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University Innovation and the Professor's Privilege†

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National policies take varied approaches to encouraging university-based innovation. This paper studies a natural experiment: the end of the "professor's privilege" in Norway, where university researchers previously enjoyed full rights to their innovations. Upon the reform, Norway moved toward the typical US model, where the university holds majority rights. Using comprehensive data on Norwegian workers, firms, and patents, we find a 50 percent decline in both entrepreneurship and patenting rates by university researchers after the reform. Quality measures for university start-ups and patents also decline. Applications to literature on university technology transfer, innovation incentives, and taxes and entrepreneurship are considered. (*JEL* I23, L26, M13, O31, O33, O34)

University researchers can create valuable commercial innovations. Standing at the frontier of knowledge, university researchers may start successful high-technology companies (e.g., Genentech and Google) and create valuable intellectual property (e.g., the Hepatitis B vaccine and the pain medication Lyrica).[1] Given these roles, university patenting and entrepreneurship have become subjects of substantial public interest and an expansive research literature, as reviewed below.

This paper studies a large shock to university innovation policy. The setting is Norway, which in 2003 ended the "professor's privilege," by which university researchers had previously enjoyed full rights to new business ventures and intellectual property they created. The new policy transferred two-thirds of these rights to

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[1] For example, University of California-San Francisco professor Herbert Boyer founded Genentech to bring genetic engineering into the marketplace, and Stanford graduate students Sergey Brin and Larry Page founded Google and revolutionized internet search. In the patenting sphere, University of California researchers produced the Hepatitis B vaccine, and Northwestern University professor Richard Silverman created the compound for a pain medication, Lyrica, which was Pfizer's top-selling drug in 2014, with global sales of $5 billion. US universities and research institutions were granted over 6,000 patents and executed over 5,000 licenses in fiscal year 2012, according to a recent survey (AUTM 2015).

the universities themselves, creating a policy regime like that which typically prevails in the United States and many other countries today. In addition to the policy experiment, Norway also provides unusual data opportunities. Registry data allow us to identify all start-ups in the economy, including those founded by university researchers. We can also link university researchers to their patents. We are thus able to study the reform's effects on both new venture and patenting channels.

Inspired partly by a belief that US universities are more successful at commercial innovation (Mowery and Sampat 2005; Lissoni et al. 2008), many European countries have enacted laws in the last 15 years that substantially altered the rights to university-based innovations. In Germany, Austria, Denmark, Finland, and Norway, new laws ended the so-called "professor's privilege." Recognizing potential complementarities between institution-level and researcher-level investments, the new laws sought to enhance university incentives to support commercialization activity, including through the establishment of technology transfer offices (TTOs). However, while these reforms may have encouraged university-level investment, they also sharply increased the effective tax rate on university-based innovators, leaving the effect of such reforms theoretically ambiguous. Broadly, these national systems moved from an environment where university researchers had full property rights to a system that looks much like the US system today (since the 1980 US Bayh-Dole Act), where the innovator typically holds a minority of the rights, often one-third, and the university holds the remainder (Jensen and Thursby 2001; Lach and Schankerman 2008).

To study the end of the professor's privilege, we leverage several datasets that allow us to examine new venture and patenting activity for all university researchers in Norway. Registry datasets provide detailed information about all Norwegian workers and firms, while also linking specific individuals to specific firms. We are thus able to identify all new firms in Norway and all new firms started by university employees. The data further provide far-reaching information about all Norwegian adults, including educational attainment, degree type, age, income, wealth, and family status, allowing us to compare the behavior of those directly affected by the policy shock (i.e., university employees) with various control samples (e.g., all Norwegian individuals, and various subsets with increasingly similar demographic characteristics to the university employees). We separately collect all patents issued in Norway and compare patenting by university-based researchers with other Norwegian inventors. In secondary analyses, we conduct a survey of university inventors to investigate both licensing behavior and individual perceptions of the reform, and, finally, we integrate all publications in the Web of Science by Norway-based researchers to examine publication outcomes.

Our primary empirical finding is that the shift in rights from researcher to university led to an approximate 50 percent drop in the rate of start-ups by university researchers. This drop appears (i) in a simple pre-post analysis of university start-up rates, (ii) when compared to background rates of start-ups in Norway, and (iii) when analyzed at the level of the individual Norwegian citizen, controlling for fixed and time-varying individual-level characteristics. We further find that university researchers substantially curtailed their patenting after the reform, with patent rates falling by broadly similar magnitudes as seen with start-ups. In addition to these effects on the *quantity* of innovative output, we find evidence for decreased *quality* of both start-ups and patents, where, for example, university start-ups exhibit less growth and university patents receive fewer citations after the reform, compared to controls. Overall, the reform appeared to have the opposite effect as intended.

Primarily, this study informs the literature on university commercialization policy (reviewed below). The end of the professor's privilege constitutes a major policy shift that was enacted in Norway and mirrored in several other European countries. The study thus informs the policy's effects in Norway, with potential additional applications to similar reforms and ex post policy regimes more generally. Notably, the post-reform regime is similar to policies that prevail in the United States today, among many other countries. The central finding is that the policy change in Norway effectively halved measured rates of innovation.

The analysis may also provide insight for other literatures. Noting that the experiment sharply changed the allocation of rights between researchers and the university, the findings can inform the role of rights allocations in knowledge production. How to balance the allocation of rights between investing parties is a classic question in economics that also features in canonical theories of innovation (Holmstrom 1982; Grossman and Hart 1986; Aghion and Tirole 1994; Green and Scotchmer 1995; Hellmann 2007). The natural experiment in this paper can be seen as supporting the idea that innovation rights matter, even in universities, where the norms of science might otherwise suggest greater willingness to put output in the public domain (Merton 1973). Related, noting that the experiment acts, in part, to increase the effective tax rate on individual university researchers, the policy change may also help inform the link between tax rates and entrepreneurial activity for an important class of high-skilled workers. The literature on taxes and entrepreneurship has almost exclusively examined sole-proprietors and self-employed workers (e.g., Gentry and Hubbard 2000), who are typically quite different from the growth-creating innovators that motivate many studies of entrepreneurship (Glaeser 2007; Levine and Rubinstein 2017). The experiment in this paper considers a class of innovators who work at the frontier of science and technology, face in part a large increase in their effective tax rate, and subsequently substantially curtail their entrepreneurial activity. All told, the empirical findings, together with an ex post survey of the university inventors, suggest that the university inventors are highly sensitive to their income rights.

This paper is organized as follows. Section I details the institutional setting, reviews relevant literature, and discusses advantages and disadvantages that can emerge when increasing university rights at the expense of researcher rights. Section II introduces the data and identification strategy. Section III presents the core results for entrepreneurship and patenting. Section IV discusses these findings, including their relevance to broader settings, as well as other margins of response empirically.[2] Section V concludes.

[2] Online Appendix I presents a simple model to further clarify motivations and pitfalls when giving majority rights to the university at the expense of the individual researcher. Online Appendix II considers additional empirical findings, studying the publication behavior of university researchers and how this changes with the reform. Online Appendix III details the results of our university inventor survey, focusing on licensing behavior and individual views of the reform. Online Appendix IV further details the patent measures. Online Appendix V discusses the broader Norwegian innovation system and provides further details and analysis regarding Norway's Technology Transfer Offices. The main findings of these additional analyses are discussed in Section IV.

I. University-Based Innovation

To frame our research questions and the potential effects of the policy reform, we review here the institutional setting of university-based innovation, including the "professor's privilege" in numerous European countries and the details of the Norwegian policy reform. We then consider core conceptual frameworks that can clarify trade-offs that arise when balancing rights between the researcher and the university.

A. *Institutions*

The long-standing upward trend in patenting and new venture activity among US universities has triggered an enormous literature investigating university innovation and entrepreneurship. Scholars have seen universities as increasingly important wellsprings of innovative ideas, and researchers have investigated the legal systems, incentive conditions, organizational attributes, technology areas, and local business environment among other features that may help explain the relative success of various universities in commercializing innovations both along patenting and new venture channels (see, e.g., Lockett et al. 2005; Rothaermel, Agung, and Jiang 2007; Grimaldi et al. 2011; Merrill and Mazza 2010). A major thrust of this research (and associated policy debate) takes the goal of university-based innovation as given and seeks to understand the features that influence its success.[3]

The 1980 Bayh-Dole Act is a signal event for researchers and policymakers in this space. The law eliminated US government claims to university-based innovation, giving US universities the rights to innovative ideas that were federally funded. Studies have since examined the potential effects of Bayh-Dole on patent rates (e.g., Mowery et al. 2001), patent quality (e.g., Henderson, Jaffe, and Trajtenberg 1998), and entrepreneurship (e.g., Shane 2004) among other issues. Interestingly, while US university patenting rates were approximately five times larger in 1999 than in 1980, there is no evidence that Bayh-Dole caused a structural break in the preexisting trend (Mowery and Sampat 2005).

The acceleration of patenting and licensing from US universities eventually caught the attention of European policymakers, who concluded that European universities lagged their US counterparts in commercialization outcomes (Geuna and Rossi 2011). European policymakers associated Bayh-Dole with high rates of university-based innovation and sought to emulate Bayh-Dole (Mowery and Sampat 2005; Lissoni et al. 2008). Thus, in the early 2000s, numerous European countries passed laws that attempted to encourage universities' interest and success in commercialization. New legislation was implemented in several countries (Germany, Austria, Denmark, Finland, and Norway) by ending the "professor's privilege." Under the professor's privilege (i.e., prior to the reform), a university researcher retained blanket rights to his or her invention. The new policies shifted substantial

[3] Separately, many scholars have addressed whether universities should engage in commercial innovation activity given potential trade-offs with other activities, especially basic research (e.g., Krimsky 2003; Washburn 2008; Merrill and Mazza 2010). These potential trade-offs bear on a complete assessment of the welfare consequences of commercialization policy. We discuss these trade-offs in Section IV, with further analysis in online Appendix II.

rights to the university. Notably, although policymakers in Europe were inspired by the post-Bayh-Dole Act environment in the United States, the policy changes around the professor's privilege were quite different from the Bayh-Dole Act. Instead of transferring rights away from the government, this transfer came from the researchers themselves. The end result was that these European countries obtained a legislative environment similar to that in the US post-Bayh-Dole.

In contemporaneous studies of the professor's privilege, Czarnitzki et al. (2015) find a decline in university patenting in Germany after the reform there, while Astebro et al. (2015) find lower rates of PhDs leaving universities to start companies in the United States than in Sweden, which has maintained its professor's privilege. The findings in these two working papers will be discussed in tandem with our empirical findings in Section IV.

In Norway, the professor's privilege (*laererunntaket* in Norwegian) was abolished by unanimous Parliament decision in June 2002, and made effective for all public higher education institutions from January 1, 2003.[4] The new law gave the university the formal ownership rights to the commercialization of research (including start-ups and patents). Each Norwegian university also formally established a Technology Transfer Office (TTO).[5] After the law change, Norwegian universities shared one-third of the net income with the researcher, so in effect the policy change reduced the inventor's pre-tax expected income by two-thirds.[6] Given income taxes in Norway, this change represents an approximately 33 percentage point increase in the effective tax rate the researcher faces when forming new ventures or creating patentable inventions.[7]

The premise behind the policy change was to encourage universities to make investments that support patenting and licensing by their researchers and labs, so that this property rights transfer would improve commercialization outcomes (Czarnitzki, Hussinger, and Schneider 2011). However, empirical evidence that could motivate this view was lacking (Lissoni et al. 2008). Moreover, the policy arguments, and literature on the Bayh-Dole Act more generally, tend to focus on intellectual property outcomes rather than new ventures, which is a primary commercialization alternative (e.g., Gans and Stern 2003). As we will show, both patenting and new business formation appear to have been severely affected by the end of the professor's privilege.[8]

[4] The nonpublic higher education sector is very small in Norway. The law change is named Proposition 67 of the Odelsting (2001–2002). A full transcript of the Parliamentary session leading to Proposition 67 is available at https://www.stortinget.no/globalassets/pdf/referater/odelstinget/2002-2003/o021107.pdf.

