commercialization of university research via academic patenting and licensing (e.g. Henderson et al. 1998a,b; Thursby and Thursby 2002; Azoulay et al. 2009; Czarnitzki et al. 2009), academic entrepreneurship (e.g. Ding and Stuart 2006, Toole and Czarnitzki 2010) and the engagement in contract research (e.g. Lach and Schankerman 2004; Carayol 2007) and collaborative research (e.g. Zucker et al. 2002). Although consulting and contract research are often the quid pro quo for industry funds, there is only a handful of empirical evidence on the effects of industry funding on university research directly.

This study aims to add to previous research by studying the effects of industry sponsoring on professors' scientific productivity. Our data contains information on laboratory and funding characteristics as well as on publication and patent output for 678 professors at 46 different universities in Germany covering a broad range of research fields in science and engineering. Germany is particularly interesting for studying the effects of industry funding as it has a strong tradition of public research funding on the one hand, and on the other hand experienced the most significant increase in industry funded university research among all OECD countries. We find that a higher budget share from industry reduces publication output of professors in terms of both quantity and quality in subsequent years. In turn, industry funding has a positive impact on the quality of applied research if measured by patent citations. Industry funding may thus still have beneficial effects by improving impact and quality of more applied research. Our results have important implications for policy makers aiming at encouraging technology transfer between science and industry and for public funding authorities. An increasing reliance on industry funding may indeed have an impact on the development of science in the long run. On the other hand, industry funded research results in successfully patentable and industrially relevant technologies that may create economic as well as social value.

The following section gives an overview of insights from the literature on industry-science links and their impact on academic research and the role of industry funding for universities. Section 3 describes our data set. The set-up of our empirical study and the results of the econometric analysis are presented in section 4. Section 5 concludes.

2 Industry-science links and academic productivity

Private sector incentives for engaging in relationships with science can be found in the increased speed and scope of technological change and the emergence of complex and multidisciplinary research fields. “Science-based technologies" such as biotechnology or nanotechnology have further strengthened the role of science for technological innovation. Public science provides important knowledge inputs and organizational pre-conditions and reduces the risk for firms to expand in new fields of technology (e.g. Mowery 1998; Zucker and Darby 1996; Zucker et al. 2002).

To stimulate incentives for the commercialization of university research in the scientific sector, reforms of the (legal) research environment in the U.S., but also in Europe, were aimed at reducing the (administrative) burden of such activities for university researchers. Reforms generally increased commercialization efforts. In the U.S., for example, academic patenting soared (Mowery et al. 2001; Sampat 2006). Additionally, policies encouraging industry funding of academic research such as tax credits (OECD 2002) and government sponsored programs to support technology partnerships (for instance the SBIR in the U.S., see Audretsch et al. 2002; Link and Scott 2005) have been installed. The increased involvement of university researchers in such activities, however, has also generated a considerable controversy about the potential long-term effects on the future development of scientific. These concerns rest on the assumption that there is indeed a trade-off between research that is being disclosed in publications and more applied work that is of interest for industry (Rosenberg and Nelson 1994).

This stands in contrast to the observation that research can result in both basic research findings and industrial applications. As argued by Stokes (1997), research can be located in “Pasteur’s Quadrant” implying that increased commercial incentives may lead to a shift from basic to applied research or from basic to dual-purpose research (see also Azoulay et al. 2009; Murray 2002; Levin and Stephan 1991). Sauerman et al. (2010) suggest that the latter argument could also imply that researchers who were engaged in dual-purpose research before do now merely exploit the commercial potential of their research without fundamentally changing their research agendas. Rosenberg (1998) regards industry contacts as a source of new research ideas and thus argues that science can benefit from increased collaboration with industry. Moreover, Azoulay et al. (2009) suggest that researchers benefit from the realization of complementarities between basic and applied research that otherwise would remain foreclosed. The authors point to intra-person economies of scope that emerge when a scientist is involved in both the development of academic and commercial research outcomes. Furthermore, it has been argued that crowding-out of traditional research can be averted if scientists are assisted in their work for industry by their university's technology transfer office (TTO). The involvement of a TTO may reduce the individual researchers' burden and hence leave more time for other research projects (Hellman 2007). From the scientists' perspective, industry grants provide an attractive source of funds supplementing 'core funding' and other public research funding. Such funds can be used to hire additional scientists who increase the lab's overall research output for both applied and basic research.

Despite these arguments in favor of industry funding for university research, skeptics argue that the traditional incentives in science that were characterized by knowledge sharing and rapid disclosure of research outcomes may be affected by industry grants and contracts (David et al. 1992, Dasgupta and David 1994; Nelson 2001). The critical question is thus to what degree increasing industry sponsoring induces a "skewing problem". Does the option to attract industry funding (in addition to the core institutional funding) change the incentives of scientists to contribute to public (i.e., non-excludable) advances in the scientific literature? Even though the relative magnitude of industrial funding is not really high, it may be a critical resource influences faculty behavior. Slaughter and Leslie (1997) as well as Benner and Sandström (2000) argue that funding influences the behavior and outputs of researchers. Scientists' incentives to create and immediately publish their research findings are obvious if their careers depend on their contributions to science in the form of publications and (graduate) education. The possibility to generate additional funds from industry may affect these incentives. That financial incentives do also play a role for scientists to engage in commercial activities has been emphasized in the literature (e.g., Ding and Stuart 2006; Jensen et al. 2003, Lach and Schankerman 2008). Monetary incentives may not only affect scientists' willingness, but also their ability to share information with fellow scientists. Publishing of research results may for instance be hampered if industry funding has "strings attached" that affect incentives to disclose research results for free in academic journals. As a survey described in Thursby and Thursby (2002) documents that firms usually require researchers to sign a contract that includes a delay of publication clause (see also Louis et al. 2001). Cohen et al. (1994) report that a significant share of industry–university research centers in the U.S. allows cooperating firms to delete information from published reports and the right to delay publication.

As knowledge sharing among scientists is the basis for cumulative knowledge production and thus for scientific progress (Haeussler et al. 2010), industry funding that affects the incentives to share knowledge may have detrimental effects on the development of science. Further, long-run effects from industry-funded research projects may arise from the intensively and continuous involvement of the professors in the projects. This involvement has been shown to be necessary for university inventions to be successfully commercialized, but at the same time may distract researchers from other types of research (Jensen and Thursby 2001; Toole and Czarnitzki 2010).

Finally, there may be a tradeoff between doing research for industry and publishing simply because of the time that is consumed by these alternative activities. It may become more attractive to spend time doing research that is closer aligned to industry interests than other (basic) research. In other words, due to time constraints, researchers' publishing rates may decrease in favor of industry funded projects.

