Individual versus institutional ownership of university-discovered inventions

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Abstract

We examine how the ownership of intellectual property rights influences patenting of university-discovered inventions. In 2002, Germany transferred patent rights from faculty members to their universities. To identify the effect on the volume of patenting, we exploit the institutional structure of the German research system along with the researcher-level exogeneity of the 2002 policy change using a novel researcher-level panel database. For professors who had existing industry connections, the policy decreased patenting, but for those without prior industry connections, it increased patenting. Overall, fewer university inventions were patented following the shift from inventor to institutional ownership.

Keywords: Intellectual property, patents, technology transfer, policy evaluation

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1 Introduction

Intellectual property (IP) policies are among the most powerful instruments shaping the incentives that drive the discovery and commercialization of knowledge. For U.S. academic institutions the Bayh-Dole Act of 1980 is perhaps the most influential and far-reaching of these IP policies. The legislation facilitated private institutional ownership of inventions discovered by researchers who were supported by federal funds. Many observers credit the Bayh-Dole Act with spurring university patenting and licensing that, in turn, stimulated innovation and entrepreneurship (The Economist 2002; OECD 2003; Stevens 2004). Based on this perceived success, the Bayh-Dole Act has become a model of university IP policy that is being debated and emulated in many countries around the world including Germany, Denmark, Japan, China, and others (OECD 2003; Mowery and Sampat 2005; So et al. 2008).

The key component of the Bayh-Dole model is granting the university, not the inventor, ownership rights to patentable inventions discovered using public research funds (Crespi et al. 2006; Geuna and Nesta 2006; Kenney and Patton 2009). However, the incentive effects on academic inventors of university versus individual ownership are not well understood. In a theoretical contribution, Hellmann (2007) found that university ownership is efficient when inventors must search for a commerical partner as long as the cost of search is higher for inventors than for the university. Using survey and case study evidence, Litan et al. (2007) and Kenney and Patton (2009) argued that confliciting objectives and excessive bureaucracy make institutional ownership ineffective and suggest as individual ownership system may be superior. Due to a paucity of evidence, however, the U.S. National Research Council recently concluded that “arguments for superiority of an inventor-driven system of technology transfer are largely conjectural” (NRC 2010).

Our analysis uses the framework of Pakes and Griliches (1984) and a quasi-experimental research design to provide the first systematic evidence on how intellectual property rights impact patenting of university-discovered inventions. We examine a fundamental change in German patent law from individual to institutional ownership. Prior to 2002, university professors and researchers had exclusive intellectual property rights to their inventions. This "Professor's Privilege" allowed university researchers to decide whether or not to patent and how to commercialize their discoveries, even if the underlying research was supported by public funds. After 2002, universities were granted the intellectual property rights to all inventions made by their employees and this shifted the decision to patent from the researchers to the universities. The policy goal was to increase patenting of university-invented technologies which is often used as a surrogate indicator of successful university technology transfer.

By changing the agent who makes the patenting decision, the abolishment of Professor's Privilege caused a "regime shift" that substituted institutional benefit and cost schedules for those of the individual inventors. The net effect on the volume of patenting depends primarily on the relative costs between the regimes. To identify how the regime shift affected patenting, we exploit the institutional structure of the German research system along with the researcher-level exogeneity of the 2002 abolishment of Professor's Privilege. We use a difference-in-difference methodology and control for the arrival of new patentable discoveries using publications and peer-to-peer matching.

Our analysis shows that fewer university inventions were patented following the 2002 regime shift. For a given discovery, the schedule of benefits to institutional owners, who are the post-change patent decision makers, is lower because the university became an additional party in the negotiations over the split of expected revenues. This partly explains why fewer inventions qualified for patent protection following the regime shift. However, the effect on expected revenues can be offset if institutional costs (broadly conceived) are sufficiently lower than those faced by individual researchers (Hellmann 2007). Our results show that institutional patenting costs were lower for the subset of university inventors who did not have relationships with industry partners prior to the policy change. For those individuals, patenting increased. But, the data also show that most German patenting professors had prior industry relationships. Post-change institutional costs were not low enough to offset the revenue effect for this group. Our results highlight the critical importance of understanding the nature and strength of faculty-industry relationships before undertaking policy initiatives intended to foster technology transfer.

The remainder of this paper is structured as follows. Section 2 summarizes the background and implementation of the law change in Germany. Section 3 describes the Pakes and Griliches (1984) framework and develops our hypotheses. Section 4 presents the empirical approach, the data collection strategy and provides descriptive statistics. Section 5 shows the econometric results, and robustness checks are presented in Section 6. The final section 7 concludes with a discussion of the implications for policy.

2 The Regime Change: From Inventor to University Ownership

In February 2002, the German Federal Government launched a comprehensive new program called "Knowledge Creates Markets" to stimulate technology transfer from universities to private industry for innovation and economic growth[1]. The program was

[1] Bundesministerium für Bildung und Forschung and Bundesministerium für Wirtschaft und Technologie (2001), Wissen schafft Märkte - Aktionsprogramm der Bundesregierung.

largely a reaction to the "European paradox" (European commission 1995). At that time, policymakers believed that Germany had one of the world's leading scientific research enterprises, but was lagging the United States in terms of technology transfer and commercialization. The new program addressed a wide spectrum of science-industry interactions including processes and guidelines governing knowledge transfer, science-based spin-offs, collaboration, and the exploitation of scientific knowledge in the private sector. The abolishment of Professor's Privilege was one of the most significant changes from both a legal and cultural perspective. Professor's Privilege originated from Article 5 of the German constitution that protects the freedom of science and research. The new program repealed Clause 42 of the German employee invention law that had granted university researchers - as the only occupational group in Germany - the privilege to retain the ownership rights to their inventions that otherwise rest with the employer[2].