[5] These TTOs were established in 2003, although they were often based on precursor technology offices that had been financed by the Norwegian Research Council since 1996. By 2005, the TTO offices typically had approximately ten employees. Further institutional detail is given in online Appendix V. See also Rasmussen, Moen, and Gulbrandsen 2006.

[6] The one-third split with the university researcher was not formally established in the law per se but called for by the parliamentary committee chairman when passing the law. This norm was formally established in university bylaws later in the decade.

[7] The marginal tax rate in Norway is approximately 50 percent on both labor and business income so that 100 kroner in commercialization profits pre-reform would have net value of about 50 kroner for the researcher. Post-reform the net value would be one-third, i.e., 16.7 kroner, so that the post-reform effective tax rate would be 83 percent. The increase in effective tax rate is thus approximately 33 percentage points.

[8] Interestingly, Lissoni et al. (2008) have shown that, in contrast to the US experience where 69 percent of university-based inventions are assigned to universities, the great majority of university-based inventions in France, Italy, and Sweden are actually assigned to private firms. While it is not known whether these firms are new ventures, the Lissoni et al. study raises further questions about the empirical motivation for the European policy reforms. Once

The Norwegian innovation system more broadly is characterized by a mix of private sector entities and public sector support. Large technology-related firms in the economy include Statoil (oil and gas), Norsk Hydro (aluminum), Yara (chemicals), Telenor (telecom), the Kongsberg Group (weapons technology), and Opera Software (computing). The university system is primarily public with the largest universities and innovation hubs in Oslo, Bergen, Trondheim, and Stavanger. Norway's venture capital investment as a percentage of GDP is above the EU average (Statistics Norway 2015). Innovation Norway, with offices in every Norwegian county, is the government's major vehicle for promoting technology companies and financing new ventures. Further details about the Norwegian innovation system, including the leading patent classes, research publication, and start-up areas, and details of the TTOs are provided in online Appendix V.

B. *Theoretical Perspectives*

Several theoretical perspectives can motivate the professor's privilege reform (and, by extension, motivate systems like those typically found in the United States and many other countries today). However, theory also suggests substantial caution. This section reviews perspectives in the economics of innovation to better understand motivations and potential pitfalls associated with the policy change. The richness of these theories suggests the importance of empirical analysis, which in turn can help limit the set of relevant mechanisms, as we will discuss in Section IV.

The professor's privilege reform creates a large shift in the allocation of rights, and core theoretical ideas in the economics of innovation engage these issues (Aghion and Tirole 1994; Green and Scotchmer 1995; Scotchmer 2004; Hellman 2007). Aghion and Tirole (1994) analyzed innovation contexts where different agents bear private costs but share in future payoffs and emphasize the challenge in effectively balancing incentives across investing parties. These theories suggest that rights should be balanced toward the party whose investment matters more.[9]

Online Appendix I formalizes this reasoning in the university context, where the rights allocation is divided between the researcher and the research institution, who both may make separate investments in pursuit of a commercial outcome. Investments by the individual researcher, as the source of the ideas, appear critical. The university may also play important roles by supporting infrastructure for applied research, searching for commercializable ideas within university laboratories, facilitating patent applications, managing licensing, and otherwise investing to promote successful commercial outcomes (e.g., Rothaermel, Agung, and Jiang 2007; Baldini 2011). In light of these potential advantages, encouraging investments by universities may be important, so that giving all income rights to the professor (as in the professor's privilege) may reduce university-based innovation compared

these privately-owned patents are accounted for, university researchers in these three European countries (especially Sweden) show only modestly lower patenting rates than US universities, which undercuts the empirical view that European universities were laggards in commercialization activities in the first place.

[9] Other things equal, giving a greater share of the surplus to the party whose investment affects the surplus more will encourage more surplus creation. It is possible to undo this intuition, however, if a particular agent's effort responds relatively weakly to their share (for example, if a party faces a multitasking problem and would not devote effort to creating this particular joint surplus even if given substantial rights to it).

to a policy with more balanced rent sharing.[10] Moreover, one can construct examples where university-based innovation is maximized when the university receives two-thirds of the income and the researcher receives one-third, as in the more typical regime. Online Appendix I provides a formal example.

This income rights reasoning, as a potential a priori justification for the reform, can also point out potential pitfalls. In particular, one may be skeptical about the value of university-level investments. Some scholars argue that university technology transfer offices (TTOs) have poor capabilities or inappropriate incentives and suggest reallocating rights toward the faculty in pursuit of greater technology transfer (Litan, Mitchell, and Reedy 2007; Kenney and Patton 2009). To the extent that the complementary investments by the university are not especially important, giving the university income rights may reduce rather than promote innovation (see also online Appendix I). In practice, the appropriate income rights allocation in the university context remains unknown.

The professor's privilege reform might also be motivated by a belief that university researchers care relatively little about income, so that lessened income rights would have little effect on researcher's entrepreneurial or inventive effort. For example, Mertonian norms of science, including ideas of communalism that emphasize the placement of research outputs in the public domain (Merton 1973), may suggest relatively weak links between personal financial reward and effort in the university setting. Evidence suggests that university-based researchers on average value income relatively less than industrial researchers (Stern 2004), and entrepreneurs appear to have strong tastes for autonomy and other motivational characteristics distinct from income (e.g., Evans and Leighton 1989; Hamilton 2000; Shane, Locke, and Collins 2003; Sauermann and Roach 2012). The extent to which university-based innovators, or high-skill innovators more generally, react to effective tax rates appears unknown.

Beyond income rights, the professor's privilege reform also affected control rights, with the university gaining decision-making authority over knowledge-related assets. Such control rights may matter when university and researcher interests are not aligned and contracts are incomplete. As one example, the researcher might prefer her patented invention to be used as widely as possible, while the university may prefer monopoly pricing. Disagreement may result in Williamsonian haggling costs that further destroy surplus, and anticipation of such haggling may in turn dissuade the researcher's effort.

While theories emphasizing rights allocations in the economics of innovation are highly influential, empirical studies examining these theories remain relatively few (Lerner and Merges 1998; Lach and Schankerman 2008; Lerner and Malmendier 2010). Coupling the "professor's privilege" reform with the richness of Norwegian data provides a context for examining the potential importance of rights allocations, leveraging a large change in the rights regime.

[10] Incentive mechanisms limited to sharing the joint surplus are known to be an imperfect instrument for achieving first-best effort (Holmstrom 1982). Thus, neither the professor's privilege nor the post-reform regime with a one-third/two-third split would produce first-best investment. At the same time, second-best outcomes will typically depend on a careful balance of income rights across the investing parties.

Overall, integrating across these theoretical perspectives, there are many contending ways in which the professor's privilege reform might affect university-based innovation. The actual effects are very much an empirical question, which we turn to next.

II. Data and Identification

In this section, we describe the datasets and the econometric methods we employ.

A. *Data*

The start-up analysis draws on several Norwegian register databases. The sociodemographic data, compiled by Statistics Norway, cover the Norwegian adult population and consist of yearly records of workplace ID in addition to education level, gender, income, wealth, marital status, and many other variables. We identify university employees through their workplace ID and researchers as individuals with a PhD degree. These university-employed PhDs are the "treatment group" in our analyses.

The start-up data, collected from the government registry *Brønnøysundregisteret*, cover the population of incorporated companies started in Norway between 2000 and 2007, and provide total equity, owner ID, and ownership shares at the incorporation date. The owner ID, which is available for any individual who owns at least 10 percent of the company, can be matched to the sociodemographic data, and in this manner we identify new firms started by university researchers as well as the sociodemographic characteristics of entrepreneurs more generally. The data further contain anonymous ID numbers for the start-ups, allowing us to match at the firm-year level with accounting data collected from Dun & Bradstreet. The accounting data run through 2012; they identify which sector the start-up operates in and contain annual measures of start-up performance such as sales, profits, and employees.[11]

The patenting analysis is based on separate data collected from several sources. Norwegian Patent Office (NPO) data do not link to the administrative datasets discussed above and we therefore proceed by other means.[12] We first obtained a list of the names of university-sector researchers for the period 1995–2010 from the Nordic Institute for Studies in Innovation, Research and Education (NIFU).[13] There are 11,905 unique university researchers in this data. In addition to full names, this dataset contains sociodemographic information such as gender, age, and PhD

[11] Note that we focus on incorporated companies, which does not include self-employment. Levine and Rubinstein (2017) show in the US context that incorporation is an important indicator for locating growth-creating innovators and organizations, while self-employment is misleading for capturing such entrepreneurial firms. As in other industrialized countries, starting an incorporated company in Norway carries tax benefits relative to self-employment (e.g., write-offs for expenses such as home office, company car, and computer equipment). With the exception of very small projects, incorporation is more tax efficient than self-employment status. The formal capital requirement for registering an incorporated company was NOK 100,000 (€ 13,000) during the study period. Incorporated companies are required to have an external auditor certify annual accounting statements submitted to tax authorities.

[12] The patent data provides names of inventors and applicants as strings and, in the absence of the anonymized firm or individual ID numbers discussed above, cannot be merged into administrative datasets.

[13] The NIFU list of university researchers is biannual for 1995–2006 and annual for 2007–2010.

type, as well as the specific university employer. From the Norwegian Patent Office (NPO) we obtained a list of all patents granted in Norway where an inventor has a Norwegian address from 1990 through September 2014.[14] We then matched the names from NIFU with the inventor names in the patent data to determine which patents had university inventors. The matching procedure uses full first names and surnames; robustness checks to account for potential noise in name-matching for the patent data are included below. We further examined several quality metrics for the NPO patents, including citations received, patent renewals, and indicators for transnational patenting via the European Patent Office, Japanese Patent Office, and US Patent and Trademark Office (EPO, JPO, and USPTO, respectively).[15] Further detail regarding the patent data is given in online Appendix IV.

Table 1A provides summary statistics for start-up firms in Norway between 2000 and 2007. In total there were 48,844 start-ups and 128 of these were started up by individuals with PhDs employed at a university. We define a university start-up as a newly incorporated company where at least one of the initial owners is a full-time university employee with a PhD. By comparison, there were 452 start-ups by individuals with PhDs who were not employed at universities. Overall, we see that university PhD start-ups were substantially more likely to survive than companies started by the broader background population, while survival among non-university PhD start-ups is more similar.[16] University PhD start-ups tend to be somewhat smaller in employees, sales, and profits than non-university start-ups, with a closer match to non-university PhD start-ups.[17] Comparing the university PhD start-ups and non-university PhD start-ups, *t*-tests indicate that differences in means are not statistically significant except for profits at 5 years.[18] Looking at median outcomes, the firms at five years tend to be very small. The seventy-fifth percentile company in each category features 1–3 employees while sales reach 1.2–3.3 million NOK, depending on the population, while the ninety-fifth percentile companies are substantially larger, with 5–12 employees and sales of 6.9–16.4 million NOK across categories. Overall, we see greater performance similarity among start-ups by PhDs than with start-ups in the background population. These findings also indicate the relative rarity of substantial entrepreneurial success, which suggests the low likelihood of substantial returns to starting new companies.[19]

Table 1B provides summary statistics on entrepreneurs in Norway. On average, university entrepreneurs are older, more educated, higher income, and more likely to be male and married than non-university entrepreneurs. Compared to non-university

[14] These Norwegian patents include patents that were granted by the European Patent Office and then registered at the Norwegian Patent Office, which became possible starting in 2008.