In the light of these arguments on why science may benefit from industry involvement such as research funding and why it may not, the net-effects from on science are not obvious.

Empirical Evidence on the effects of industry-sponsored research

Blumenthal et al. (1996a, b) and Campbell et al. (2002) report survey-based evidence on negative effects from industry sponsoring on the publication of research results, knowledge sharing and the speed of knowledge disclosure. Blumenthal et al. (1997) find that U.S. academic life scientists had withheld research results due to intellectual property rights discussions such as patent applications (see also Louis et al. 2001). Godin and Gingras (2000), on the other hand, find that Canadian university researchers with funding from industry produce more scientific publications than their colleagues without such funding. They argue that this may be due to the fact that there is no trade-off between many types of contract research and academic science, and/or that scientific quality is a prerequisite for attracting such contracts in the first place. Industry may thus not only look at the researchers' past patenting profile in order to assess their skills but also at publications and hence even strengthen the incentives for publishing by creating a signal of the scientist's quality.

Behrens and Gray (2001) study effects of different funding sources (industry, government and no external sponsor) on a variety of research processes and outcomes for graduate students at engineering departments in the U.S. of which almost 50% spent most of their time working on a project which was supported by industry. The authors argue that most industry support is channeled by cooperative research centers where it is complemented by government support. As a consequence, total industry support amounts to approximately 20%-25% in the disciplines they study. Their findings suggest, however, that although the source of sponsorship and, to a lesser degree, the form of sponsorship are associated with a number of differences, these differences tend to be minor and related to structural aspects of a student's research involvement and not eventual research outcomes. Gulbransen and Smeby (2005) find that researchers at Norwegian universities who had grants from industry also collaborate more extensively with industry than those without grants or contracts. They also study the relationship between industry funding and professors' self-assessment of their research focus, i.e. basic, or more applied, and conclude that industrial funding is related to applied research, but not to basic research or development. Gulbransen and Smeby also find a positive correlation between industry funding and scientific productivity, but no correlation between commercial outputs and publications. Gulbrandsen and Smeby, however, do neither have information about the amount of funding nor on the share of that funding of the entire research budget. They just have information whether or not someone received funding from industry. Thus, it may be that the information of whether or not a professor has funding from industry is insufficient, as the number of grants or the relative share of industry funding compared to core funding may constitute the critical factor. Bozeman and Gaughan (2007) focus their study on the impact of research grants and contracts on interactive activities with industry and find that industry funding strengthens industry-science collaboration. They, however, provide no implications of increased collaboration on scientific productivity. Boardman and Ponomariov (2009) study the effects of industry grants on a broad set of indictors. They conclude that additional industry grants increase the likelihood of university scientists co-authoring papers with industrial scientists for academic journals, however, provide no "before and after" comparison of the university researchers' publication behavior.

Van Looy et al. (2004) find no evidence of a skewing problem at the Catholic University of Leuven in Belgium. They find that professors with industry contracts publish more than their colleagues without such contracts. However, selection effects are not controlled for in the study which makes it difficult to determine whether industry funding is causal or a reflection of the fact that industry selects the most productive researchers. Interestingly, a study on the same university by Kelchtermans and Veugelers (2011) – although not distinguishing between the sources of funds – finds that having access to project funding is positively related to research output, but that the effect of funding on productivity is smaller for higher quantiles and even negative at the very top of the distribution.

In summary, while the role of particular forms of technology transfer channels appear to be quite well understood, the effects of industry funding are not as clear. This study aims to shed light on the impact of private sector research sponsoring on professors' subsequent scientific achievements.

3 Data

The empirical analysis of this paper is based on a unique dataset that had been created from different data sources. The core data had been collected by a survey among research units at German higher education institutions in the fields of science or engineering, i.e. physics, mathematics and computer science, chemistry and pharmaceuticals, biology and life sciences, electrical and mechanical engineering and other engineering and related fields such as geosciences. In spring 2000 the Centre for European Economic Research (ZEW, Mannheim) conducted a survey among a random sample of research units at general universities, technical universities and polytechnic colleges ("universities of applied sciences") stratified by regions. The questionnaire addressed "head of departments", in general full professors who have budget and personnel responsibility.[i]

The German public research system also comprises non-university institutions such as Fraunhofer Society, Max-Planck Society, HGF Association of German Research Centers and WGL Science Association, to name only the four largest associations of publicly funded research institutes. The original survey also addressed such public non-profit research institutions. We do not consider these institutions in our analysis as they differ substantially from research units at universities and polytechnics, for instance with respect to the organizational structure and the fact that there is no teaching. General universities have both a research and an education mission within one organizational unit. They account for the lion's share of total R&D expenditure on public research in Germany with about 45%. Technical Universities (TUs) specialize in science and engineering and account for about 7% of total public R&D. Universities of Applied Sciences (UaS) account for about 2% (Czarnitzki and Rammer 2003).

The overall response rate to the survey was 24.4% providing us with information on 724 different professors and their research teams. After the elimination of incomplete records, our final sample contains 678 professor-research unit observations from 46 different institutions of which 56% are universities, 23% are TUs and 21% are UaS. For each of the 16 German States (*Länder*), the sample comprises at least one observation (see Table A.2 for details). The key variables of interest are obtained directly from the survey. The professors were asked to indicate the amount and composition of "third-party funding"[ii] that they received during 1999 in addition to their core funding as a share of their total budget. In the final sample more than 61% of the professors received funds from industry. The amount of industry funding and its share of the total budget *(INDFUND)* at the level of the research unit differ between the types of institutions (see Table 1). The share of research grants from public sources of total budget *(GOVFUND)* is comparable between universities and technical universities, but considerably lower at UaS.

TUs show the highest share with 10.6% of their total budget which amounts to more than 160 thousand Euros on average in the year of the survey. The average number of staff per research unit (*LABSIZE*) is about 20 (median 13). The teams are slightly larger at technical universities compared to non-technical universities. UaS show significantly smaller numbers. The share of team members with a non-scientific, but technical background *(TECHS)* is larger than a quarter at UaS and thereby also larger at both techs and universities. Also the share of people in the team with a PhD *(POSTDOCS)* is largest at UaS. This, however, is due to the smaller overall team size and the lack of doctoral students. We know from the survey whether the professor had contact to his institution's Technology Transfer Office *(TTO).* As it is conceivable that such contacts may impact both stronger technology transfer awareness and the time burden of such activities, it may also have effects on patenting and publishing activities. At universities, only two thirds of the professors had contacts to the TTO compared to 79% at TUs and 87% at UaS. The number of female professors is negligible with only 22 of the 678 professors in or sample being female.