Under the new law, German academic researchers are required to cull their research findings for inventions and report any inventions to the university – unless the researcher decides to keep his or her inventions secret by not publishing or patenting. The university has four months to consider any submitted inventions for patenting. If the university does not claim the invention, the rights to pursue patenting and commercialization are returned to the researcher. If the university does claim the invention, the inventor receives at least 30% of the revenues from successful commercialization, but nothing otherwise. Furthermore, the university handles the patenting process and pays all related expenses such as processing fees, translation costs and legal expenses. University researchers retain

[2] Gesetz über Arbeitnehmererfindungen in der im Bundesgesetzblatt Teil III, Gliederungsnummer 422-1, veröffentlichten bereinigten Fassung, das zuletzt durch Artikel 7 des Gesetzes vom 31. Juli 2009 (BGBl. I S. 2521) geändert worden ist.

the right to disclose the invention through publication two months after submitting the invention to the university. Prior contractual agreements with third parties also remained valid during a prescribed transition period.[3]

At the time of the law change, German universities had little experience undertaking technology transfer activities, and only a few universities maintained professionally managed technology transfer offices (TTOs) (cf. e.g. Schmoch et al., 2000). Therefore the government decided to support the commercialization activities by establishing regional patent valorization agencies (PVAs), which was supported with a budget of 46.2 million EUR to be used before the end of 2004 (Kilger und Bartenbach 2002). Universities were free to choose whether to use the PVAs' services or not. To date, 29 PVAs serve different regional university networks and employ experts specialized in these universities' research areas. The PVAs support the entire process from screening inventions, finding industry partners, and determining fruitful commercialization paths. They are also supposed to promote collaboration between their member universities and industry.

To date, a handful of prior studies have examined the effects of abolishing Professor's Privilege on patenting rates and ownership patterns in Germany. Schmoch (2007) found that the number of university-owned patents increased. Based on inventor lists, his data also suggested the most active faculty inventors were discouraged by the abolishment of Professor's Privilege and that non-patenting professors were encouraged, which suggests the law changed the mix of inventors. In a follow-up study, Cuntz et al. (2012) showed that the share of university-owned inventions increased after 2002 while the share of individually

[3] Contracts made before July 18th 2001 were to be treated under the old law until February 2003 (Gesetz über Arbeitnehmererfindungen, § 43 ArbnErfG).

or industry- owned university inventions decreased. Von Proff et al. (2012) found that the policy change did not increase university-invented patents. They also suggested an ownership shift from individual and firm-owned patents to universities. Our analysis extends this work by combining an established economic framework with a stronger research design and a more comprehensive researcher-level database.

3 Economic framework and hypotheses

In economic models, patents reflect the combined influence of an agent's propensity to patent and the arrival of new knowledge through the agent's inventive process.

$$(patents)_{it} = (propensity\ to\ patent)_{it} \cdot (new\ knowledge)_{it} \quad (1)$$

Pakes and Griliches (1984) called this relation the patent indicator function. The propensity to patent can change due to legal or economic conditions that affect the expected benefits and costs of having a patent. It captures the decision to patent. In equation (1), increments to knowledge reflect investments into discovery, which Pakes and Griliches summarized as the "knowledge production function." Their analysis focused on the relationship between new knowledge and the volume of patenting, holding the propensity to patent constant. In this paper, we focus on how the volume of patents responds to changes in the propensity to patent, holding increments to knowledge constant.[4,5]

[4] A substantial literature has emerged that examines how commercial incentives influence the rate, direction, and disclosure of academic research. This literature focuses on the knowledge production function component of equation (1). Some references include: Jensen and Thursby (2001, 2004); Banal-Estanol and Macho-Stadler (2010); Thursby et al. (2007); Lach and Schankerman (2008); Dechenaux et al. (2009); Azoulay et al. (2007, 2009), Czarnitzki et al. (2011, 2014).

[5] We recognize the regime shift could have an indirect influence on patenting through the knowledge production function; however, proprer analysis of this effect would require a separate model focusing on new knowledge (i.e. publications) instead of patents.

Germany's abolishment of Professor's Privilege exogenously changed the agent responsible for the decision to patent university-discovered inventions. In terms of equation (1), the law transferred the propensity to patent from the faculty inventor to the university. Under the former Professor Privilege system, faculty inventors would apply for patents on their discoveries when the expected benefits of patent protection were greater than the costs. Since 2002, faculty members no longer make this choice, but instead must disclose any inventions to the university. The university, perhaps with the PVA, decides to apply for a patent based on its assessment of expected benefits and costs. Consequently, the effect of revoking Professor's Privilege on the volume of patents depends on how the expected benefit and cost schedules shift due to the regime change from the individual faculty inventor to the university.

For any set of discoveries, the schedule of expected benefits considered by the university after the regime change is lower than the schedule of benefits faced by any faculty member prior to the abolishment of Professor's Privilege. After the policy change, the share of revenue appropriable by the university is limited by three-way bargaining between the university, the faculty member, and the licensee company. Under reasonable assumptions about bargaining power and recognizing that the university cannot increase the market value of the discovery, the university will capture a smaller share of the expected revenue stream in three-way bargaining than the faculty member would under two-way bargaining (Frank et al. 2007; Hellmann 2007).[6] If the university and faculty cost schedules were the same, the reduction in benefits after abolishment of Professor's Privilege would

[6] Under Professor's Privilege, the faculty member also had a stronger bargaining position for obtaining non-pecuniary benefits associated with collaborative research and technology development. These non-pecuniary benefits would further reduce the university's benefit schedule relative to the faculty member.

lead to fewer patents. Put simply, the policy change would decrease the propensity to patent.

At that time, however, policy makers believed the cost schedules faced by universities would be lower than those faced by individual faculty members. They interpreted the small share of university-owned patents in Germany prior to 2002 as evidence that individual researchers could not afford to undertake the costly and time-consuming process of applying for a patent and pursuing potential licensees (Becher et al. 1996). If the costs of patenting for universities were sufficiently lower, the volume of university inventions receiving patents could increase. So, the net effect of the regime shift on the volume of patenting depends on the costs of the universities compared to the pre-policy costs of faculty inventors.