[15] We are indebted to Stefano Breschi and Rainer Widmann for help in matching the NPO data and PATSTAT to determine citation counts as well to match NPO patents with European, US, and Japanese patent databases. Patent renewal data come from the NPO.

[16] Nonsurviving firms are defined as those that stop reporting profits or whose sales fall below 50,000 NOK after their first year.

[17] Performance at five years is not conditional on survival. The greater survival but lower average performance is consistent, for example, with university PhDs relying less on the start-up for income, given their university employment, and hence being more likely to continue with lower performing firms.

[18] These *t*-tests for differences in sample means find *p*-values as follows: survival ($p = 0.28$), sales ($p = 0.61$), employees ($p = 0.14$), and profits ($p = 0.064$).

[19] Guzman and Stern (2015a, b) document the rarity of high-growth entrepreneurship in the United States and in the environs of US universities.

TABLE 1A—SUMMARY STATISTICS FOR START-UP FIRMS IN NORWAY, 2000–2007

		Non-University	Non-University PhD	University
Number of start-ups		48,844	452	128
Fraction surviving at 5 years	Mean	0.74	0.83	0.87
Sales at 5 years	Mean	5,160	2,308	2,659
	(Standard deviation)	(13,282)	(4,777)	(9,934)
	Median	1,751	628	183
	75th percentile	4,834	2,210	1,550
	95th percentile	20,769	10,815	9,374
Employees at 5 years	Mean	3.31	1.68	1.22
	(Standard deviation)	(7.77)	(3.16)	(2.89)
	Median	1	1	0
	75th percentile	4	2	1
	95th percentile	13	7	5
Profits at 5 years	Mean	198	220	100
	(Standard deviation)	(554)	(599)	(600)
	Median	43.1	41.2	−6.50
	75th percentile	283	296	215
	95th percentile	1,358	1,555	1,555

Notes: Sales, employees, and profits are conditional on survival at year 5. Profits and sales are measured in 1,000 NOK.

PhD entrepreneurs, the university entrepreneurs look much more similar. By construction, individuals in both groups have PhDs. They also have similar average ages (47) when starting companies and similar marital status (74 percent married). The income and wealth for the non-university PhDs is somewhat larger and the non-university PhD entrepreneurs are slightly less likely to be male.[20]

Table 1C provides summary statistics for patents. Over the 1995–2010 period, we see that university researchers applied for 454 patents in exactly those years where the individual was employed at university. A broader construct includes all patents by individuals who were employed at universities at some point over the sample period, which identifies a total of 750 patents. We will examine variants of these samples below to examine the effect of the reform on patenting rates not only among current university employees but also to capture ongoing patenting by those who leave university employment. Compared to NPO patents as a whole, university researchers' patents are more likely to be cited by other patents and more likely to receive transnational patent protection via the European Patent Office, Japanese Patent Office, or US Patent and Trademark Office. Although about two-thirds of the university PhD workforce is male, university inventors are 93 percent male. The background population of Norwegian inventors is estimated to be 94 percent male. The substantial propensity toward male inventors echoes the similar gender propensity seen in entrepreneurship above.

[20]Two sample t-tests indicates no significant difference for age ($p = 0.83$) or marital status ($p = 0.89$) while there is a marginally significant difference for gender ($p = 0.095$) and differences for prior year earnings ($p = 0.017$) and wealth ($p = 0.040$). The somewhat greater income of the non-university PhDs is consistent with observations elsewhere that university researchers are paid less than those taking jobs in industry (Stern 2004). In the regression analyses below, the results are robust to including individual fixed effects as well as time-varying, individual-level controls.

Table 1B—Summary Statistics for Entrepreneurs in Norway, 2000–2007

	Non-University	Non-University PhD	University
Number of entrepreneurs	69,496	413	125
Age of founder, mean	41.6	47.4	47.8
(Standard deviation)	(9.95)	(8.98)	(8.90)
Median	40	46	47
Fraction with highest degree	0.23	1	1
Bachelors	0.09	1	1
Master's	0.006	1	1
PhD			
Income, mean	422	752	609
(Standard deviation)	(675)	(513)	(265)
Median	343	631	527
Wealth, mean	1,520	1,610	1,140
(Standard deviation)	(12,200)	(2,910)	(1,550)
Median	449	731	581
Marital status, mean	0.59	0.74	0.74
(Standard deviation)	(0.49)	(0.44)	(0.44)
Median	1	1	1
Fraction male	0.79	0.88	0.94

Notes: Income and wealth are measured in 1,000 NOK. Income, wealth, marital status, and age are measured in year prior to founding of firm.

Table 1C—Summary Statistics for Patenting in Norway

	All Norway	University
Number of patents granted	7,341	454[a]
Percent cited at least once	53.4	60.4
Percent patented at EPO, USPTO, or JPO	41.7	50.2
Number of unique inventors	6,890	268
Percent male, workforce	50.4	65.9
Percent male, inventors	94.3[b]	92.9
Period	1995–2010	1995–2010

Notes:

[a]University patents and inventors are defined here by being full-time employees of universities in the application year of the patent. When noted we will also examine patents by university researchers in periods when they are not employed at university; these individuals account for 750 total patents over the sample period.

[b]Male percentage here is estimated using gender for common names in Norway. Gender for the university sample is given directly by the NIFU database and gender for the overall Norwegian workforce from census data. Citations by other patents are counted at the patent family level. Online Appendix IV provides further detail on the patent data.

Based on the Norwegian census data at the end of 2002, there were 3,747 university researchers in Norway, 8,272 PhDs who worked outside universities, and a total Norwegian workforce of 2.501 million. The PhD workforce expanded more rapidly than the broader Norwegian workforce over the 2000–2007 period. In particular, the university PhD workforce, non-university PhD workforce, and total Norwegian workforce grew by 65 percent, 39 percent, and 7 percent, respectively.

B. *Econometric Approach*

Our analyses primarily consider difference-in-differences regressions, using the end of the professor's privilege to divide the sample into pre- and post-periods and comparing start-up and patenting rates inside the university sector (the treatment group) and outside the university sector (the control group). We first study panel models of the following form:

$$(1) \qquad y_{it} = \beta_0 Post_t + \beta_1 Treat_i + \beta_2 Treat_i \times Post_t + \varepsilon_{it},$$

where the dependent variable y_{it} is a count of start-ups or patents, $Post_t$ is a dummy variable equal to 1 in years after the reform (2003 or later), and $Treat_i$ is a dummy equal to 1 if the observation represents universities, i.e., those affected by the end of the "professor's privilege."

When using data at the sector or individual level, we extend the panel model in (1) to incorporate sector or individual fixed effects (α_i) and time fixed effects (μ_t). In some specifications we will also incorporate time-varying individual characteristics (X_{it}), such as lagged income and wealth. These difference-in-differences regressions thus generally take the form[21]

$$(2) \qquad y_{it} = \alpha_i + \mu_t + \beta_1 Treat_i + \beta_2 Treat_i \times Post_t + \gamma X_{it} + u_{it}.$$

In the relevant regression models, we cluster standard errors at the individual level.

III. Results

In this section we present the main results of the paper. We consider entrepreneurship in Section IIIA and patents in Section IIIB.

A. *Start-Ups*

The Rate of Entrepreneurship.—We first consider how the rate of start-ups for university researchers changes after the reform and then compare it to changes in start-up rates for the background Norwegian population. Figure 1A plots the annual number of university start-ups (red dashed line, left vertical axis) and non-university start-ups (blue line, right vertical axis) over the sample period.[22] While the non-university start-up rate is approximately constant across years, the university start-up rate drops dramatically from the pre-reform (2000–2002) to the post-reform (2003–2007) period. The pre-reform period averaged 24.7 university start-ups per year, while the post-reform period averaged 10.8 university start-ups per year, for a drop of 56 percent.

[21] Note that the time fixed effects absorb the $Post_t$ term. The sector-level fixed effects do not absorb the $Treat_i$ term because treatment status varies within sectors. The individual fixed effects do not in general absorb the $Treat_i$ term because individuals may move between university and non-university employment.

[22] The vertical axes in Figure 1 and related figures in the paper begin at 0 so that the percentage changes in the data being compared can be seen visually.

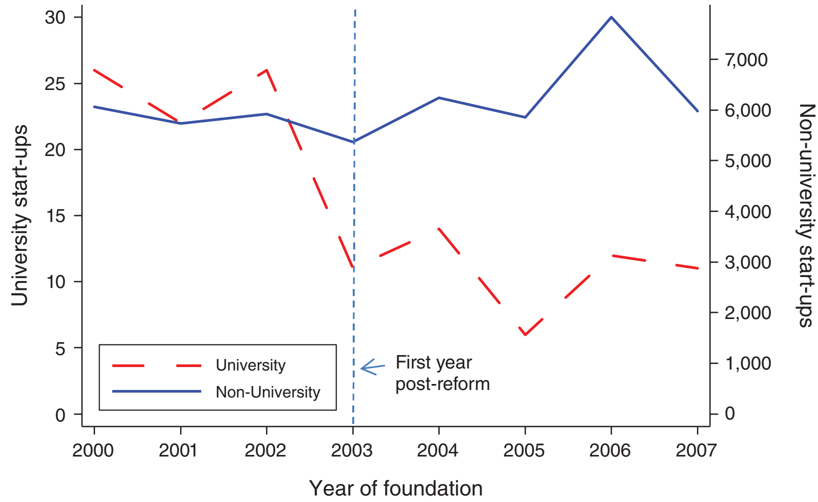

Figure 1A. University Start-Ups versus Non-University Start-Ups

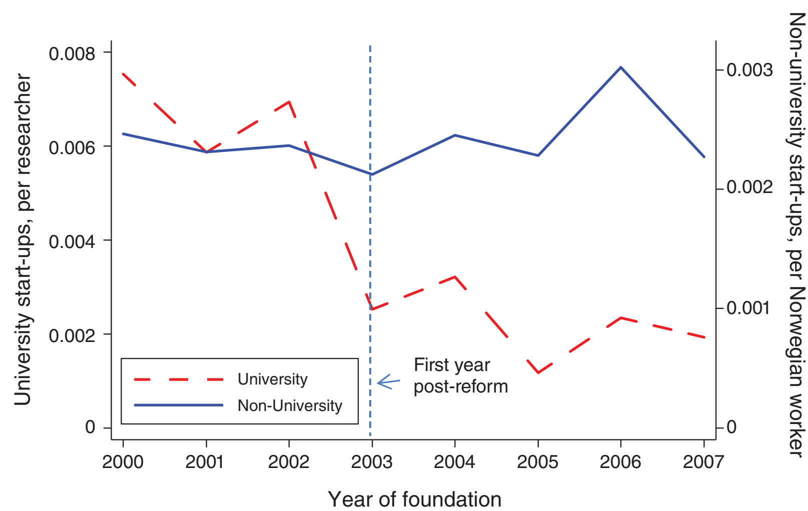

Figure 1B. University versus Non-University Start-Ups, per Worker

Figure 1B considers the same data on a per-worker basis for the relevant groups. On average, 0.678 percent of university researchers started a new firm in a given year prior to the reform, while 0.224 percent of university researchers started a new firm in a given year after the reform, for a 67 percent drop in the per-worker rate. The drop is slightly larger on a per-worker basis (Figure 1B) than on a count basis (Figure 1A) because the number of university researchers is increasing relatively rapidly over the period compared to the Norwegian workforce as a whole.