3.1 Publication and Patent data

As we are interested in the scientific performance at the level of the individual researcher, or more precisely at the level of the head of the research unit, we supplemented the survey data with publication and patent information. We use the publication and patent output of the responding professor as a proxy for the research output of his research unit.[iii] The data base of the German Patent and Trademark Office (DPMA) contains all patents filed with the DPMA. Since applicants are obliged by law to disclose the name of the inventor in the patent application, we searched through this database for all patents which listed professors from our sample as inventors. One technique for measuring the quality or impact of patents is patent citation analysis. There are basically two types of citations on a patent. First, citations of other patents by the inventor (or the applicant) and citations added by the examiner of the patent application. We focus on "forward citations" to the patents, defined as the number of citations received by each patent following its issue. Patent forward citations have been proved to be a suitable measure for the quality, importance or significance of a patented invention and have been used in various studies (see e.g. Henderson et al. 1998a; Hall et al. 2001; Trajtenberg 2001 or Czarnitzki et al. 2008). The publication histories of the professors were traced in the ISI Web of Science® database of Thomson-Scientific (Philadelphia, PA, USA) which provides data on publications in scientific journals and bibliometric indicators. Thomson Scientific identifies and indexes a broad range of journals in all areas of the sciences, social sciences, and arts and humanities. The database covers all significant document types within these journals including articles, letters, notes, corrections, additions, excerpts, editorials and reviews. Records contain information such as the title, authors, keywords, cited references, abstracts and other document details. We searched for publications (articles, notes, reviews and letters) of professors in our sample through the *ISI Web of Knowledge®* platform by their name and subsequently filtered results on the basis of affiliations, addresses and journal fields. In order to assign the publications correctly to the professor, we also collected information of their career paths that allowed us to relate publication records to professors even if the affiliation on the publication did not correspond to the current one. The publication record in the database also contains the number of citations that each publication received. We use the citation counts, i.e. the number of forward citations to those publications as indication of publication quality or impact of each professor. Several authors have shown, that - despite some limitations - citation counts are an adequate indicator to evaluate research output (e.g. Garfield and Welljams-Dorof 1992; Baird and Oppenheim 1994).[iv]

Since we are interested in the professors' publication and patent track record and the respective citation counts *before* the survey as well as in their performance in the years after, we collect all patents and publications from the professor's first entry until the end of 2007. The number of past publications depends of course on the academic experience or seniority of the researcher. To control for differences in experience, we therefore gathered information from the German National Library on the year in which the professors received their PhDs.[v] From this information, we calculate the years of the professors' experience (*EXPERIENCE*) in academia. Although our professors are all rather senior (and tenured) academic staff heading a research unit, we still want to control for life cycle effects as publication output has been shown to depend on the position in the academic life cycle (see e.g. Thursby et al. 2007). The average professor had been working for 22 years since receiving his PhD when filling out the survey in the year 2000 (median is 22, too). This relatively high level of experience is of course due to the fact that the survey targeted "head of research units". However, for a few professors, who according to their CVs either obtained their doctoral degree abroad or do not have a PhD[vi], we used the year of their first publication as a proxy for the beginning of their academic career. If professors with very common names like "Müller" or "Fischer" and also common first names appeared in our dataset, we preferred to drop these observations from our dataset since publication and/or patent data could not be uniquely identified for them. For our main analysis, we limited the time horizon for publications, patents and citations to the period from 1994 to 2007[vii]. We thus fixed the "activity window" to six years before (1994-1999) and the eight years after the survey (2000-2007). In the former period, professors at universities on average published 16 items, professors at TUs about 6 and UaS professors 2. While we find high citations counts for university publications, the 'times cited' for the other two categories is much lower (344 compared to 128 and 23, respectively). This is also reflected in the average number of citations per publication although the difference between universities and technical universities is much smaller (see Table 1). For patent applications, the picture is less diverse across types of institutions. The average number of patent applications is 1.54 for university patents, 1.27 for patents from technical universities and 1.20 from UaS. Patents from technical universities are, however, cited more frequently. In our data, a relatively small number of university professors are responsible for the majority of publications. 14% of the professor published nearly 50% of the total number of publications. The same is true for citations: there are very few highly cited professors, 11% with more than 1,000 total citations or more than 40 citations per paper. This pattern is characteristic for publication output (see e.g. Kyvik 1991, 2003). For patent applications and citations, we find a similar picture. 45% have not applied for a patent at all. From the total of 3,079 patent applications, 10% of the professors account for a quarter of these patents. The fact that not all patent applications are usually successful has to be taken into account while looking at the mean of patent forward citations which indicates that 67.7% of the patents received no forward citation at all. The average number of application among those with at least one patent is 6 with a maximum of 67 patent applications in the period 1994-2007.

Looking at industry funding by research fields shows that it is highest in engineering, in particular for mechanical engineering with more than 240.000€ or about 14% of their total budget. The distribution of industry funds, however, is skewed (the median for mechanical engineering is about 88.000€ and 10% of total budget). The share of industry funding is lowest in physics and mathematics which is probably due to the rather theoretical research orientation of many professors in these fields (Table 2). Looking at research productivity by fields illustrates that in chemistry, physics, and biology, professors published most and also received a larger number of citations per publication compared to mechanical or electrical engineering. Patenting activity is highest among electrical engineers and as expected lowest among mathematicians and computer scientists both in terms of patent application as well as in terms of citations that their patents receive (Table 3).