It is important to remember that the propensity to patent incorporates the benefits and costs of patenting that are expected upon commercialization. The expected revenues from commercialization are compared to the expected costs of achieving commercialization both with and without patent protection. The relevant concept of costs is broader than simply the patent application fees and legal fees. It also includes costs from searching for an industry partner for commercialization, development costs, and so forth. While these costs may be close to homogeneous across universities in the post-policy change period, they are likely to be heterogeneous within the population of university inventors before the abolishment of Professor's Privilege.

We can identify two groups in the population of university inventors who faced significantly different costs of patenting under Professor's Privilege. The first group consists of university inventors who had relationships with one or more industry partners. These individuals already paid the costs of searching for licensee companies and negotiating their pecuniary and non-pecuniary benefits. In these relationships, industry partners would typically pay the application and legal fees, manage the development process and commercialize the product or service. For this group of "low cost" university inventors, the regime shift to institutional ownership almost surely led to a higher cost schedule as the university, possibly through the PVA, had to renegotiate established relationships (Frank et al. 2007; Kilger and Bartenbach 2002). For this group, we expect the regime shift in the propensity to patent led to a lower benefits schedule and a higher cost schedule. Our first hypothesis is:

H1: Faculty members who had established connections to industry partners experienced a decrease in the volume of patenting, ceteris paribus.

The second group consists of university inventors who did not have a relationship with an industry partner. These individuals obtained a patent, but still needed to search for a licensee company and negotiate pecuniary and non-pecuniary benefits. For this group of "high cost" university inventors, the university may have a considerable cost advantage. The cost advantage could stem from many sources. Hellmann (2007) postulates that a TTO (or PVA) may have a comparative advantage in identifying potential industry partners due to the efforts of specialized managers or, on the licensee's side, a single institutional source may make it easier to find university discoveries (e.g. Debackere and Veugelers 2005, Siegel et al. 2003). For this group, we expect the post-policy cost schedule shifted downward more than the post-policy benefits schedule. Our second hypothesis is:

H2: Faculty members who did not have established connections with industry partners experienced an increase in the volume of patenting, ceteris paribus.

With cost heterogeneity in the population of university inventors, the net effect of the policy change depends on the share of inventors of each type. If the pre-policy inventor population was predominantly low cost faculty inventors, then the net effect of the policy would be to reduce the volume of patents. Whereas, the policy would increase the volume of patenting of university-discovered inventions if faculty inventors were mostly high cost. As discussed in the data section, most patenting professors were in the low cost group before the policy change.

4 Empirical Model and Data

4.1 Identification Strategy and Estimation Approach

The German policy change provides a unique opportunity to separate the influence of the propensity to patent from the influence of new knowledge on the volume of patenting. The abolishment of Professor's Privilege was an exogenous "shock" to the propensity to patent university inventions. As seen in equation (1), once new knowledge is held constant, this exogenous variation will identify the effect of the propensity to patent on the volume of patenting. In the literature on academic research, publications are the accepted standard for measuring knowledge production. The database compiled for this analysis includes complete publication histories for university inventors and their peers in non-university, public research organizations (PROs) such as the Max Planck, Fraunhofer, and Helmholtz institutes as well as other federal and state research institutions.[7]

[7] Major research institutions in Germany are not only universities but other public research institutions that have many branches in a variety of different scientific disciplines. For instance, the Fraunhofer Society has 59 institutes in Germany with about 17,000 employees, the Max Planck Society has 76 institutes with about 12,000 employees. The Leibniz Association employs 16,100 people in 86 research centers. The Helmholtz Association has about 30,000 employees in 16 research centers.

We identify the policy effect using a difference-in-difference (DiD) research design with university inventors as the treatment group and PRO researchers as the control group. Like university professors, PRO researchers conduct academic research at publicly funded institutions in Germany. They work in similar academic fields and experience similar changes in research opportunities that affect the discovery of new knowledge. But unlike university professors, PRO researchers did not have Professor's Privilege and the patent rights to their inventions were always owned by the institution. To further control for changes in research opportunities, we use peer-to-peer matching between university faculty members and PRO researchers based on characteristics such as publications, scientific discipline, and career age before undertaking DiD estimation. Our DiD setup also accounts for common macroeconomic trends and individual-specific unobserved effects that capture an academic inventor's "taste" for patenting and commercialization.

For the population of German academic inventors, the DiD model takes the following form:

(2) $$PAT_{it} = \beta_0 + \beta_1(Prof_i \cdot NewPolicy_t) + \beta_2(CareerAge)_{it} + \beta_3(CareerAge^2)_{it} + \beta_4(3yrAvgPubs)_{i,t-1} + \delta_i + \gamma_t + u_{it}$$

where PAT_{it} is the volume of patents by researcher *i* applied for in year *t* (i.e. researcher-year observations). The policy effect is captured by the coefficient β_1 on the interaction term $(Prof \cdot NewPolicy)$. $Prof$ is a dummy variable that takes the value of 1 when the academic inventor is a university professor and 0 when the inventor is a PRO researcher. $NewPolicy$ is a dummy variable that takes the value of 1 following the policy change, 2002 onward, and 0 otherwise. A quadratic in career age captures academic inventor life-cycle effects. We use a three year moving average of past research publications, $(3yrAvgPubs)_{i,t-1}$, to capture the arrival of new knowledge. δ_i is a researcher-level fixed effect and γ_t is a vector of time dummy variables covering 2-year periods. Note that the professor dummy variable gets absorbed into the researcher fixed effects. Similarly, the new policy dummy variable gets absorbed by the general time trend.

As patent counts take only nonnegative integer values, we use the fixed effects Poisson quasi-maximum likelihood estimator (QMLE). As a member of the linear exponential family of distributions, the Poisson QMLE produces consistent estimates of the population parameters as long as the conditional mean is correctly specified (Gourieroux, Monfort, Trognon 1984; Wooldridge 1999). We use robust standard errors to account for any over- or under-dispersion.