Together, these figures show a sharp drop in entrepreneurship by university researchers that is coincident with the professor's privilege reform. By contrast, the

TABLE 2—START-UPS, AGGREGATE, AND SECTOR-LEVEL ANALYSIS

	Aggregate					Sector		
	log start-ups	log start-ups per worker	log start-ups	log start-ups per worker	log start-ups, pre period individuals	log start-ups	Start-ups	Start-ups, pre period individuals
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treated × *Post*	−0.912	−1.102	−0.603	−0.667	−0.737	−0.504	−0.591	−0.548
	(0.172)	(0.179)	(0.232)	(0.242)	(0.257)	(0.265)	(0.206)	(0.216)
Treated	−5.477	1.167	−0.961	−0.998	−0.934	−5.214	−0.969	−0.964
	(0.0546)	(0.0614)	(0.110)	(0.128)	(0.108)	(0.229)	(0.103)	(0.0977)
Post	0.0517	0.0163	−0.258	−0.478	−0.258	–	–	–
	(0.0671)	(0.0650)	(0.170)	(0.113)	(0.170)			
Year FE	–	–	–	–	–	Yes	Yes	Yes
Sector FE	–	–	–	–	–	Yes	Yes	Yes
Control sample	Norwegian workforce	Norwegian workforce	PhD workforce	PhD workforce	PhD workforce	Norwegian workforce	PhD workforce	PhD workforce
Period	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007
Model	OLS	OLS	OLS	OLS	OLS	OLS	Poisson	Poisson
Observations	16	16	16	16	16	120	160	160
R^2	0.997	0.849	0.909	0.800	0.899	0.97	–	–

Notes: Columns 1 and 3 consider aggregate counts per year for the treatment and control groups. Columns 2 and 4 consider aggregate counts per worker. In column 5 we consider a fixed sample of pre-period treated individuals (see text). In columns 6 through 8, observations are sector × year for the treatment and control groups, with sector determined by the 1-digit NACE code. Robust standard errors in parentheses.

start-up rate for the background population is largely flat, increasing 5.9 percent comparing the post- and pre-periods (Figure 1A) and increasing 2.1 percent on a per-capita basis (Figure 1B). Thus, the large decline in start-up rates by university researchers is not seen in the background Norwegian population.

The "visual" difference-in-differences shown in Figure 1 are explored further by regression. Table 2 presents aggregate analysis, looking at changes in log annual counts per year and log annual counts per worker. The regressions implement the econometric model (1). Examining the $Treat_i \times Post_t$ coefficient, we see that the drops in both start-up counts and start-up counts per worker are statistically significant compared to the Norwegian workforce as a whole (columns 1 and 2). On net, and consistent with the mean changes seen in Figure 1, we find a 67 percent decline (i.e., $1 - e^{-1.102}$) in the start-up rate per worker comparing university PhDs against the Norwegian workforce. Columns 3 and 4 repeat this analysis using PhDs not employed at university as the control group. We again see statistically significant declines in start-ups by university PhDs, with a 49 percent decline in start-ups per worker comparing university PhDs against non-university PhDs. Column 5 defines treated individuals as those employed at university in 2002 and regardless of whether they remain so after the reform. This specification captures any start-ups of these researchers even should the treated individuals leave the university system. We see a 52 percent decline in start-ups for this group.

Table 2 further considers sector-level analysis. This analysis can account for compositional changes in the sectors of start-up activity that might otherwise influence the results. In this analysis, the start-up counts are constructed by sector-year for

Table 3—Start-Ups, Individual-Level, All Workers

	All workers (1)	All workers (2)	All workers (3)	Entrepreneurs only (4)	Entrepreneurs only (5)
Treated × *Post*	−0.00450	−0.00457	−0.00431	−0.131	−0.114
	(0.000974)	(0.00110)	(0.00111)	(0.0283)	(0.0285)
Treated	0.00358	0.000343	−0.000142	−0.000436	−0.0136
	(0.000914)	(0.00156)	(0.00160)	(0.0440)	(0.0450)
Post	−0.000275	–	–	–	–
	(2.88e-05)				
Observations	19,937,044	19,937,044	19,937,044	535,039	535,039
R^2	0.000	0.164	0.165	0.029	0.032
Year fixed effects	No	Yes	Yes	Yes	Yes
Individual fixed effects	No	Yes	Yes	Yes	Yes
Age fixed effects	No	No	Yes	No	Yes
Individual time-varying controls	No	No	Yes	No	Yes
Period	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007

Notes: The dependent variable is an indicator for whether the individual started a company that year. Estimates are the linear probability model. Nonlinear probability models (probit or logit) produce similar results, as discussed in text. The individual time-varying controls include lagged marital status, lagged total years of education dummies, log income, and log wealth. Standard errors are clustered by individual in parentheses.

the treatment and control groups, where sector is determined by the 1-digit NACE code.[23] Column 6 examines the log start-up count as the dependent variable. Because this approach drops sector-years with zero counts, column 7 repeats the analysis with a Poisson count model that includes the full set of observations. Column 8, like column 5, tracks the start-ups of pre-period university researchers, even should they leave the university. The difference-in-differences drop in university start-up rates is similarly large and negative across these sector-level specifications.

Table 3 considers regression evidence at the individual level, using econometric model (2) and exploiting data for every individual in the Norwegian workforce. The dependent variable is now binary, indicating whether a given individual started a company in a given year. We use a linear probability model, which allows the inclusion of individual fixed effects, with standard errors clustered by the individual. Nonlinear models, such as logit or probit, show similar results.[24] Column 1 presents the simplest analysis, with no individual-level controls. Column 2 adds individual and year fixed effects, and column 3 additionally adds time-varying individual-level information, including age fixed effects, fixed effects for highest educational degree, marital status, lagged income, and lagged wealth.[25] The latter two specifications allow us to control for population differences between the treatment

[23] We use 1-digit sectors because start-up counts for the treatment group are not large enough to allow analysis for more granular sector categorizations. NACE is the standard industrial classification system in the European Union.

[24] We present the linear probability model primarily to allow inclusion of individual fixed effects and to compare results with and without these fixed effects. Logit or probit specifications are also presented below as alternatives and typically show more precise results (smaller standard errors). Given the increased precision seen with the nonlinear models, the emphasis on the linear probability model in the exposition also appears conservative. Complete results using nonlinear models are available from the authors upon request.

[25] Income and wealth controls for each worker are quadratics in the log of each variable, lagged by one year. Wealth is provided in the registry data due to the Norwegian tax code, which includes a wealth tax.

TABLE 4—START-UPS, INDIVIDUAL-LEVEL, SIMILAR WORKERS

	Master's or more (1)	PhD (2)	PhD logit (3)	PhD propensity score match (4)	PhD entrepreneurs only (5)	PhD entrepreneurs only (6)	PhD earned pre-2000 (7)
Treated × Post	−0.00339	−0.00231	−0.00177	−0.00382	−0.0865	−0.0878	−0.00280
	(0.00114)	(0.00143)	(0.00057)	(0.00190)	(0.0284)	(0.0288)	(0.0015)
Treated	−0.00072	−0.00135	−0.00006	−0.00142	0.0478	0.0474	−0.0011
	(0.00165)	(0.00190)	(0.0005)	(0.00267)	(0.01999)	(0.0200)	(0.0021)
Observations	1,222,103	97,660	97,167	55,800	4,029	4,029	78,467
R^2	0.173	0.177	–	0.271	0.017	0.030	0.165
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	No	Yes	No	No	Yes
Age fixed effects	Yes	Yes	Yes	Yes	No	Yes	Yes
Individual time-varying controls	Yes	Yes	Yes	Yes	No	Yes	Yes
Period	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007

Notes: The dependent variable is an indicator for whether the individual started a company that year. Estimates are the linear probability model, except in column 3 which computes Logit, marginal effects. Column 1 restricts sample to Norwegian workers with at least a master's degree. All other specification restrict sample to Norwegian workers with a least a PhD. The individual time-varying controls include lagged marital status, lagged total years of education dummies, log income, and log wealth. Propensity score matching predicts treatment status (university employment) using age fixed effects, detailed PhD type fixed effects, gender, and marital status. Standard errors, in parentheses, are clustered by individual.

and control groups, either via unobservable, fixed individual-level characteristics or several observable and time-varying characteristics, that may explain individual start-up tendencies, including possible compositional changes with time that might create shifts around the reform year. In practice, we see little change in the $Treat_i \times Post_t$ coefficient when adding these controls, which suggests that changes in the socioeconomic characteristics of the underlying populations in the treatment and control samples do not drive the results. Given that most Norwegian workers do not start companies, columns 4 and 5 repeat the individual-level specifications while restricting the sample to those individuals who started at least one company in the 2000–2007 period. These regressions show that, conditional on starting a company at some point, university PhD entrepreneurs were far less likely to do so after the reform compared to other active entrepreneurs in Norway. The magnitude of the effect in these individual-level analyses remains very large. For example, using column 1, the propensity for university PhDs to start companies declines by 63 percent after the reform.[26]

In Table 1A we see that a small minority of Norwegian entrepreneurs have advanced degrees, especially PhDs. Table 4 thus presents further individual-level analysis, using control samples of workers who share increasingly similar observable characteristics to university researchers. Column 1 of Table 4 limits the control group to those with at least a master's degree and shows large declines in start-up propensities of university researchers compared to this narrower control group. The

[26]To see this magnitude, consider that the mean of the dependent variable in columns 1 through 3 of Table 3 is 0.00389. Looking at column 1, we see that university PhDs, prior to the reform, started companies at a rate 0.00358 higher, or at about twice the background rate for the average Norwegian worker. After the end of the professor's privilege, university PhDs start companies at a rate 0.00450 less than before, which is a 63 percent decline in their prior rate.

remaining columns of Table 4 limit the control group to those with PhDs, who thus match the educational attainment of the university researchers. Column 2 suggests a somewhat less precise effect for this control group using the linear probability model ($p = 0.11$) while nonlinear models show greater precision as shown in column 3 ($p < 0.001$). Using a propensity score match to find the single nearest neighbor to each university-employed PhD, with matching based on age, PhD type, gender, and marital status, the magnitude and statistical significance using the linear probability model increases, as shown in column 4. This propensity-score sample provides the most closely matched control group to the university workers. In columns 5 and 6, the sample is restricted to those who started at least one company in the 2000–2007 period. Conditional on starting a company at some point, university PhD entrepreneurs were far less likely to do so after the reform compared to other PhD entrepreneurs in Norway.