Table 1: Funding and scientific productivity (variable means by type of institution)

Description	**Variable**	**Uni**	**TU**	**UaS**
Funding:				
Amount Ind. Funding (T €)		98.044	168.463	61.735
Share of Ind. Funding in % of Total Budget	*INDFUND*	7.60	10.56	9.29
Amount Gov. Grants (T €)		181.56	192.07	11.53
Share of Gov. Grants in % of Total Budget	*GOVFUND*	26.64	25.04	6.11
Scientific Output 1994-1999:				
Publications	$PUB_{1994\text{-}1999}$	16.35	6.46	2.28
Citation Count of Publications	$CITPUB_{1994\text{-}1999}$	344.77	128.17	22.82
Average Citations per Publication	$CITperPUB_{1994\text{-}1999}$	15.44	7.52	4.67
Patents	$PAT_{1994\text{-}1999}$	1.54	1.27	1.20
Citation Count of Patents	$CITperPAT_{1994\text{-}1999}$	16.25	35.61	12.77
Average Citations per Patent	$CITPAT_{1994\text{-}1999}$	3.81	4.23	3.71
Scientific Output 2000-2007:				
Publications	*PUB*	26.24	13.34	2.99
Citation Count of Publications	*CITPUB*	256.73	124.17	15.76
Average Citations per Publication	*CITperPUB*	7.46	3.57	1.85
Patents	*PAT*	1.44	1.20	1.28
Citation Count of Patents	*CITPAT*	1.02	1.17	1.17
Average Citations per Patent	*CITperPAT*	0.23	0.24	0.10
Controls:				
Number of people at lab	*LABSIZE*	21.38	24.31	15.73
Number of years since PhD	*EXPERIENCE*	22.57	24.46	16.32
Contact to TTO dummy	*TTO*	0.66	0.79	0.87
% technical employees	*TECHS*	7.01	7.85	19.87
% employees with PhD	*POSTDOCS*	22.54	19.52	25.50
Female Professor dummy	*GENDER*	0.03	0.03	0.04

In our sample, we find that there are three types of scientists. First, purist researchers who did neither file patents nor received industry funding (27%). The finding that almost half of our professors never patent is in line with findings by Agrawal and Henderson (2002) who report similar numbers for faculty at MIT. A second group of professors may be named "commercialists". They engage actively in patenting and receive a substantial share of their budget from industry funding (*INDFUND* > 10% and at least 3 patent applications between 1994 and 2007, 11%). These professors publish below average (on average 9 publication from 1994-1999 and about 19 from 2000-2007). Third, the sample comprises a considerable number of researchers in between the two extremes.

Table 2: Funding by Research Field

Field	**Freq.**	**%**	**Amount of Industry Funding (T €)**	**% Ind. Funding of Total Budget**
Physics	104	15.34	47.52	4.32
Mathematics and Computer Science	107	15.78	39.09	5.95
Chemistry	95	14.01	68.05	6.06
Biology	58	8.55	28.70	7.46
Electrical Engineering	101	14.90	130.75	11.54
Mechanical Engineering	110	16.22	241.43	14.13
Other Engineering	103	15.19	150.48	10.13
	678	100.00		

Table 3: Scientific Productivity by Research Field

	Publications	**Citation Count**	**Citations per publication**	**Patents**	**Citation Count**	**Citations per patent**
Field	**Publications 1994-1999**			**Patents 1994-1999**		
Physics	22.47	612.89	21.74	1.11	17.11	2.97
Mathematics and Computer Science	3.97	44.49	6.57	0.21	0.84	0.56
Chemistry	27.53	513.24	16.07	1.80	23.24	5.47
Biology	11.52	320.59	21.83	0.91	7.60	3.67
Electrical Engineering	3.93	53.88	5.62	2.27	33.74	7.28
Mechanical Engineering	3.46	28.12	4.99	1.84	39.69	5.65
Other Engineering	6.94	93.62	7.97	1.57	12.33	1.70
	Publications 2000-2007			**Patents 2000-2007**		
Physics	33.29	419.68	9.45	0.91	1.06	0.20
Mathematics and Computer Science	6.50	39.54	3.61	0.25	0.08	0.02
Chemistry	39.06	376.64	8.40	1.52	0.67	0.13
Biology	19.45	247.71	9.26	1.14	0.76	0.15
Electrical Engineering	11.58	84.04	3.00	1.90	2.11	0.45
Mechanical Engineering	6.54	24.91	2.31	1.91	0.91	0.26
Other Engineering	15.33	94.94	3.78	1.79	0.84	0.20

3.2 The abolishment of the Professors' Patent Privilege

As our sample comprises patent applications before and after 2002, we cannot get away without discussing the potential impact of a legal reform that abolished a special clause in the law on employee inventions and came into force in February 2002 (Arbeitnehmererfindungs-Gesetz, ArbEG, 2002). Prior to this reform, university researchers were exempted from the general obligation of employees to disclose job-related inventions to their employers and could thus keep the ownership of their patents. While in the years after the Bayh-Dole Act U.S. university patent applications escalated, von Ledebur et al. (2009) find no such evidence for Germany. As thus the reform basically led to a shift in the ownership of the patents, but not in its numbers, it should not affect our data as we looked up patents based on academic investors not applicants. Moreover, a substitution of university ownership for firm ownership of patents (if the patent was the result of paid contract research and therefore belongs to a firm) should not affect our results as we take the overall count and not just university owned patents on which the scientist is mentioned as inventor.

4 Empirical Analysis

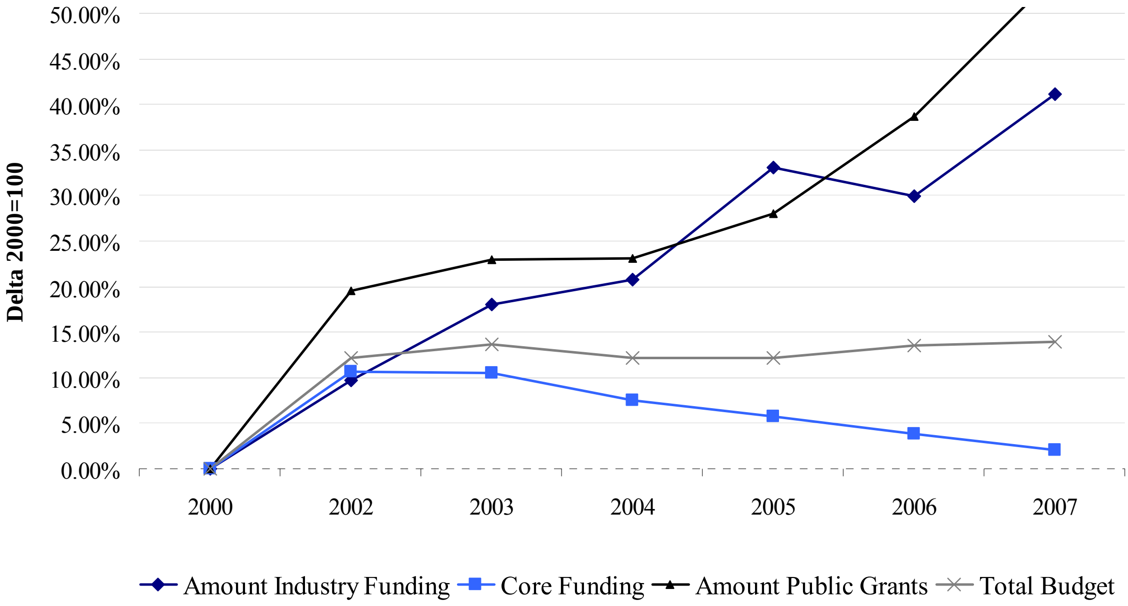
Primarily, our analysis aims to shed light on the effects of industry funding on scientific productivity. As potential effects are unlikely to show up immediately, we observe the scientific output up to eight years after the survey. We thus expect journal publication output and patent applications in the post-survey period 2000-2007 to be a function of the share of industry funding *(INDFUND)* and public grants *(GOVFUND)* the professors received for their research unit, their past publication and patenting efforts *(PUB1995-1999, PAT1995-1999* as past performance is likely to affect future performance due to a „cumulative advantage"), their lab size *(LABSIZE),* their experience *(EXPERIENCE),* the skill composition at the lab in terms of the percentage of technical employees *(TECHS)* and post doctoral researchers *(POSTDOCS).* In addition, we consider further attributes such as the research field, the type of institution and gender.