4.2 Data and Descriptive Statistics

As the aim of this research is to examine the effects of abolishing Professor's Privilege on the decision to patent of university-discovered inventions, we focus on German academic inventors. This population includes all researchers affiliated with a university or PRO who appeared as an inventor on at least one patent submitted to the German or European Patent Offices between 1978 and 2008. Academic inventors are a subpopulation of all academic researchers in Germany. The broader population includes academic researchers who only published. However, the transfer of patent rights to institutional ownership did not impact these researchers as they never participated in the intellectual property system over the entire time period.

We constructed a researcher-level panel dataset of academic inventors following a multistep procedure, which is summarized in Table A.1 in Appendix A. This process yielded a sample with 3,718 professors and 8,294 PRO researchers.[8] We defined the study period to extend from 1995 through 2008 so that we observed enough time periods before and after the policy change. For each academic inventor, our data contains the individual's history of patenting between 1978 and 2008 and the individual's history of publications between 1990 and 2008. Beyond patent and publication characteristics, this information allowed us to calculate each researcher's career age which is used to model quadratic life cycle effects in equation (2). Career age starts when we observe the researcher's first publication or patent application and increases incrementally thereafter to a maximum of 35 years after which we assume the researcher retires. To account for earlier exit, we adopted a 5-year rule that has a researcher leaving the panel if he or she had no patenting or publishing activity for five consecutive years.[9] Researcher industry connections were determined from the patent data. An academic researcher is identified as having an industry connection when he or she is observed as an inventor on a company owned patent. This allows us to distinguish high cost and low cost academic inventors prior to the abolishment of Professor's Privilege and to estimate the model on subsamples to test hypotheses 1 and 2. The estimation sample contains 108,263 researcher-year observations. All of the variables used in the analysis are described in Table A.2 in Appendix A.

Figure 1 shows the average number of patents per academic inventor for university and PRO researchers over time. To better compare the trends, annual patents were normalized using 1995 as the reference year (i.e. each data point is relative to 1995). In the years leading up to the policy change, the trends in academic patents by professors and PRO

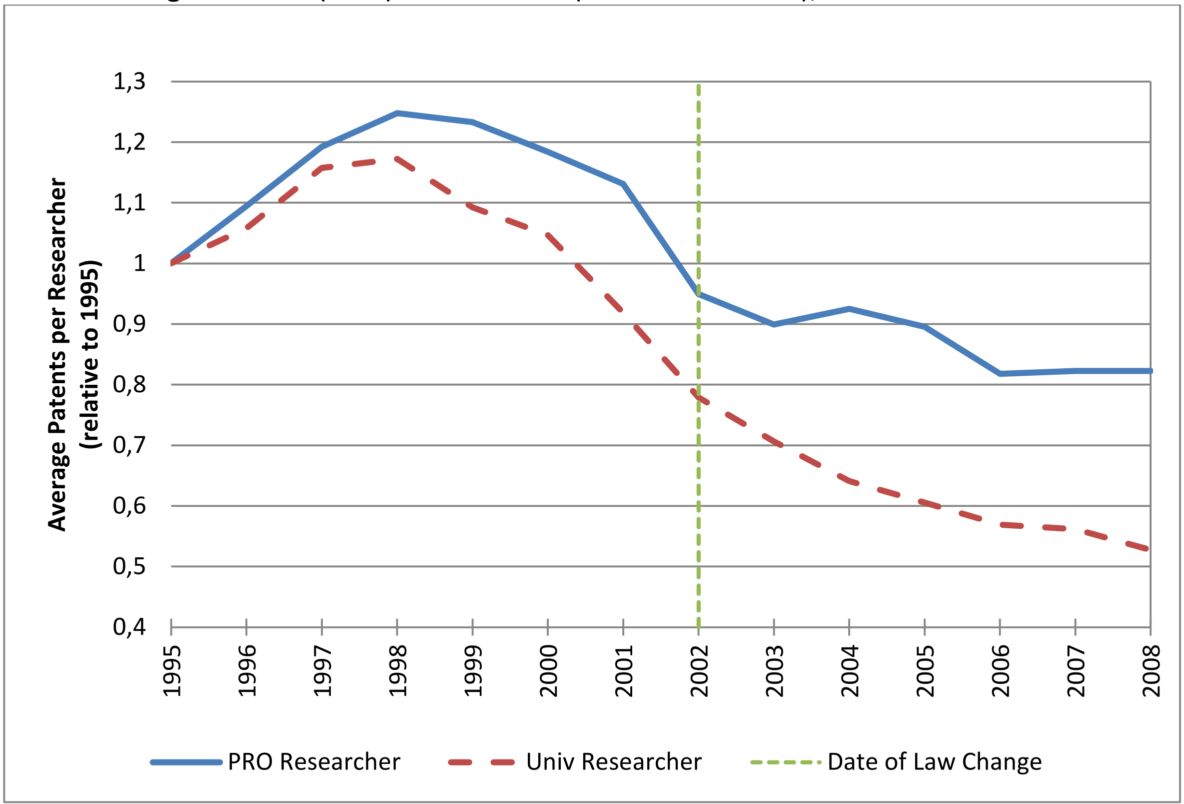
[8] This sample excludes those researchers who were employed at both a PRO and university, as it is not clear which patent regime applied to these researchers.

[9] In section 6 we present an alternative exit rule; however, the results do not change in a meaningful way.

researchers were quite similar. Both series show a peak in 1998 and a downward trend up to 2002. After the abolishment of Professor's Privilege in 2002, the patenting trends diverge with university professors showing a steeper downward trend than PRO researchers. This suggests that abolishing Professor's Privilege led to an overall decrease in the volume of patenting of university-discovered inventions.