While the PhD control group shares close observable similarities to the treatment group, which may provide identification advantages, this control group might also be entangled to some degree by the reform. For instance, the university's rights may extend to recent PhD students, to the extent their innovations are based on research conducted while at the university. Column 7 thus drops those with recently received PhDs. We see slightly larger negative effects than in column 2. More generally, to the extent that start-ups by non-university PhDs (the control group) could be negatively affected by the reform, either because PhDs themselves were recently university-based researchers or because they tend to start companies in partnership with university researchers, the difference-in-differences results comparing university and non-university PhDs would be biased against finding effects, i.e., be conservative. One might alternatively imagine sources of nonconservative biases for this control sample, although the plausibility for the reform positively affecting start-ups by non-university PhDs may be limited.[27] To the extent that the reform affects non-university PhDs in ways that could lead to biases, one may return toward the analyses using broader control populations, as featured first above.

We can further investigate underlying margins of response by university researchers. One question is whether the decline in university entrepreneurship is seen among individuals who remain employed at the university (the intensive margin) versus a decline driven by entrepreneurially minded individuals leaving the university (the extensive margin). The latter case, were it the main story, might suggest substitution in the accounting for university-based entrepreneurship rather than a decline in entrepreneurship from these individuals.

Table 5 provides evidence to tease out these dimensions. We first consider a balanced panel of individuals over the 2000–2007 period and define "pre-period university researchers" as those who were employed at universities from 2000–2002. In columns 1 through 3, we analyze the start-up rates for these workers, regardless of whether they stay at university, compared against workers who were not employed

[27] One mechanism might be as follows. To the extent that non-university PhD start-ups compete with university PhD start-ups, the decline in university PhD start-ups might potentially encourage more entry by the non-university PhD group. This possibility is hard to test specifically, although the broader evidence and environment does not suggest it. For example, the non-university PhD start-up rate does not go up in absolute terms after the reform, and more generally university researcher start-ups are a very small percentage of businesses in any sector, which may limit the plausibility of such competition effects.

Table 5—Start-Ups, Individual-Level, Intensive Margin

	Pre-period university researchers			Stayers		
	All (1)	PhD (2)	PhD logit (3)	All (4)	PhD (5)	PhD logit (6)
Treated × *Post*	−0.00495	−0.00302	−0.00240	−0.00502	−0.00305	−0.00248
	(0.00130)	(0.00165)	(0.000616)	(0.00138)	(0.00173)	(0.000625)
Treated	–	–	0.000134	–	–	0.000134
			(0.000722)			(0.000722)
Observations	16,523,512	66,310	63,161	16,521,472	64,270	63,996
R^2	0.153	0.159	–	0.153	0.159	–
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	No	Yes	Yes	No
Age fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Individual time-varying controls	Yes	Yes	Yes	Yes	Yes	Yes
Period	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007	2000–2007

Notes: The dependent variable is an indicator for whether the individual started a company that year. Estimates are the linear probability model, except in columns 3 and 6, which report marginal effects from logit regressions. The control group is all Norwegian workers in columns 1 and 4 and non-university PhDs in other columns. Individual time-varying controls include lagged marital status, lagged total years of education dummies, log income, and log wealth. Standard errors, in parentheses, are clustered by individual.

at universities over the period of our data. This analysis includes among the treated any start-up created by a university researcher after the individual leaves the university. The findings are similar to the earlier findings. Thus, the decline in start-ups in university settings is not offset by university researchers departing the university and starting new firms. Figure A1 further presents the difference-in-differences coefficients by founding year and echoes the widening gap between treatment and controls seen in the raw data (Figure 1).

Table 5 further considers the intensive margin of "stayers," defined as university researchers who are employed at the university throughout the 2000–2007 period. The control group consists of workers who were never employed at universities during the 2000–2007 period. Columns 4 through 6 show that the "stayers," who are the large majority of university researchers, experience a large decline in entrepreneurship. The results for "stayers" are extremely similar to the prior results. Thus, there is strong evidence of reform effects at the intensive margin: the decline in entrepreneurship came among a consistent set of university employees, who started firms at lower rates after the reform than they did before.

Lastly, Table A1 looks explicitly at exits from university employment. We trace forward the employment of all researchers employed at university in the year 2000. The exit regressions ask whether university researchers who appeared relatively exposed to the reform were more likely to leave university employment after the reform, compared to other university faculty who appeared less exposed to the reform.[28] These regressions do not suggest an increased exit effect, which is

[28] We take two alternative approaches to studying an exit effect while accounting for underlying exit propensities of university researchers. In the first approach, the treated group includes science and engineering faculty, who are more likely to start companies and patent, and the control group is university researchers in social sciences and humanities, who are less likely to start companies and patent and hence should be relatively immune from the reform. In the second approach, the treated group are science and engineering faculty who started companies prior to the reform, and the control group are science and engineering faculty who did not start companies prior to the

Table 6A—Start-Up Performance at Year 5

	Survive (1)	log sales (2)	log employees (3)	log assets (4)	Survive (5)	log sales (6)	log employees (7)	log assets (8)
Treated × Post	−0.1510	−0.9366	−0.0337	−0.5341	−0.0820	−0.7436	0.0827	−0.4037
	(0.0868)	(0.4489)	(0.1274)	(0.3557)	(0.1047)	(0.5574)	(0.1449)	(0.4045)
Treated	0.0326	−0.4647	−0.2682	0.0758	−0.0102	−0.0461	−0.2011	0.2476
	(0.0547)	(0.2916)	(0.0878)	(0.1962)	(0.0689)	(0.3828)	(0.1025)	(0.2572)
Observations	48,972	36,172	44,277	36,199	580	485	543	485
R^2	0.0419	0.1441	0.0914	0.0437	0.317	0.1657	0.1378	0.1327
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2-digit sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control sample	Norway	Norway	Norway	Norway	Non-Uni PhD	Non-Uni PhD	Non-Uni PhD	Non-Uni PhD

Notes: Dependent variables are indicated at top of each column and indicate performance at year 5 after the founding year. Firms all founded 2000–2007, and performance data is then 2005–2012. Robust standard errors in parentheses.

consistent with the similarity across specifications in Table 5, where results focused on the intensive margin (stayers) are similar to the results when allowing for any university researcher departures (pre-period researchers).

The Quality of Entrepreneurship.—Beyond the quantity of start-ups, we can also consider the quality of start-ups and whether this changes after the reform. We examine the rate of survival as well as the sales, employees, and assets of new ventures. Lastly, we consider measures for the technology-orientation of university start-ups.

Tables 6A and 6B consider start-up performance before and after the reform. As before, we use difference-in-differences. In columns 1–4 of Table 6A, the control group is the background population of new ventures in Norway. Column 1 shows the probability of survival to year 5. We see a weakly significant but large decline of 15 percentage points in the probability of survival by university start-ups after the reform. Conditional on survival, sales also become substantially lower for university start-ups, while employment in and the assets of these start-ups are negative but statistically insignificant. When comparing to start-ups by non-university PhDs in columns 5–8, the results appear broadly similar in their point estimates but with less precision so that there is no statistical significance at conventional levels.

Table 6B considers performance at year 5 using a binary dependent variable for whether the performance indicator is in the upper quartile of performance among Norwegian new ventures. This analysis can account transparently for changes in the rate of "relatively good" start-ups while avoiding upper tail outliers that can otherwise influence the results.[29] The threshold for an upper quartile start-up is

reform. Either way, we see no evidence of increased exit by those who seem relatively impacted by the reform. We have similarly examined entry rates into university employment by new PhDs, although we are limited here to the first approach. We find no evidence that the reform relatively dissuaded the entry of technical PhDs. Note that this test may be weak to the extent that most technical PhDs in university faculties do not start new companies or patent.

[29] In general, evidence suggests that successful start-ups are rare, even in clusters around universities (Guzman and Stern 2015a, b), and the evidence about firm size in Table 1A further suggests the thick upper tail in start-up growth, so that mean regression analysis of performance may be driven by outliers.

Table 6B—Probability of Achieving 75th Percentile Performance at Year 5

	Sales (1)	Employees (2)	Assets (3)	Sales (4)	Employees (5)	Assets (6)
Treated × *Post*	−0.1198	0.0170	−0.1303	−0.1091	0.0155	−0.0695
	(0.0490)	(0.0536)	(0.0757)	(0.0628)	(0.0663)	(0.0933)
Treated	−0.0262	−0.1032	0.0810	0.0169	−0.0418	0.0507
	(0.0452)	(0.0373)	(0.0550)	(0.0547)	(0.0484)	(0.0684)
Observations	48,972	48,972	48,972	580	580	580
R^2	0.0591	0.0585	0.0283	0.1197	0.1036	0.0813
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
2-digit sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Control sample	Norway	Norway	Norway	Non-uni. PhD	Non-uni. PhD	Non-uni. PhD

Notes: Dependent variables are binary indicators for achieving at least the seventy-fifth percentile of performance in the indicated measure, where the seventy-fifth percentile is defined for Norwegian start-ups as a whole. Robust standard errors in parentheses.

3.3 million NOK in sales and 3 employees at an age of 5 years.[30] The findings in Table 6B broadly echo the results above. The probability that a university start-up surpasses the seventy-fifth percentile of sales declines by 12 percentage points at conventional significance levels after the reform, compared to other start-ups. The probability of surpassing the seventy-fifth percentile of assets at year 5 declines by a similar magnitude while employment shows little effects. As before, effects are statistically weaker, but broadly similar in magnitude, when using the non-university PhD start-ups as the control group.

Separately from accounting performance, and with the caveat that sample sizes become small, we can further examine whether there is a decline in higher-technology start-ups. To perform this analysis, we examine start-up counts again but now use the Eurostat classifications of 2-digit NACE codes to exclude (i) manufacturing sectors that are defined as "low-technology" and (ii) service sectors that are considered "less knowledge intensive."[31] Table 6C considers the aggregated counts, using the same regression as in Table 2 but now counting only the remaining, higher-technology firms.

Column 1 indicates a substantial decline in higher-technology start-ups by university researchers after the reform when compared to higher-technology start-ups in Norway as a whole. Column 2 shows a negative but insignificant decline compared to non-university PhDs. In both column 1 and column 2, the *Post* dummy is notably negative and significant, indicating that higher-technology start-ups declined more generally in Norway after the reform. The decline seen in the *Post* dummy is driven by the decline in information and computing technology (ICT) start-ups across Norway.[32] Columns 3 and 4 show that, removing such ICT start-ups from the sample, the *Post* coefficient is no longer large or significant. These columns

[30] The upper quartile is determined across the set of all new ventures (i.e., including those that do not survive to five years, for which we impute a value of 0 for sales, assets, and employees).

[31] The Eurostat sectoral classifications by technological intensity can be found at: http://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an2.pdf.

[32] Start-ups in "computer and related activities" (NACE code 72) were frequent in the early 2000s in Norway, as they were elsewhere.