Figure 1 depicts the development of industry funding for all German higher education institutions in the period 2000-2007 that is not covered by the survey. Compared to the year 2000, the amount has increased by more than 40%. Remarkably, the institutions' core funding has been decreasing since 2002, while total budgets remained largely unchanged. Concerns raised by Lee (1996) regarding the effects of industry involvement in science on long-term, disinterested, fundamental research in the light of 'declining federal R&D

support' in the U.S. can thus be raised here as well. Unfortunately, the information on industry funding in the survey is limited to the year 1999. Data at the institutional level (as shown in Figure 1) documents an increase at the aggregate level in the post-survey years. This leads us to regard the survey-numbers for 1999 at the research unit level as "lower bound" of the industry funding received by the research unit in subsequent years. Public grants increased likewise which confirms Auranen and Nieminen (2010), who report a development towards a more competitive funding structure. *GOVFUND* is included to control for a professor's success in attracting public funds.

Additionally, as publication or patent output may not only be affected in terms of quantity, but also quality, we estimate the effects on citation counts (*CITPUB, CITPAT*) and average citations per publication and patent (*CITperPUB, CITperPAT*), respectively.

Figure 1: University Funding (% changes relative to the year 2000)



Source: DESTATIS, series 11, issue 4.3.2, own calculations.

4.1 Econometric set-up

The number of publications and patent applications is restricted to non-negative integer values and also characterized by many zeros, since not all of the professors in our sample show a positive number of publications and/or patents. The same applies for the number of citations for both measures. Hence, in order to investigate the relationship between funding and research output, we estimate count data models. This leads to the following estimation equation which is assumed to be of an exponential functional form:

$$\lambda_{it} = E\left[Y_{i,2000-2007} \mid Z_{i,1999}, X_{it}, c_i\right] = exp\left(\alpha Z_{i1999} + X_{it}^{'}\beta + c_i\right)$$

where Y_i is the count variable and stands either for publication counts *(PUB)*, publication citations *(CITPUB)*, patent applications *(PAT)*, patent citations *(CITPAT)* or citations per item *(CITperPUB, CITperPAT)* by scientist *i* within the time span 2000 until 2007 which is assumed to be Poisson distributed with $\lambda_{it} > 0$. $Z_{i,1999}$ denotes the share of industry funding (*INDFUND*) in the survey's reference year 1999. X_{it} represents the set of controls including the share of public grants (*GOVFUND*), α and β are the parameters to be estimated. c_i is the individual specific unobserved effect, such as individual skills of each scientist or their attitude towards publishing or patenting.

Usually, cross-sectional count data models are estimated by applying Poisson and negative binomial regression models (negbin). A basic assumption of the Poisson model is equidispersion, i.e. the equality of the conditional mean and the conditional variance which is typically violated in applications leading to overdispersion. This led researchers to the use of the negbin model since it allows for overdispersion. Although the negbin model relaxes this assumption of equidispersion, it is only consistent (and efficient) if the functional form and distributional assumption of the variance term is correctly specified. For the Poisson model, however, it has been shown that it is consistent solely under the assumption that the mean is correctly specified even if overdispersion is present (Poisson Pseudo (or Quasi) Maximum likelihood). In case the assumption of equidispersion is violated and hence the obtained standard errors are too small, this can be corrected by using fully robust standard errors (see Wooldridge 2002), which is what we do.

A major drawback of our cross-sectional dataset is that it usually does not allow to control for unobserved heterogeneity which is most likely to be present in our data. Hence, if unobserved effects like, e.g., specific skills of each scientist are positively correlated with the right hand side variables, such as industry funding, the estimated coefficient of the industry funding variable is upwards biased. A solution is provided by the linear feedback model suggested by Blundell et al. (1995, 2002) who argue that the main source of unobserved heterogeneity lies in the different values of the dependent variable Y_i with which observation units (professors, in our case) enter the sample. The model approximates the unobserved heterogeneity by including the log of the Y_i from a pre-sample period average in a standard pooled cross-sectional model (ln[*PUB_MEAN*], ln[*PAT_MEAN*] etc.). In case Y_i is zero in the pre-sample period, e.g. a professor had no publications, a dummy is used to capture the "quasi-missing" value in log Y_i of in the pre-sample period (*d*[*PUB_MEAN = 0*], *d*[*PAT_MEAN = 0*] etc). We constructed the pre-sample mean estimator by using six pre-sample observations values of *Y* for 1994 to 1999.

4.2 Results

Table 4 presents the results of the Poisson regressions on the publication output indicators. The effect of *INDFUND* is significantly negative for both the publication count and the citations count and citations per publication in the years after the survey. That is, a higher share of industry funding (in 1999) leads to a lower publication output in subsequent years (2000-2007) both in terms of quantity and quality. To be more precise, an additional percentage point of in the share industry funding of total budget reduces publication output by 0.8%. This implies an average loss of one publication for a 5.5% increase in industry funding (that on average about 6000 €) in the following 8 years. This effect becomes more pronounced if we look at the indicators referring to publication quality. The number of citations decreases 1.3% (and 1.6% fixed effects model) and the number of citations per publication is reduced by 1.3% in both specifications. The share of public research grants (*GOVFUND*) on the other hand has a positive and significant effect on publication output both in terms of publication count and citations per publication. This effect, however, is not robust to the fixed effects specification.

Table 5 depicts the results from the patent equation. Interestingly, a higher share of industry funding has no effect on the number of patents, but does have a *positive* impact on patent citations and citations per patent. That is an increase of 2.6% (2.5% in the model with fixed effects) with each additional percentage point sponsored by the private sector.