Finding a decrease in patents per academic researcher after 1998 was somewhat surprising because it does not mirror the overall trend in German patent applications over this period. Upon further inquiry, the same pattern for academic patents was found by prior researchers (Cuntz et al., 2012; Schmoch 2007; Von Proff et al. 2012). These authors and others have speculated about the reasons for the decrease. Some suggestions include an increased emphasis on publications in academic performance evaluations, decreased entry into academic jobs, the end of the New Economy boom, and legal uncertainties surrounding patenting in the field of biotechnology (Cuntz et al. 2012, p.21-22; Schmoch 2007, p. 5-8).

Figure 1: Trends in German academic patenting for university and public research organization (PRO) researchers (relative to 1995), 1995-2008.



As described in section 3, the overall effect of the policy depends on the composition of university inventors prior to the regime change. If most patenting professors were in the low cost group, the policy would reduce university patenting. The data show that 2,657 (71%) of the university inventors had at least one patent before 2002 and 78% of these inventors had existing industry connections. It is clear that most university inventors were low cost. Among PRO inventors, 5,008 (80%) had patented before the law change and 44% of these inventors had industry connections. The lower percentage of PRO inventors with industry connections probably reflects the institutional ownership system already in place for these researchers.

Table 1 shows descriptive statistics at the researcher-year level for university professors (i.e. the treatment group) and PRO researchers (i.e. the control group) separated into the pre- and post-policy change periods. These groups are further subdivided into those with industry connections in the top portion of the table and those without industry connections in the bottom portion. Looking at academic inventors with industry connections, mean patents by professors declined by 44% after the abolishment of Professor's Privilege while patenting by PRO researchers declined by 27%. Among those without industry connections, mean patents by professors increased 55% after the law change, but only 9% for PRO researchers. These findings are consistent with the hypothesized effects discussed in Section 3. Citation-weighted patents, which partially adjust the raw counts for the "quality" of the inventions, also fell more for professors than PRO researchers among those with industry connections. While the average number of patents by university professors without industry connections increased by 55%, the citation-weighted patents actually fell by 15%. The differences in career age show that university professors were slightly older than PRO researchers over the whole sample period.

Table 1: Descriptive Statistics for the treatment and control groups (researcher-year observations)

	Prior to law change (1995-2001)				**After law change (2002-2008)**			
	Professors with industry connection							
	N = 12508 researcher-years				N = 9141 researcher-years			
Variable	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
# Patents	0.88	2.02	0	64	0.49	1.50	0	28
# Citation-weighted patents	0.67	2.78	0	119	0.27	1.43	0	39
Career age	9.86	6.74	0	34	16.25	6.73	2	35
Avg. publications	2.75	5.51	0	67.33	4.13	6.97	0	67
	Control group with industry connection							
	N = 13101 researcher-years				N = 9854 researcher-years			
# Patents	1.01	1.98	0	44	0.73	1.70	0	26
# Citation-weighted patents	0.81	2.55	0	55	0.42	1.68	0	41
Career age	8.06	6.02	0	34	14.22	6.43	2	35
Avg. publications	1.21	3.41	0	110.67	2.00	3.95	0	64.67
	Professors without industry connection							
	N = 6633 researcher-years				N = 8121 researcher-years			
Variable	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
# Patents	0.20	0.59	0	11	0.31	0.84	0	27

# Citation-weighted patents	0.13	0.75	0	15	0.15	0.77	0	19
Career age	5.71	3.89	0	27	9.35	5.92	0	32
Avg. publications	3.03	5.73	0	100.67	3.63	7.07	0	80.67
	Control group without industry connection							
	N = 19855 researcher-years				N = 29050 researcher-years			
# Patents	0.34	0.76	0	13	0.37	0.93	0	24
# Citation-weighted patents	0.22	0.92	0	16	0.21	1.07	0	61
Career age	4.50	4.06	0	29	7.16	5.53	0	35
Avg. publications	1.12	2.51	0	44	1.32	2.89	0	63.67

Note: Avg. publications are a three-year moving average of publication counts in t-1 for each researcher.

5 Econometric Results

Our baseline results identify the treatment effect of Germany's 2002 policy change that transferred patent ownership rights from inventors to the universities on the decision to patent. Table 2 presents the parameter estimates based on Poisson QMLE with robust standard errors. The overall treatment effect, which is revealed by the coefficient on $(Prof \cdot NewPolicy)$ in column 2, is negative and statistically significant at the 1% level. This indicates that the overall effect of abolishing Professor's Privilege was to decrease the volume of university patenting in Germany. It is economically significant as well. Holding the arrival of new knowledge and researcher life cycle effects constant, the coefficient estimate shows the volume of university patents decreased by 18%, on average. At least in part, this result reflects the reduction in benefits appropriable by the universities after abolishment of Professor's Privilege due to three-way bargaining. It would fully describe the effect of the 2002 policy change if the university and faculty cost schedules were the same. The arrival of new knowledge, as captured by a three year moving average of past publications, increases patents by academic inventors with one additional publication boosting expected patents by 14%.

The overall effect, however, masks potential heterogeneous treatment effects due to differences in patent and commercialization costs before the policy change. Even with the reduction in benefits appropriable by the university, the effect of the policy change on the volume of patenting depends on the costs of the university compared to costs of faculty inventors before the transition to institutional ownership. In Section 3, we argued that faculty with prior industry connections were relatively low cost and postulated that the decrease in patent volume due to the policy change would be even larger for this group. As seen in column 3 of Table 2, this hypothesis is supported. In the subsample of academic inventors with industry connections, the expected number of university patents decreased by 26%, holding other factors constant.

For faculty without prior industry connections, we postulated that cost advantages for universities would offset the reduction in benefits and increase patenting. As seen in column 6 of Table 2, treatment effect for this subsample is positive and significant at the 1% level. Holding the arrival of new knowledge and researcher life cycle effects constant, the estimate shows the volume of university patents increased by 39%, on average. For faculty without prior industry connects life cycle effects are statistically stronger while the link between publications and patents is still positive, but becomes insignificant at the 10% level. As seen in the subsample breakout, the overall decrease in patenting of university-discovered inventions reflects the composition of university academic inventors before the regime change – most academic inventors had pre-existing connections with industry.