Table 6C—Start-Up Sectors

	log start-ups (1)	log start-ups (2)	log start-ups (3)	log start-ups (4)
Treated × *Post*	−0.727	−0.277	−1.239	−1.245
	(0.322)	(0.391)	(0.352)	(0.632)
Treated	−4.046	−0.484	−3.201	0.520
	(0.263)	(0.243)	(0.265)	(0.434)
Post	−0.252	−0.701	−0.0305	−0.0240
	(0.117)	(0.251)	(0.0809)	(0.531)
Observations	16	16	16	16
R^2	0.987	0.673	0.978	0.386
Control sample	Norwegian workforce	PhD workforce	Norwegian workforce	PhD workforce
Start-up type	Higher tech	Higher tech	Higher tech, no ICT	Higher tech, no ICT

Notes: Dependent variables are log of start-up counts for the indicated start-up type in the last row of table. Robust standard errors in parentheses.

further show large, negative effects of the decline in (non-ICT) technology-oriented start-ups from university researchers, with similar size effects using either control group.[33] Poisson models (not reported) rather than ordinary least squares (OLS) show similar effects with increased precision. The decline in higher-technology start-ups by university researchers can also be seen in individual-level analysis, controlling for individual-level characteristics.[34] Notably, the difference-in-differences decline in technology start-up rates in columns 3 and 4 implies a 71 percent drop. This decline is larger than the decline for university start-ups generally, indicating that these university technology start-ups fell proportionately more on average, although this excess decline is not statistically significant.[35]

Related, we can also look at the decline in start-up rates among university researchers with science and engineering PhDs as opposed to those with nontechnical PhDs. We find that university researchers with nontechnical PhDs saw a 39 percent decline in their start-up rates after the reform. Those with science and engineering PhDs, who produced 57 percent of pre-reform start-ups, saw a much larger 62.9 percent decline in their start-up rates after the reform. Thus, the decline in start-ups came disproportionately among university researchers with technical PhDs.

Lastly, we collected the incorporation documents for all university start-ups to search for patents by these young firms. This analysis faces data limitations, as we cannot match start-up founder identifiers to inventor names. To proceed, we thus looked indirectly by searching the Norwegian Patent Office database for patents where the academic start-up firm name was listed as the applicant. While this method may miss substantial patents among university start-ups (if the applicant was the inventor rather than the firm), we found that, among start-ups by university

[33] These findings are also consistent with the findings in Table 2, which analyzed counts at the 1-digit sector level. Overall, PhDs are more active in higher-technology sectors than the general population and were more active in ICT start-ups as well. When controlling for sector, the results become more similar across the control groups. See columns 5–7 of Table 2 as well as columns 3 and 4 in Table 6C.

[34] These further analyses follow those in Tables 3 and 4. Results are available from the authors upon request.

[35] Prior to the reform, 27 percent of university-based start-ups were in higher-technology sectors (41 percent including ICT); after the reform only 17 percent of university-based start-ups were in these sectors (33 percent including ICT).

researchers founded prior to the reform, 12 percent obtained a patent as the applicant within five years of founding. Among university start-ups founded after the reform, only 2 percent obtained a patent in this manner within this window. This decline is significant at the 1 percent level using a simple *t*-test.

Overall, integrating across start-up quality measures based on accounting data, technology-intensity of the sector, technical PhD of the founder, or patenting, the results indicate that these measures, if anything, declined after the end of the professor's privilege.

Hidden Ownership.—As a robustness check, we further considered whether the end of professor's privilege might potentially provoke "hidden ownership," where university researchers continue to start businesses but attempt to shield their ownership via family members or possibly through preexisting companies. We can test this possibility in two ways. First, the Norwegian registry data identify the family members of each worker. We can therefore also examine new venture activity by the family members of university researchers and test for any increase, after the reform, in businesses started by family members. Second, the Norwegian business registry traces ownership of businesses by other businesses. We can therefore additionally ask whether university researchers might own new start-ups indirectly through other companies the researchers own, thus opening a different potential means of attempting to hide ownership from the university. Implementing these analyses, we find no evidence for hidden ownership. There is no increase in start-ups among family members. Moreover, taking all firms owned by university researchers, we find zero cases of such indirect ownership of new firms.[36]

Summary.—In sum, we see a large drop in entrepreneurship by university researchers starting in the year of the professor's privilege reform. This decline (56 percent) appears in a simple pre-post of university researcher start-up behavior, and it appears similarly large when compared to the background start-up rates for a range of control groups. Detailed individual-level controls do not change this conclusion, which is driven on the intensive margin of individual university researchers who started firms at a substantially lower rate after the policy reform. We also see a decline in some accounting performance measures for new ventures started by university researchers and, separately, a substantial decline in university start-ups in higher-technology sectors or with associated patents. Thus, not only does the quantity of start-ups by university researchers decline, but there are declines in several quality measures for these start-ups as well.

B. *Patents*

To study patenting, we follow similar lines as the entrepreneurship analysis above but with more limited data. Recall that university-based patents were determined by matching Norwegian inventor names with the NIFU registry of Norwegian university researchers (see Section IIA). The resulting dataset cannot be linked to the

[36] These analyses are available from the authors upon request.

Norwegian registry data; therefore, the patent analysis allows comparisons among inventors only (university versus non-university inventors) and does not contain demographic information, beyond name and address, for non-university inventors.[37]

The Rate of Patenting.—Figure 2A plots the annual number of university patents (red dashed line, left vertical axis) and non-university patents (blue line, right vertical axis) over the 1995–2010 period, with the year defined by the patent application date.[38] Recall that these patents are all successfully granted NPO patents with grant dates through September 2014. We see that the non-university patent rate rises slightly through the late 1990s and then falls somewhat after 2000. The university patent rate rises similarly in the late 1990s, with a peak in 2002, the pre-reform year, before falling more steeply in the post-reform period. Figure 2B considers the same data on a per-worker basis for the relevant groups.[39] Given that the number of Norwegian university researchers rose relatively rapidly over the 1995–2010 period, the per-worker measures show a larger differential drop for the university patenting rate. On average, 0.94 percent of university researchers applied for a patent in a given year prior to the reform, while 0.48 percent of university researchers applied for patents per year after the reform, for a 49 percent drop in the per-worker rate. By contrast, the broader Norwegian workforce averaged 0.019 percent patents per year prior to the reform and 0.016 percent after the reform, for a 15 percent drop in the per-worker rate. Together, these figures show a sharp drop in patenting by university researchers that is coincident with the professor's privilege reform.

Table 7 considers regression results, looking at changes in annual patent counts and annual patent counts per worker. Column 1 shows that the aggregate rate of university patents declines relative to non-university patents, although the decline is not statistically significant. Column 2 considers patents per worker. Consistent with the larger visual difference-in-differences in Figure 2B, the $Treat_i \times Post_t$ coefficient now indicates a 43 percent decline in the patenting rate per university worker, compared to the background per-worker rate. Column 3 considers the number of unique inventors per worker and finds a similarly large and statistically significant decline of 47 percent. Patenting per university researcher thus declines substantially after the reform.[40]

Noting that researchers can move in/out of university employment, the next two columns of Table 7 consider patent counts for fixed sets of treated individuals. In column 4, we define the treatment group as university researchers who were employed at university throughout the 1995–2010 period. We see a large and statistically significant decline in these researchers' collective patents after the reform. In column 5,

[37] Recall that the Norwegian census and business registry data use an anonymized numerical identifier for each individual, while the Norwegian Patent Office data do not use such identifiers. Thus, we do not have sociodemographic information for Norwegian inventors in general (although, via NIFU, we do have detailed information about the university researchers, including age, gender, PhD year, PhD type, and academic department).

[38] University patents are defined as those where at least one inventor matches with a university researcher.

[39] For non-university inventors, this normalization is the number of non-university patents divided by the size of the non-university Norwegian workforce.

[40] The total patenting rate from universities falls less than the per-worker rate due to the rapid expansion of university employment over this period. In fact, given that the ranks of university researchers expanded by 65 percent over the 2000–2007 time frame while the Norwegian workforce grew only 7 percent (see Section IIA) it is remarkable that the aggregate rate of patents from universities still falls.

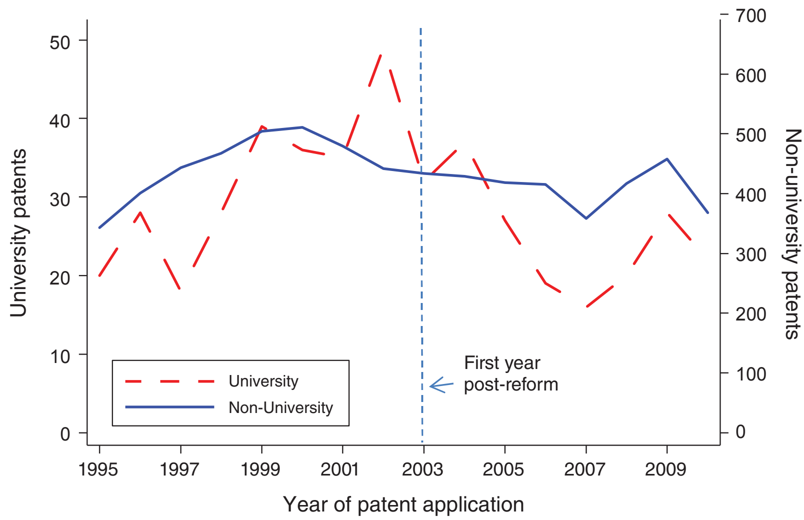

Figure 2A. University Patents versus Non-University Patents

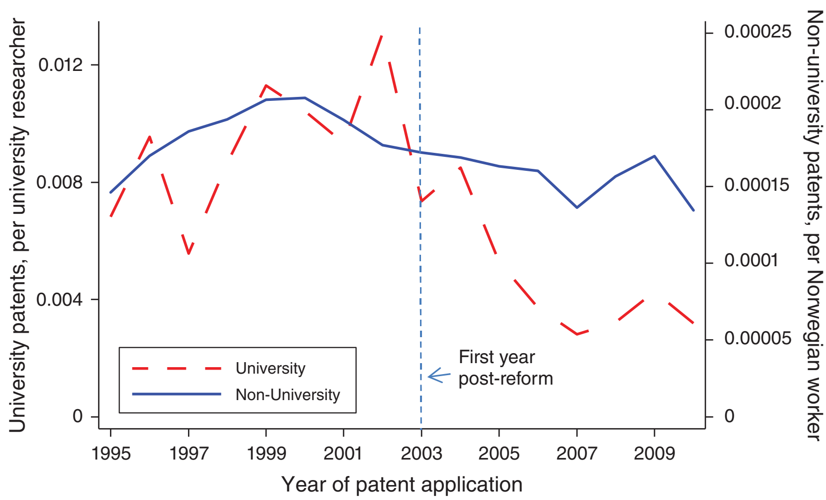

Figure 2B. University Patents versus Non-University Patents, per Worker

we focus on individuals who were employed at university in the two years prior to the reform. We then count these individuals' patenting activity regardless of whether they stay or leave university, thus capturing possible "offsetting" patenting should the reform have caused patent-interested individuals to leave university employment. We see large and statistically significant declines in patenting from these individuals. We further examine these individuals in the individual-level panel below. The last three columns of Table 7 analyze the data in technology-class-by-year form, with the patent counts now constructed at the 1-digit IPC code level.[41] This analysis

[41] As with the start-up analysis, we use 1-digit categories because patent counts for the treatment group are not large enough to allow analysis for more granular technology categorizations.