As patents can only receive citations if they were granted, the positive effect here can also be interpreted as a novelty and quality effect of industry funds on professors' patents. Unlike in the publication model, where past publication record was significant but not past patenting activity, the patent equation shows that both past publications and past patent applications significantly determine future patent outcome. Public grants, on the contrary, have no impact on future patent activity.

To sum up, depending on the expression of Y_i, we find that:

1. $\alpha < 0$ if
    - Y_i denotes publication counts *(PUB),* the total number of citations to publications *(CITPUB)* or the average number of citations per publication *(CITperPUB)*
2. $\alpha = 0$ if
    - Y_i stands for patent applications *(PAT)*
3. $\alpha > 0$ if

- Y_i stands for patent citations *(CITPAT)* or the average number of citations per publication *(CITperPUB).*

The main results are robust to the inclusion of the fixed ‘effect’ in the linear feedback model. It should be noted that we also tested a non-linear specification, i.e. we included the squared value of *INDFUND* to test whether the negative (or positive effect in the patent citation equations) effect of *INDFUND* may only occur up from a certain level of industry funding. The inclusion of $INDFUND^2$, however, did not affect the significance of *INDFUND*, but it was never significant itself. The institution type (Uni, TU, UaS) dummies are jointly significant in the publication equations, but not in the patent equations. Generally, publications were significantly lower at TUs and UaS compared to universities that served as reference category. The research field dummies are in all models jointly significant (except in the *CITperPUB* fixed effect specification) capturing differences in publication patterns among research fields. The contact to a TTO has a positive impact on patent citations. We do not observe any “age”-related effects which is not surprising since the professors in our sample are quite homogenous in their level of experience.

5 Conclusion and Discussion

While from a private-sector perspective, the benefits from collaborating with academia are found to be unambiguously positive, the effects on the scientific sector were not as clear. We began this paper with the observation of a substantial growth in industry funding of university research and this study aimed at filling a gap in the literature by providing insights on the effects of such funding for scientific productivity. Our results show that the share of industry funding of total budget has reached a point (already in 1999 and shares have been increasing ever since) that is sufficiently high to negatively affect publication output. In other words, professors in our sample publish less in subsequent years the higher the share of industry funds relative to their total budget. This finding supports the “skewing problem” hypothesis for science and engineering faculty in Germany. If information sharing among scientists via publications is the basis for cumulative knowledge production and thus for scientific progress, industry funding that reduces publications may have detrimental effects on the development of science. Cohen et al. (2002) find the most important channel for knowledge transfer from science to industry to be the publication of research results. Thus, if industry funding reduces publications, not only the development of science could be impeded, but also technology transfer. Transfer may be strengthened between the university and the firms providing funds, but may be reduced for all the others. On the other hand, we find that a higher share of industry funding does not impact the number of patent applications on which the respective professor is listed as inventor. We do, however, observe a significant positive effect on their impact in terms of forward citations to those patents. This effect can also be interpreted as a quality indicator as naturally only granted patents can receive citations. Thus, industry financing may increase the likelihood that a patent is granted. Patents of professors whose research is supported by industry may not only be more successful in the granting process, but also more visible and relevant for further applications in industry and hence receive more forward citations.

We believe the results from this study are provocative for policy analysis and public funding authorities. An increasing reliance on industry funding compared to stagnating core funding may indeed affect the development of science in the long run if publication output is reduced. On the other hand, industry funding may be very valuable for professors' applied research and the success of their patenting activities.

Despite all efforts, our study is not without some limitations and the results presented ought to be interpreted with those caveats in mind. It could be argued that there is a bias in direction of above-average performers as our sample comprises information on "heads of research units" only (see Kelchtermans and Veugelers 2011). These academics must have performed well in their past carrier in order to hold such a position at all. Studying a sample of professors that are less homogenous in terms of their level of experience could also reveal interesting results that have remained foreclosed in our study. Researchers at earlier stages of their career may be led by other incentives that for instance increase their paper output despite of industry funding. From the funding perspective, we do neither know from which or how many firms funding had been obtained. Further, we can not make any judgment on the effects on research content. Future research could assess the effects on the scientists' research content measured by changes in journal types and patent classifications. Additional insights into the professors' patent activity could be gained from studying the type of citations to patents and their technology classifications. Such detailed information would allow statements regarding a shift in research content caused by increased industry funding for such research. It would have also been interesting to study effects of industry funding at a more disaggregate level. The effects on scientific productivity are very likely to depend on both the institutional setting (university provisions to support such activities) as well as on the actual activity that had been sponsored. Perhaps even more importantly, the extent to which more traditional scientific activities are affected will certainly depend on what industry expects in return for their sponsoring. In other words, an analysis of "sponsoring firms and sponsored academics"-pairs would be valuable to refine the insights from this study. Finally, it should be kept in mind the results may strongly depend on the institutional setting in Germany where university research traditionally has been predominantly financed by public sources and where the increase in industry sponsorship had been most significant. It would therefore be highly desirable to study the relationship between industry funding and scientific productivity at the individual level in settings that are comparable to those of Germany, for instance Austria, but also in very different settings like in the U.S. or U.K. In the U.S and the U.K industry sponsorship accounts for a much lower share of university research funding on average and had been declining in the period 1997 to 2007 (OECD 2009). Moreover, sponsoring firms seem to focus on top institutions as compared to a rather equally distributed allocation of such funds in Germany. Geuna (1997) finds that in the U.K. industrial funding that is long-term and/or has "no strings attached" is focused on a few universities, while a larger number of technology oriented institutions receive the shorter-term and less basic contracts. Further research in that direction may help to explain the differences between the results from this study and the research performance of scientists at top institutions like for instance MIT that is funded to a high degree by the private sector.