Table 2: Poisson models of patenting output

# Patents	Overall		With industry connection		Without industry connection	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Professor*NewPolicy	-0.184***	(0.053)	-0.262***	(0.067)	0.391***	(0.085)
Career age	-0.028**	(0.014)	-0.030	(0.019)	-0.106***	(0.020)
Career age squared/100	0.002	(0.028)	-0.064*	(0.038)	0.721***	(0.065)
Avg publications	0.028***	(0.005)	0.017***	(0.005)	0.045***	(0.007)
Time dummies (base 1995)						
1996-1997	0.136***	(0.033)	0.160***	(0.039)	0.090	(0.062)
1998-1999	0.210***	(0.052)	0.304***	(0.066)	0.008	(0.086)
2000-2001	0.189**	(0.075)	0.307***	(0.098)	-0.002	(0.113)
2002-2003	0.087	(0.097)	0.184	(0.129)	-0.099	(0.144)
2004-2005	0.094	(0.118)	0.189	(0.156)	-0.117	(0.175)
2006-2007	0.034	(0.139)	0.127	(0.186)	-0.232	(0.203)
2008	-0.068	(0.157)	0.115	(0.210)	-0.446*	(0.228)
# obs.	108,263		44,604		63,659	
# obs. PRO researchers	71,860		22,955		48,905	
# obs. professors	36,403		21,649		14,754	
# obs. Professors after policy change	17,262		9,141		8,121	

Robust standard errors. Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Note: Avg. publications are a three-year moving average of publication counts in t-1 for each researcher.

Conditional Difference-in-Difference

One important characteristic of our control group is that they are German academic researchers. Like university professors, these individuals understand the literatures in their disciplines as well as other developments in their fields. Peer-to-peer matching can help control for potential changes in research opportunities. We constructed a matched sample of university professors and PRO researchers by applying caliper matching (caliper threshold = 0.005) to identify the nearest neighbor for each university professor. The academic inventors were matched based on their career achievements in 1998 (4 years prior to policy change) using their publication count, publication subject field[10] and career age. We estimate the DiD specification in equation (2) using observations from 1999 through 2008.

The treatment effects from the abolishment of Professor's Privilege are quite similar in magnitude and significance to those presented in Table 3. The overall treatment effect indicates that patents on university-discovered inventions decreased by 19% instead of 18%, on average. Among those academic inventors with prior industry connections, expected patents decreased by the same magnitude, 26%. The magnitude of the treatment effect for university faculty who were previously high cost increased by four percentage points and now indicates the policy increased patenting for this group by 43%, on average.

Table 3: Conditional Difference-in-Difference Poisson models of patenting output

# Patents	Overall		With industry connection		Without industry connection	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Professor*New Policy	-0.19**	0.09	-0.26**	0.11	0.43***	0.13
Time dummies (base 1998-1999)						
2000-2001	-0.10**	0.05	-0.16***	0.05	0.23**	0.11
2002-2003	-0.23***	0.08	-0.34***	0.10	0.18	0.12
2004-2005	-0.31***	0.09	-0.44***	0.11	0.17	0.13
2006-2007	-0.35***	0.10	-0.58***	0.13	0.35***	0.13
2008	-0.38***	0.12	-0.60***	0.16	0.29**	0.14
Observations	33728		18591		15137	

Robust standard errors. Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

[10] The subject fields of the publications have been assigned based on the classification in the ISI Web of Science Citation Index /Science Citation Index. We followed Leydesdorff and Rafols (2009) and defined 18 aggregated publication fields. A researcher has been allocated to one of these aggregated fields by using the field occurring most frequently in his or her publication record.

6 Robustness checks

6.1 Citation-weighted patent volume

It is well known that the economic value distribution associated with patents is highly skewed with a very small number of patents accounting for most of the value created through invention. So, even though the German policy change reduced the volume of patents, one might wonder whether the policy change simply eliminated the low value patents and thereby resulted in a smaller quantity of higher quality patents. To address this issue, forward citations are commonly used to weight raw patent counts as a way to partially adjust for the unobserved quality of invention (Trajtenberg 1990).

Table 4 reports the results from applying the DiD research design to citation-weighted patents. As before, the parameters are estimated using Poisson QMLE with robust standard errors. From column 2, the overall treatment effect from revoking Professors Privilege was to reduce the volume of university citation-weighed patents by 27%, holding the arrival of new knowledge and researcher life cycle effects constant. For university professors who had prior industry connections, university citation-weighed patents fall by 25%, on average. However, for university professors who did not have prior industry connections, the results are different from those found previously. While the volume of un-weighted patents increased for this group, citation-weighted patents show no significant change. This suggests that while the new policy increased the volume of patenting by professors without industry connections, it did not improve the average quality of these inventions. Among the other covariates, the only notable difference is that new knowledge is no longer significantly related to citation-weight patents among professors with prior industry connections.

Table 4: Poisson models of Citation-weighted patenting output

# Citation-weighted patents	Overall		With industry connection		Without industry connection	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Professor*NewPolicy	-0.274***	(0.086)	-0.254**	(0.104)	0.103	(0.147)
Career age	-0.072***	(0.026)	-0.061*	(0.035)	-0.179***	(0.044)
Career age squared/100	-0.000	(0.045)	-0.052	(0.058)	0.797***	(0.135)
Avg publications	0.014**	(0.007)	0.002	(0.008)	0.026**	(0.011)
Time dummies (base 1995)						
1996-1997	0.111*	(0.065)	0.113	(0.077)	0.097	(0.116)
1998-1999	0.337***	(0.106)	0.373***	(0.130)	0.217	(0.177)
2000-2001	0.099	(0.147)	0.153	(0.184)	-0.019	(0.237)
2002-2003	0.062	(0.195)	-0.003	(0.250)	0.123	(0.308)
2004-2005	0.211	(0.237)	0.134	(0.304)	0.275	(0.372)
2006-2007	0.143	(0.283)	-0.048	(0.356)	0.267	(0.450)
2008	-0.318	(0.318)	-0.389	(0.408)	-0.310	(0.496)
Observations	64,030		32,300		31,730	

Robust standard errors. Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Note: Avg. publications are a three-year moving average of publication counts in t-1 for each researcher.