Table 7—Patents, Annual Rates, Aggregate, and Technology-Level Analysis

	Aggregate					Technology		
	log patents (1)	log patents per worker (2)	log inventors per worker (3)	log patents balanced (4)	log patents, pre-period individuals (5)	Patents (6)	log patents per worker (7)	Patents, pre-period individuals (8)
Treated × Post	−0.136	−0.555	−0.630	−0.375	−0.335	−0.145	−0.431	−0.345
	(0.131)	(0.150)	(0.191)	(0.137)	(0.117)	(0.091)	(0.096)	(0.105)
Treated	−2.694	3.895	4.393	−3.014	−2.642	−2.653	3.813	−2.611
	(0.101)	(0.090)	(0.105)	(0.091)	(0.087)	(0.198)	(0.247)	(0.197)
Application year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tech class FE	–	–	–	–	–	Yes	Yes	Yes
Control sample	Non-University inventors	Non-University inventors	Non-University inventors	Non-University inventors	Non-University inventors	Non-University inventors	Non-University inventors	Non-University inventors
Model	OLS	OLS	OLS	OLS	OLS	Poisson	OLS	Poisson
Observations	32	32	32	32	32	256	230	256
R^2	0.99	0.99	0.99	0.99	0.99	–	–	–
Period	1995–2010	1995–2010	1995–2010	1995–2010	1995–2010	1995–2010	1995–2010	1995–2010

Notes: In column 1, observations are aggregate patent counts for the treated and control groups, by year, while columns 2–3 consider counts per worker, where worker count is the Norwegian workforce for the control sample and worker count is the university researcher workforce for the treatment sample. In columns 4 and 5 we consider balanced panels of university researchers (see text). In columns 6 through 8, observations are technology class × year for the treatment and control groups, with technology class determined by the 1-digit IPC code. Model is Poisson for count data in columns 6 and 8, which allows incorporation of zero counts. Robust standard errors in parentheses, except columns 6 through 8 which cluster standard errors by technology class.

can help account for compositional changes in the technologies receiving patents. We see that technology-class level analyses and the aggregate count analyses show similar results, with somewhat greater precision at the technology-year level.

Figure 2 indicates a temporary increase in patenting by university researchers in 2002, suggesting a possible race to patent ahead of the reform. Looking within the year 2002, the month of December sees the most activity of any month that year, accounting for 20 percent of the 2002 university researcher patents, which is further suggestive of some racing. The regressions in Table 7 are robust, with similar statistical significance and slightly less negative coefficients, when dropping application year 2002 from the analysis.

Table 8 considers regression evidence at the individual level. In these regressions, all individuals are inventors and the question is how the patenting rate per inventor changes for university inventors compared to non-university inventors. The dependent variable is a dummy variable indicating whether an individual applies for one or more patents in a given year.[42] Column 1 shows that university-based inventors show a large drop in their patenting after the reform, where the individual university researcher (conditional on being an inventor at some point) sees a 4.5 percentage point drop in their probability of producing a patent during the post-period. Interestingly, this decline almost exactly offsets the tendency for university researchers to produce patents more regularly than non-university inventors. Thus,

[42] Count data models, where the dependent variable is the patent count for the given individual-year as opposed to a dummy variable, show similar results. In practice, conditional on patenting in a given year, 87 percent of inventors apply for one patent only.

Table 8—Patents, Individual-Level, Inventors

	Indicator for patenting in given year			
	All inventors	All inventors	All inventors	Rare names
	(1)	(2)	(3)	(4)
Treated × *Post*	−0.045	−0.044	−0.045	−0.037
	(0.011)	(0.011)	(0.011)	(0.016)
Treated	0.049	0.048	0.042	0.040
	(0.009)	(0.009)	(0.012)	(0.017)
Post	−0.006	–	–	0.017
	(0.002)			
Application year fixed effects	No	Yes	Yes	Yes
Individual fixed effects	No	No	Yes	Yes
R^2	0.00	0.00	0.00	0.00
Observations	109,184	109,184	109,184	75,008
Period	1995–2010	1995–2010	1995–2010	1995–2010

Notes: The dependent variable is an indicator for whether the individual patented at least once that year. Estimates are the linear probability model. Standard errors clustered by individual.

university inventors move from being unusually prolific in their patenting rate prior to the reform to being rather ordinary in their patenting rate after the reform. This finding is virtually identical whether or not we control for individual fixed effects or application year fixed effects in columns 2 and 3. Figure A2 further presents the difference-in-differences coefficients by year, pre- and post-reform, with findings that echo that widening gap in patenting seen in the raw data in Figure 2. To guard against potential errors in name matching, column 4 limits the sample (both inside and outside universities) to "rare names": those individuals whose names appear three or less times in the Norwegian population as a whole. We see that the results remain similar.

Lastly, Table 9 considers whether the decline in university patenting may be driven by the exit of university researchers, or whether it appears on the intensive margin of university employees who remain at the university. Commensurate with the analysis of Table 5, columns 1 and 2 consider pre-period university researchers, those individuals employed at universities from 2000–2002, and then tracks patenting by these individuals regardless of whether they remain in university employ. Columns 3 and 4 focus instead on "stayers," examining whether the patenting decline appears among those who are consistently employed at university in the post-period.[43] The findings are all similar to the results in Table 8. Thus, the decline in patenting in university settings is not driven by individual researchers exiting university employment and continuing to patent. Instead, we see large effects on the intensive margin, so that a consistent set of individual university inventors patent much less often after the reform.

The Quality of Patenting.—Table 10 considers changes in the quality of patenting using various standard measures: citations received, patenting in multiple

[43] To match the start-up analysis, we define stayers in Table 8 based on continual university employment over the 2000–2007 period. The results are robust to alternative employment durations for defining these stayers, including using the whole sample period for patents (1995–2010), as also indicated in the aggregate results in Table 7.

Table 9—Patents, Individual-Level, Intensive Margin

	Indicator for patenting in given year			
	Pre-period university researchers		Stayers	
	(1)	(2)	(3)	(4)
Treated × Post	−0.045	−0.045	−0.047	−0.046
	(0.012)	(0.012)	(0.015)	(0.015)
Treated	0.047	–	0.049	–
	(0.009)		(0.012)	
Post	−0.005	–	−0.005	–
	(0.002)		(0.002)	
Application year fixed effects	No	Yes	No	Yes
Individual fixed effects	No	Yes	No	Yes
R^2	0.00	0.00	0.00	0.00
Observations	105,840	105,840	104,928	102,864
Period	1995–2010	1995–2010	1995–2010	1995–2010

Notes: Following Table 5, in columns 1 and 2 the treated sample includes university researchers employed at the university from 2000–2002, regardless of whether they remain at university after the reform. In columns 3 and 4, the treated sample contains researchers who are at the university throughout the 2000–2007 period. Results are similar using the full sample period (2000–2015) to define these "stayers." In all cases, the control sample is inventors who were never employed at university throughout the sample period. Standard errors clustered by individual.

Table 10—Patents, Quality Measures

	Cited (1)	Citation count (2)	Citation count (3)	EPO patent (4)	US patent (5)	Triadic patent (6)	EPO, US, or JPO (7)	In force duration (8)
Treated × Post	−0.089	−0.276	−2.725	−0.097	−0.070	−0.054	−0.132	−0.046
	(0.047)	(0.181)	(1.169)	(0.046)	(0.045)	(0.031)	(0.049)	(0.029)
Treated	0.109	0.410	3.142	0.159	0.057	0.087	0.149	0.047
	(0.030)	(0.119)	(1.078)	(0.032)	(0.031)	(0.025)	(0.032)	(0.025)
Application year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regression model	OLS	Poisson	OLS	OLS	OLS	OLS	OLS	Poisson
R^2	0.02	–	0.04	0.02	0.01	0.02	0.01	–
Observations	7,341	7,341	7,341	7,341	7,341	7,341	7,341	7,304

Notes: Columns 1–3 consider counts of citations received by each patent, with column 1 focused on a binary indicator for being cited at least once and columns 2 and 3 using the integer count. Columns 4 through 7 examine the propensity for the Norwegian Patent Office patent to also receive protection at the EPO (column 4), USPTO (column 5), in all of the European, US, and Japanese patent offices (column 6), and in any of these patent offices (column 7). Column 8 looks at the duration the patent remains in force due to the payment of renewal fees. Robust standard errors in parentheses.

jurisdictions, and the payment of patent maintenance fees. Observations are individual patents, and we again use difference-in-differences, comparing patents by university researchers to patents by non-university researchers, before and after the reform. Application year fixed effects are included to capture nonlinearities in the quality measures over time.

In Table 10, columns 1 through 3 consider the citations a patent receives, with citation counts to each patent calculated using the PATSTAT database.[44] Column

[44] Citations received have been shown to be positively correlated with market and social value (e.g., Trajtenberg 1990; Hall, Jaffe, and Trajtenberg 2005). The PATSTAT citation counts consider citations to the patent family, using

1 considers a simple binary outcome variable: whether the patent has been cited at least once. We see a large decline in the probability of university patents being cited after the reform ($p = 0.061$) compared to controls. Column 2 considers total citation counts using a Poisson model, which shows an approximate 25 percent decline in citations received per patent, although this result is not statistically significant at conventional levels ($p = 0.128$). Column 3 considers citations counts with OLS and shows an average loss of 2.7 citations to university patents after the reform, which is now statistically significant ($p = 0.020$). A limitation for citation count metrics in our context is that later applications years, coupled with delays until patent grants, leave little time for the more recent patents to accumulate citations. The application year fixed effects in Table 10 deal in one fashion with this issue while online Appendix IV considers alternative citation count measures. Overall, the $Treat_i \times Post_t$ coefficients are large and negative regardless of the measure, while statistical significance is mixed, with p-values in the 0.05–0.15 range.

Columns 4–7 examine a forward-looking quality metric, which is the tendency for an NPO patent to also seek patent protection outside of Norway. The idea here is that patents of greater expected global value will tend to be patented more widely. Column 4 indicates whether the patent is also patented at the European Patent Office (EPO). We see a statistically significant decline of 9.7 percentage points (or a 38 percent decline against the baseline rate) in the probability of university patents also being EPO patents after the reform compared to controls. The propensity to be patented in the United States declines by a broadly similar magnitude, as seen in column 5, but this decline is not statistically significant ($p = 0.121$). In column 6 we look at whether a patent receives protection in all of Europe, the United States, and Japan, a so-called "triadic patent" (Dernis and Khan 2004), and see a statistically significant decline in this tendency as well. Column 7 looks at whether a patent receives patent protection from one or more of these jurisdictions (Europe, United States, Japan) and finds a large, statistically significant decline.

The final column of Table 10 considers the duration with which a patent is maintained as valid with the NPO. The tendency to make renewal fee payments (i.e., maintain the patent's legal rights) can indicate a relatively valuable patent from the perspective of the patent holder (Harhoff et al. 1999). Column 8 shows that patent duration tends to be somewhat shorter for university patents after the reform, compared to controls, but this result is not quite statistically significant ($p = 0.114$). The online Appendix considers variants of this analysis, given that patent duration is truncated in recent application years.

Overall, the $Treat_i \times Post_t$ coefficients are negative across a wide range of patent quality measures, while statistical significance is mixed. Comparing across quality metrics, one limitation is that recent patent applications have had less time to accumulate citations or be renewed. By contrast, quality measures based on multi-jurisdictional patenting have the advantage of not requiring substantial post-issuance windows to observe. In any case, a general feature across these analyses is that the treated coefficient indicates, prior to the reform, that university patents were more likely to be cited, more likely to be patented in multiple jurisdictions, and more

the DOCDB definition, for the given patent. Online Appendix IV provides further background on the patent data and metrics.

likely to be maintained compared to non-university patents. The reform acts to substantially offset this advantage (compare the *Treated* × *Post* coefficients with the *Treated* coefficients in Table 10), so that university patents appears to have gone from being extraordinary to relatively ordinary in the post-reform period.