Table 4: Estimation results (678 obs.) on **publication output** (with *INDFUND*)

	Poisson Model			**Poisson Model with Fixed Effects**		
Variable	*PUB*	*CITPUB*	*CITperPUB*	*PUB*	*CITPUB*	*CITperPUB*
INDFUND	-0.008**	-0.013**	-0.013***	-0.008**	-0.016***	-0.012***
	(0.004)	(0.006)	(0.005)	(0.003)	(0.006)	(0.005)
GOVFUND	0.007***	0.005	0.005**	0.004	0.002	0.003
	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)
$PUB_{1994-1999}$	0.013***					
	(0.002)					
$PAT_{1994-1999}$	0.012					
	(0.011)					
$CITPUB^{\blacklozenge}{}_{1994-1999}$		0.001***	0.014***			
		(0.000)	(0.002)			
$CITPAT^{\blacklozenge}{}_{19945-1999}$		-0.000	-0.003**			
		(0.001)	(0.002)			
LABSIZE	0.123*	0.366***	0.103*	0.111**	0.165**	-0.042
	(0.069)	(0.102)	(0.057)	(0.057)	(0.065)	(0.052)
$LABSIZE^2$	-0.000	-0.000**	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
EXPERIENCE	-0.042	-0.027	0.015	-0.054	-0.038	-0.001
	(0.037)	(0.034)	(0.020)	(0.034)	(0.028)	(0.020)
$EXPERIENCE^2$	0.000	-0.000	-0.000	0.001	0.000	-0.000
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
TTO	0.215*	0.049	0.136	0.130	0.096	0.180**
	(0.129)	(0.138)	(0.089)	(0.119)	(0.118)	(0.091)
TECHS	0.003	0.007	0.000	0.005	0.008	0.004
	(0.007)	(0.010)	(0.004)	(0.005)	(0.005)	(0.004)
POSTDOCS	0.002	-0.004	-0.004	-0.000	-0.009***	-0.004
	(0.004)	(0.005)	(0.002)	(0.004)	(0.003)	(0.002)
GENDER	0.017	-0.204	-0.203	0.136	-0.078	-0.220
	(0.194)	(0.279)	(0.193)	(0.156)	(0.248)	(0.208)
ln[*PUB MEAN*]				0.601***		
				(0.053)		
ln[*PAT MEAN*]				0.057		
				(0.068)		
ln[*CITPUB MEAN*]					-0.163***	
					(0.048)	
ln[*CITPAT MEAN*]					0.643***	
					(0.047)	
ln[*CITperPUB MEAN*]						0.277***
						(0.033)
ln[*CITperPAT MEAN*]						-0.044
						(0.030)
Log-Likelihood	-6,379.11	-63,901.38	-2,308.94	-5,348.40	-44,018.36	-2,208.85
Joint sign. inst. dum. χ^2 (2)	80.53***	43.86***	22.71***	38.26***	16.05***	10.99***
Joint sign. field dum. χ^2 (6)	57.36***	95.66***	39.32***	16.24**	14.15**	8.07
McFadden's R^2	0.487	0.603	0.337	0.570	0.727	0.366

Notes: Standard errors in parentheses are robust, all models contain a constant, field and institution type dummies.

♦ *CITperPUB and CITperPAT* for models in columns 3 and 6. Pre-sample dummies d[X_MEAN] for observations with zero means are not presented. *** (**, *) indicate a significance level of 1% (5%, 10%).

Table 5: Estimation results (678 obs.) on **patent output** (with *INDFUND*)

	Poisson Model			**Poisson Model with Fixed Effects**		
Variable	*PUB*	*CITPUB*	*CITperPUB*	*PUB*	*CITPUB*	*CITperPUB*
INDFUND	0.003	0.026**	0.028***	-0.002	0.024*	0.028**
	(0.005)	(0.011)	(0.010)	(0.006)	(0.016)	(0.013)
GOVFUND	0.003	-0.003	-0.001	0.003	-0.004	-0.002
	(0.004)	(0.011)	(0.008)	(0.004)	(0.013)	(0.008)
$PUB_{1994-1999}$	0.009***					
	(0.003)					
$PAT_{1994-1999}$	0.099***					
	(0.012)					
$CITPUB^{\blacklozenge}_{1994-1999}$		0.000***	-0.002			
		(0.000)	(0.006)			
$CITPAT^{\blacklozenge}_{1994-1999}$		0.000	0.002			
		(0.000)	(0.004)			
LABSIZE	0.157	0.540*	0.492**	0.115	0.464*	0.405**
	(0.118)	(0.317)	(0.220)	(0.102)	(0.325)	(0.204)
$LABSIZE^2$	-0.000	-0.000	-0.000	-0.000 *	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
EXPERIENCE	-0.039	0.097	0.088	-0.049	0.150	0.111
	(0.064)	(0.104)	(0.075)	(0.050)	(0.111)	(0.083)
$EXPERIENCE^2$	0.000	-0.003	-0.002	0.000	-0.004	-0.002
	(0.001)	(0.002)	(0.002)	(0.001)	(0.003)	(0.002)
TTO	0.269	1.176***	0.494	0.099	0.937**	0.335
	(0.345)	(0.364)	(0.450)	(0.330)	(0.394)	(0.464)
TECHS	0.001	0.005	0.013	-0.001	0.004	0.008
	(0.006)	(0.011)	(0.011)	(0.005)	(0.012)	(0.010)
POSTDOCS	0.006	-0.005	0.002	0.007	-0.003	0.003
	(0.006)	(0.013)	(0.009)	(0.005)	(0.015)	(0.011)
GENDER	0.179	-2.131***	-2.925***	0.341	-2.255***	-2.977***
	(0.331)	(0.826)	(0.871)	(0.225)	(0.636)	(0.681)
ln[*PUB MEAN*]				0.032		
				(0.075)		
ln[*PAT MEAN*]				0.523 ***		
				(0.088)		
ln[*CITPUB MEAN*]					0.198**	
					(0.087)	
ln[*CITPAT MEAN*]					0.259**	
					(0.136)	
ln[*CITperPUB MEAN*]						0.195*
						(0.101)
ln[*CITperPAT MEAN*]						0.090
						(0.088)
Log-Likelihood	-1,343.47	-1,318.19	-348.20	-1,173.97	-1,190.98	-325.91
Joint sign. inst. dum. χ^2 (2)	1.27	3.05	4.17	0.78	1.07	2.05
Joint sign. field dum. χ^2 (6)	19.48***	24.68***	20.01***	11.42*	14.00**	11.64*
McFadden's R^2	0.250	0.235	0.183	0.345	0.309	0.236

Notes: Standard errors in parentheses are robust, all models contain a constant, field and institution type dummies.

♦ *CITperPUB and CITperPAT* for models in columns 3 and 6. Pre-sample dummies d[X_MEAN] for observations with zero means are not presented. *** (**, *) indicate a significance level of 1% (5%, 10%).