6.2 Exclusion of Pre-Policy Uncertainty Period

As part of our research process, we reviewed the public discussion regarding the abolishment of Professor's Privilege. The possibility of a policy change became public as early as December 1997 when the German Federal Council requested the federal government to review the efficacy and appropriateness of Professor's Privilege. At that time, some policy makers were concerned that only 4% of all German patents originated from universities.[11] As discussed in section 3, they believed professors were not willing or able to invest the time and money for commercialization, but focused instead on academic publications. After this initial inquiry, Professor's Privilege was debated through March 2001 when the federal government published its action plan for enhanced science-to-industry technology transfer that officially announced the abolishment of the Professor's Privilege. When the final version of the law was published in October 2001, it was clear that Professor's Privilege would be abolished effective February 2002.

To verify that the timing of the policy change does not affect our findings, we exclude this described pre-policy "uncertainty period" from the sample, and compare academic patenting in 1995-1997 (before the law change and before the public discussion has been initiated) with the time period after the law change, 2002-2008. As seen in Table 5, the coefficient magnitudes on the treatment effects are larger. The effect of new knowledge trough publications is smaller, but statistically significant across all specifications.

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[11] This was discussed in many German newspapers at the time. An example can be found in "Der Spiegel" which is one of the most prominent weekly news magazines in Germany (see http://www.spiegel.de/wissenschaft/mensch/patentoffensive-bulmahn-will-hochschullehrerprivileg-abschaffen-a-101092.html). Our data also shows that about 4% of all patents applied for at the German Patent Office and the European Patent Office were university-invented patents. For instance, in 1995 there were 320,000 patents applied for by German inventors at the German Patent Office and the European Patent Office. Out of these, we find 4.7% to be university-inventions. In 2000, there were 460,000 patents out of which 3.3% originated from universities.

Table 5: Poisson models of patenting using only 1995-1997 as pre-treatment time periods

# Patents	Overall		With industry connection		Without industry connection	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Professor*NewPolicy	-0.230***	(0.069)	-0.328***	(0.084)	0.827***	(0.152)
Career age	-0.014	(0.017)	0.012	(0.025)	-0.139***	(0.025)
Career age squared/100	-0.078**	(0.031)	-0.102**	(0.041)	0.531***	(0.069)
Avg. publications	0.030***	(0.006)	0.020***	(0.007)	0.041***	(0.009)
Year dummies (base 1995)						
1996-1997	0.082**	(0.037)	0.084*	(0.046)	0.017	(0.067)
2002-2003	0.245*	(0.128)	0.036	(0.180)	0.549***	(0.179)
2004-2005	0.235	(0.154)	-0.035	(0.216)	0.607***	(0.219)
2006-2007	0.156	(0.181)	-0.166	(0.254)	0.583**	(0.254)
2008	0.055	(0.203)	-0.229	(0.285)	0.468*	(0.284)
Observations	64037		25986		38051	

Robust standard errors. Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Note: Avg. publications are a three-year moving average of publication counts in t-1 for each researcher.

6.3 Robustness on the Exit Rule

For our main analysis we adopted a 5-year rule that has a researcher leaving the panel if he or she had no patenting or publishing activity for five consecutive years. This rule was necessary due to data limitations that prevent us from observing when a researcher retires or leaves academic employment. To verify our results are not driven by this limitation, we imposed a very strict 2-year rule in which academic researchers are dropped after two consecutive years of inactivity. The results using the strict exit rule are very similar to those found using the 5-year rule (Table 6).

Table 6: Poisson models of patenting using the 2-year exit rule

# Patents	Overall		With industry connection		Without industry connection	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Professor*NewPolicy	-0.172***	0.055	-0.258***	0.070	0.473***	0.085
Career age	0.008	0.015	-0.013	0.020	-0.032	0.021
Career age squared/100	-0.093***	0.033	-0.096**	0.044	0.432***	0.064
Avg. publications	0.020***	0.005	0.011**	0.006	0.033***	0.007
Time dummies (base 1995)						
1996-1997	0.096***	0.034	0.130***	0.041	0.041	0.062
1998-1999	0.212***	0.056	0.327***	0.070	-0.004	0.091
2000-2001	0.188**	0.078	0.322***	0.101	0.004	0.12
2002-2003	0.068	0.103	0.201	0.137	-0.147	0.154
2004-2005	0.079	0.124	0.189	0.163	-0.144	0.187
2006-2007	0.006	0.146	0.118	0.195	-0.300	0.218
2008	-0.078	0.165	0.15	0.221	-0.558**	0.244
Observations	88666		37193		51473	

7 Discussion and Conclusion

In this paper we examine how the ownership of patent rights influences the decision to patent in the context of university-discovered invention. By changing the agent who makes the patenting decision, Germany's abolishment of Professor's Privilege in 2002 caused a regime shift that substituted institutional benefit and cost schedules for those of the individual inventors. Our empirical approach exploits the institutional structure of the German public research system to identify an appropriate control group along with the researcher-level exogeneity of the policy change to implement a difference-in-difference approach to causal inference. Our analysis shows that fewer university inventions were patented following the 2002 regime shift from inventor to institutional ownership.

The German policy change that abolished professor's privilege was based on the presumption that the costs and risks of patenting were so high that professors did not have sufficient incentives to patent their discoveries or pursue commercialization. In retrospect, this presumption appears to be wrong. We find that the treatment effect was heterogeneous among university professors and depended on the costs of the university compared to costs of faculty inventors before the transition to institutional ownership. Post-policy change institutional patenting costs were lower for the subset of university inventors who did not have prior relationships with industry partners. For those individuals, patenting increased after the policy change. Yet, most German professors had prior connections with industry partners leading to higher patenting and commercialization costs under institutional ownership. For these professors, patenting decreased substantially.

One possible reason for the miscalculation is a failure to adequately assess the nature and extent of technology transfer and patenting relationships prior to the law change. Informal and formal relationships between university researchers and industry firms had evolved under the professor's privilege system. Our results highlight the critical importance of understanding the nature and strength of faculty-industry relationships before undertaking policy initiatives intended to foster technology transfer.

Our findings provide the strongest evidence to date that an inventor ownership system can produce more university-invented patents, and thereby more technology transfer, than an institutional ownership system. Does this imply that other countries such as the U.S. would increase university technology transfer by adopting an inventor ownership system? Not necessarily. The nature and strength of faculty-industry relationships will differ based on each country's institutions, culture, and historical evolution of networks and trust relationships. Rather than attempting a major policy change as was done in Germany, policymakers in other countries would benefit from a better understanding of current practices. This information could be used to design incremental changes that allow technology transfer processes the flexibility and adaptability needed to fit alternative technologies and markets.

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Appendix A

Table 1.A Data collection procedure

1. Search European Patent Office and the German Federal Patent and Trademark Office databases for every university faculty member that was an inventor on at least one patent. These individuals are identified by their “Professor Doctor” designation in the inventor name field. This method was validated and used in prior research (see e.g. Czarnitzki et al. 2007, 2009).[12]
2. Search European Patent Office and the German Federal Patent and Trademark Office databases for patents applied for by any of the German Public Research Organizations (PROs). The list of about 500 PRO institutes has been obtained from the “Bundesbericht Forschung und Innovation 2012” published by the Federal government. From these patents we keep those that list the public research organization as the only applicant. Take the inventor names of these patents. These inventors are assumed to be PRO inventors as we restrict the patents to those applied for only by the PRO (These are 70% of all patents involving a PRO). We apply this restriction to avoid having industry researchers cooperating with PROS classified as PRO researchers.
3. Pool the professors and PRO researchers obtained in step 1 and 2 and use the inventor mobility method to obtain these inventors’ lifetime history of patenting activity. This method searches the entire patent EPO and DPMA databases (all patents, with any co-applicants) from 1978 onwards to obtain similar names, both with and without academic titles (Professor Dr.) and “connects” inventors with the same name as being the same person when cross-referencing information such as common applicant names and addresses, IPC classifications, co-inventors and citations are verified. This procedure addressed the homonymy problem. It allows obtaining the lifetime patenting record of the researchers, independent of their affiliation or current academic title. Some of the professors also appear as PRO researchers at some point in time. We drop those researchers associated with both institutions. By doing so, we exclude those researchers for whom we do not know which IP policy is binding, the policy of the university or the policy of the PRO. From 1995 to 2008 we searched all 624041 patent families in the EPO and DPMA database. Our identification strategy for professor -and PRO researcher -invented patents identified 58252 patents (9.3% of overall patents) to be invented by a professor or a PRO inventor.

[12] One may be concerned that the Professor Doctor title is also given as an honorary title to individuals who are not employed at universities. While the granting of honorary titles seems to be relatively rare, some of these highly qualified individuals may be labeled as professors in our data process. We believe any misclassification error would work against finding a significant policy effect as these individuals are not affected by the policy change.

4. List of inventors from step 3 is used to perform name searches in the Thomson Reuters Web of Science publication database, 1990 – 2008. We first retrieve all publications from Web of Science that match with respect to the names in our inventor list and have at least one German affiliation. Second, we disambiguate these authors from Web of Science using cross-referencing information on journals, coauthors, citations and affiliations. This yields 296320 publications from 1995 to 2008 (52 % of all searched publications with at least one German author (572936) in this time period).
5. We link the list of unique disambiguated journal authors that have been obtained in step 4 to the list of unique patent inventors that have been disambiguated in step 3. In order to link these researchers to each other we can only use the names and affiliations taken from the patent and publications as matching criteria. If one unique author, which has been identified in step 4, has the same affiliation as an inventor obtained from step 3 these two are linked and become one researcher with both a patent and a publication record. If no publication record can be found, the researcher possesses only a patent record.
6. Generate a panel dataset of unique academic inventors that includes information on their patents, citation-weighted patents and publications for each year. We count patents at the family level to ensure that patents in different jurisdictions for the same invention are not counted more than once. The unit of observation is a researcher-year. We restrict the regression sample period to run from 1995 through 2008. However, we keep those researchers who patented before 1995 in the sample. This implies that a researcher does not need to have a patent in the 1995 to 2008 period to be in the sample. We define entry into research as the year the researcher first appeared as a patent inventor or publication author. We drop researchers that enter after 2002 as these individuals were not affected by the law change. The final database is an unbalanced panel. While the entry criteria seem reasonable – assuming that a researcher's career starts with his first public disclosure of research results – it is more difficult to define the end of a career, the exit from science, as we have no information on the researcher's real age. Exiting the researchers after they do not appear in publications or patents anymore is problematic, as this might be a result of the policy change. We therefore do the following: We exit the researchers if they do not have a publication in 5 subsequent years. This is done in order to make sure that the researcher did not leave academia and to exit those that did. Our final sample contains 3,718 professors and 8,294 PRO researchers with an overall of 48,529 patents from 1995 to 2008 (7.8% of all patents applied for at EPO and DMA in this period). We consider 196,680 publications for these researchers from 1995 to 2008 (34% of all searched publications).

Table 2.A Definition of variables

Variable name	Definition
# Patents	The number of patents applied for in year by an academic inventor
# Citation-weighted patents	The number of citations received by patents applied for in given year in the four subsequent years to the application date
Professor	The academic inventor was professor at some point in his career
Career age	The number of years elapsed since the academic inventor's first patent or publication
New policy	Dummy for years >= 2002
Professor*New policy	Interaction of Professor dummy and New Policy
Industry connection	The researcher has at least one patent applied for jointly with a firm applicant prior to 2001
Avg Publications	A moving average of journal publications over the past three years, t-1 to t-3