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7 Appendix

Table A.1: Scientific Productivity by Research Field (professors’ academic life time, e.g. all publications and patents until 2007)

	Publications			**Patents**		
Field	**Publica-tions**	**Citation Count of Publications**	**Citations per Publication**	**Patents**	**Citation Count of Patents**	**Citations per patent**
Physics	87.64	1,895.817	33.57	3.15	56.11	6.83
Mathematics / Computer Science	19.86	186.75	11.48	0.79	14.28	7.65
Chemistry	112.85	1,865.13	26.06	5.59	85.99	14.345
Biology / Life	54.17	1,109.57	32.13	3.10	79.40	25.38
Electrical	23.91	239.82	9.92	6.70	263.38	37.12
Mechanical	16.36	86.79	7.36	6.14	150.53	11.06
Other Engineering	36.93	401.79	12.72	5.85	107.54	10.16

Table A.2: Industry Funding of Higher Education Institutions in the Sample

Institution	**Type**	**State**	**Professors in sample**	**Professors surveyed in state**	**average funding from industry in % of total budget**	**average funding from industry in % of total "third party funding"**	**average funding from industry in % of total "third party funding" from survey at "state level"**	**# Students in State**
					1999	**1999**	**1999**	**2006**
Albert-Ludwigs-University Freiburg	Uni	Baden-Wurttemberg	13	66	2.71	11.23	27.56	237 611
FH Mannheim	UaS	Baden-Wurttemberg	4		0.68	50.00		
FHT Esslingen	UaS	Baden-Wurttemberg	12		2.19	25.42		
University of Stuttgart	Uni	Baden-Wurttemberg	37		10.29	23.57		
FH Augsburg	UaS	Bavaria	2	68	3.33	50.00	26.43	251 163
Ludwig Maximilian University of Munich	Uni	Bavaria	23		3.61	13.13		
TU München	TU	Bavaria	26		11.70	31.96		
University of Würzburg	Uni	Bavaria	17		4.70	10.65		
Humboldt-University of Berlin	Uni	Berlin	12	12	1.53	3.42	19.21	132120
TFH Berlin	UaS	Berlin	12		13.75	35.00		
FH Brandenburg	UaS	Brandenburg	7	7	11.35	40.00	40.00	40 786
Hochschule Bremen	UaS	Bremen	7	26	3.49	30.29	22.67	33 356
University of Bremen	Uni	Bremen	19		4.94	15.05		
Fachhochschule Hamburg	UaS	Hamburg	7	51	17.94	25.71	26.12	65 908
TU Hamburg-Harburg	TU	Hamburg	24		11.70	38.13		
University of Hamburg	Uni	Hamburg	20		6.68	14.53		
Fachhochschule Darmstadt	UaS	Hesse	13	77	1.20	26.15	29.21	157 452
Johann Wolfgang Goethe University of Frankfurt	Uni	Hesse	13		5.31	10.94		
TU Berlin	TU	Hesse	39		9.30	31.49		
University of Kassel	Uni	Hesse	12		23.54	48.25		
Ernst-Moritz-Arndt-University Greifswald	Uni	Mecklenburg-West Pom.	5	26	3.70	9.30	10.49	34 221
Fachhochschule Neubrandenburg	UaS	Mecklenburg-West Pom.	1		0.00	0.00		
Otto-von-Guericke-University of Magdeburg	Uni	Mecklenburg-West Pom.	18		7.52	24.67		
University of Rostock	Uni	Mecklenburg-West Pom.	2		1.20	8.00		
Fachhochschule Braunschweig/Wolfenbuttel	UaS	Lower Saxony	9	45	11.36	54.78	30.58	146 992
University of Goettingen	Uni	Lower Saxony	6		2.70	6.67		
University of Hannover	Uni	Lower Saxony	30		11.63	30.30		

FH Aachen	UaS	North Rhine-Westphalia	23	75	17.45	41.35	26.81	449 963
Aachen University of Technology	TU	North Rhine-Westphalia	25		14.32	29.44		
University of Dortmund	Uni	North Rhine-Westphalia	18		8.96	23.11		
University of Cologne	Uni	North Rhine-Westphalia	9		5.11	13.33		
Fachhochschule Kaiserslautern	UaS	Rhineland-Palatinate	3	37	0.00	0.00	25.19	97 514
Fachhochschule Kaiserslautern, Zweibrücken	UaS	Rhineland-Palatinate	7		7.11	48.57		
University of Kaiserslautern	Uni	Rhineland-Palatinate	27		9.79	27.01		
University of Saarlandes	Uni	Saarland	18	24	13.44	29.72	31.11	19 334
HTW Saarland	UaS	Saarland	6		12.67	32.50		
HTW Dresden	UaS	Saxony	9	50	12.02	35.00	22.86	103 583
Dresden Technical University	TU	Saxony	25		9.41	26.53		
University of Leipzig	Uni	Saxony	16		2.45	7.04		
Fachhochschule Magdeburg	UaS	Saxony-Anhalt	8	31	1.50	20.00	18.80	50 097
Martin-Luther-University of Halle-Wittenberg	Uni	Saxony-Anhalt	23		4.45	17.61		
Christian-Albrechts-University of Kiel	Uni	Schleswig-Holstein	22	33	7.11	26.53	38.55	44 893
Fachhochschule Flensburg	UaS	Schleswig-Holstein	11		11.22	50.56		
Fachhochschule Erfurt	UaS	Thuringia	1	38	0.00	0.00	16.32	48 201
Friedrich-Schiller-University of Jena	Uni	Thuringia	21		7.61	30.48		
TU Ilmenau	TU	Thuringia	16		7.19	18.48		
Total / Average			678	678	7.39	24.91	25.09	

Endnotes:

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[i] Usually a chair has only one professor. Larger universities, however, may also have several professors at one chair. Nevertheless, only one is the head of the department.

[ii] See Schmoch and Schubert (2009) for details on “third-party funds” (Drittmittel) in Germany.

[iii] Even though we do know the number of each chair’s employees and details on their qualification, we do not have further details (e.g. sex, name) of the individual team members. Thus, we cannot collect publication and patent information at the team member level.

[iv] The popular impact factor of the journal in which the article was published would have also been available, but since we study different fields of science, the journal impact factors have been shown to be not appropriate (see Amin and Mabe 2000).

[v] In Germany a dissertation needs to be published in the German National Library (Deutsche Nationalbibliothek). This central archival library among other things, collects, permanently archives, comprehensively documents and records bibliographically all German and German-language publications from 1913 onwards.

[vi] Some Professors in our sample who are employed at UaS may not necessarily have a doctoral degree nor have they gone through the procedure of habilitation or junior professor. At UaS these qualifications are not compulsory for becoming professor. Candidates can apply for the position after their doctorate or in some cases a diploma is already sufficient if the person has gained research experience in industry for several years.

[vii] We also tested the robustness of the results to a model specification with all publications and patents from the first publication or patent found in the data base. The main results remained unchanged. See Table A.1 in the appendix for descriptive statistics on publication and patent output over the professor’s entire academic life time.