Licensing.—In addition to patenting itself, the reform may also affect licensing activity from these patents. The decline in patent quantity and quality measures, as detailed above, suggests a weakening pipeline of new intellectual property, which would ultimately limit licensing activity. Nonetheless, the advent of TTOs may suggest increased licensing activity from those patents that are still created, as the university seeks and helps negotiate licensing opportunities.

Changes in licensing activity cannot be easily observed since Norwegian universities did not track licensing income under the professor's privilege regime.[45] To help inform the licensing dimension, we therefore deployed a survey of the university inventors in our sample. We performed online searches of current university websites to find the email addresses for 282 university inventors. Of these 282 university inventors, 63 individuals completed the survey, giving a response rate of 22.3 percent. Online Appendix III details the survey questions and methodology.

We consider here the self-reported licensing activity from inventors with patents before and after the reform, and we test whether the advent of TTOs is associated with improved licensing outcomes. As shown in Table 11, 36 percent of inventors with patent application dates prior to the reform licensed these patents at least once, while the corresponding post-reform fraction is 23 percent. We can reject at the 10 percent confidence level that the fraction of the responding inventors that license is larger post-reform. We also asked the respondents about their licensing income in Norwegian kroner. The mean licensing income was higher for pre-reform patents than for post-reform patents, and we can reject at the 10 percent level that mean licensing income is higher after the reform. Online Appendix III provides further detail. Overall, and with the usual caveat for surveys given limited response rates, the licensing findings are consistent with the apparent post-reform drop in patent quality measures, and the TTOs did not appear able to make "more with less" by intensifying licensing per patent in the post-reform period. We will discuss the TTOs further below.[46] The licensing findings also appear broadly consistent with Lach and Schankerman (2008), who found lower licensing income in US universities where the researchers had lower royalty shares.

Summary.—In sum, we see a large drop in patenting by university researchers after the "professor's privilege" reform. The patent rate per worker falls by approximately 45 percent, which is broadly similar to the decline in the start-up rate. The decline in patenting, like the decline in entrepreneurship, is driven on the intensive margin of individual university researchers who patented substantially less after the reform. Lastly, several quality measures also tended to decline for university patents after the reform. While noisier and based on a survey with a limited response rate,

[45] Nor do the universities maintain post-reform databases that they were able to share.

[46] The survey also provides qualitative evidence, through inventor comments, regarding their perspectives on the reform and its effects. We consider this qualitative evidence when discussing mechanisms in Section IV.

TABLE 11—SURVEY OF UNIVERSITY INVENTORS

		Respondents	Mean	Median
Licensing				
Pre-reform patents				
At least one license?		44	0.36	0 (none)
Licensing income (NOK)		16	423,400	0 (none)
Post-reform patents				
At least one license?		40	0.23	0 (none)
Licensing income (NOK)		9	2,200	0 (none)
	Respondents	Neutral/ unknown	Positive	Negative
Views of reform				
Effect on self	56	34	7	15
Effect on colleagues	56	42	4	10

Notes: The table reports key summary statistics of a survey of university inventors. These researchers applied for patents between 1995 and 2010. The survey was sent by email to 282 university inventors and was completed by 63, giving a response rate of 22.3 percent. The survey did not require respondents to answer each question; the number of respondents for each question is indicated in the table. See text and online Appendix III for further details.

licensing activity appears to have declined as well. Overall, and like the start-up analysis, university patenting exhibited a decline in both quantity and quality measures.

IV. Discussion

This section considers the results in light of several literatures. After summarizing the core empirical findings, we first discuss evidence from additional empirical studies to help inform potential representativeness for broader settings. We then consider possible trade-offs between innovative activity and research activity among university researchers. Finally, we discuss mechanisms in light of our empirical findings, drawing additionally on qualitative responses from our inventor survey, and consider applications to literatures regarding rights allocations in innovation and taxes and entrepreneurship.

A. *Summary of Empirical Results*

University researchers are potential wellsprings of innovative ideas, and the design of policies the influence innovative activity by this workforce remains the subject of substantial debate. This paper investigates a large change in national commercialization policy. In the first regime, under the "professor's privilege," university-based researchers enjoyed full rights to their inventions and new ventures. In the second regime, after the reform, Norwegian university researchers moved to a one-third/two-third income split with the university. Moreover, the universities each established TTOs to boost commercialization output. The post-reform regime was designed to look broadly similar to the United States today, and similar reforms were implemented in several European countries, including Germany.

The empirical findings suggest that the policy reform had several measurable effects. There was an approximate 50 percent drop in the rate of new venture formation by university researchers and a similar drop in their patenting. The quality of new ventures and patents also appeared to decline. These findings appear in sharp contrast to the motivations behind the Norwegian policy reform. The findings also raise questions about similar reforms in other European countries that eliminated the professor's privilege: were the Norwegian results representative, one would imagine that the rates and quality of start-ups and patenting by university researchers would rise, should universities give the researchers full rights. Since the post-reform regime looks like the US regime, among others, the interest in external validity may broaden further.

B. *Representativeness*

As guideposts on the potential generalizability of these results, descriptive facts may be informative. On a cross-country basis, Lissoni et al. (2008) examines the share of academic patents among domestic patents for several countries. The academic patenting share in professor's privilege countries, when the policy is in place, is high (Sweden is 6 percent, Finland is 8 percent) compared to countries in Europe that did not feature the professor's privilege over similar time periods (France was 3 percent, Italy was 4 percent, and the Netherlands was 4 percent).[47] Comparing across US universities, Lach and Schankerman (2008) show that university licensing income is substantially increasing in the researcher's royalty share. Their regression estimates suggest at least a doubling in income in universities with full research royalty shares compared to universities with a one-third researcher share. Thus, while such cross-sectional differences use aggregated data and do not control for many possible conflating factors, the cross-sectional evidence on patenting appears broadly consistent with the patent findings in this paper.

Two new working papers, one studying patenting and the other studying entrepreneurship, also consider the professor's privilege and find evidence in some broadly similar directions. Czarnitzki et al. (2015) study patenting rates in Germany. They find that university researchers patented less after the professor's privilege was eliminated and that this decline was greater than the decline among researchers in public research organizations that were not affected by the reform. Their estimated coefficient from a difference-in-differences regression is a drop in patenting activity by about 17 percent.[48] Separately, a recent study by Astebro et al. (2015) considers PhDs who exit university employment, comparing the United States with Sweden, which has maintained its professor's privilege. The paper finds that Swedish academics are twice as likely to exit universities and start firms as US academics are, compared to the background rates for non-university PhDs in their respective countries.

Overall, the difference-in-differences estimates established for all new ventures and patents in Norway appear broadly consistent with this other evidence. These

[47] The US academic patenting share is not clear, but university-owned patents in the United States are 4 percent of all US patents, and samples suggest that these patents represent perhaps 65–80 percent of all US patents with academic inventors (Fabrizio and Di Minin 2008; Lissoni et al. 2008). Thus, the academic patenting share in the United States may also be somewhat less than that in the professor's privilege countries, when the policy was in place.

[48] The quality of patents may have dropped too: although Czarnitzki et al. (2015) do not report separate results on patent citations, their citation-weighted difference-in-differences estimate of the reduction in patenting rates is about 24 percent, i.e., larger than the unweighted estimates.

commonalities may suggest broader external validity from the natural experiment we study. Nonetheless, important caveats are in order as one assesses both the scope of representativeness and potential policy implications. First, the Norwegian university system is predominantly public. This feature is common in European countries but less so in the United States. It is possible that the effects of rights-sharing policies may differ depending on the extent of state control, although the limited empirical evidence on this question does not suggest it.[49] Additionally, the effects of a system-wide change may be quite different from the effects of a policy change at a single university.[50] Thus, the results in this paper may generalize more naturally to policies that apply across university systems. Second, TTOs may be of heterogeneous quality, so that Norwegian TTOs may improve with time or otherwise may not represent TTOs elsewhere. As seen in Figures 1 and 2, there is little evidence within the scope of our data that patenting or new venture rates improve as the years progress. If anything, the decline appears to worsen relative to the controls, but the long-run effects may be different, given enough time. Related, we find little evidence for heterogeneous treatment effects across the different TTOs (see online Appendix V). More generally, to the extent that Norway's researchers, technology orientation, access to complementary inputs (e.g., venture financing), and broader institutions may differ from those in other countries, the findings may not generalize.

C. *Research Output*

Beyond measures of new ventures and patenting, university commercialization policy may resist strong prescriptions given the complexity of welfare analysis in this setting. Trade-offs between innovative activities and other activities by university researchers (such as basic research or teaching), where the social returns may be large but in general are unknown, suggest substantial care (Thursby and Thursby 2003; Merrill and Mazza 2010). While a complete welfare description is infeasible, we can make some further progress by looking at publication behavior to see if there is any obvious trade-off with other research outputs. This analysis is provided in online Appendix II. In line with existing studies (e.g., Fabrizio and Di Minin 2008; Azoulay, Ding, and Stuart 2009; Buenstorf 2009), we find that academic inventors typically appear *more* productive when studying their research publications compared to other university researchers. Academic inventors in our study are found to produce not only more publications but also publications with higher average citation impact. These findings, which are robust to field, researcher age, and university

[49] For example, the public university may believe that any commercialization income will be lost to public coffers. That said, the state also has revenue-oriented objectives (and private universities are typically nonprofit with public-oriented norms), so it is not clear a priori that public universities have more or less pecuniary interests than private universities. Lach and Schankerman (2008) examine US public and private universities separately and find large increases in licensing income correlated with the inventor's royalty share in both governance settings. This finding is also consistent with anecdotal observations suggesting that big public universities in the United States, such as UC Berkeley, Wisconsin, and Michigan, are often leaders in academic entrepreneurship.

[50] A system with varying royalty structures (i.e., the United States) may drive migration of innovation-oriented researchers to universities offering them higher royalty shares, as argued by Lach and Schankerman (2008). This migration effect could increase the elasticity of innovative activity to the royalty share at a given university (by attracting or repelling innovators), yet soften the effect of one university's policies on the innovative output of the national system.

fixed effects, do not suggest an obvious trade-off between invention and research when comparing across individuals.

Our analysis can also push further, comparing not just across individuals, but also looking at changes within individuals before and after the professor's privilege reform. While finding adequate control groups raises challenges, we find no evidence that the reform (which led to a substantial decline in patenting) encouraged increased publication output among individuals who were relatively likely to be affected by the reform. For example, those university researchers who patented in the pre-reform period show no increase in publications compared to closely matched researchers who did not patent in the pre-reform period.[51] See online Appendix II.

In sum, we find little evidence for a trade-off between inventive output and research output. This finding appears across individuals but also appears when looking within individuals and harnessing the policy shock of the professor's privilege reform. Conceptualizations of science based on Pasteur's Quadrant may help explain this result, where the same scientific activity may produce both applied output and new knowledge so that inventive and research activity become complements rather than substitutes (Stokes 1997; Murray and Stern 2007; Ahmadpoor and Jones 2017).

D. *Mechanisms and Views of Reform*

When considering the quantity and quality of innovative outcomes, conceptually one can consider the individual's investment choice, weighing the expected value of ideas against the fixed costs of entry. In this framing, changes in fixed costs alone would cause the quantity and quality to move in opposite directions. For example, a rise in the fixed costs of entry would cause the quantity of entry to decline (it is more costly to enter) but quality conditional on entry to rise (innovators only proceed with higher value ideas).[52] Our empirical findings, by contrast, show that both the quantity and quality move in the same direction; they both decline. By moving in the same direction, these findings thus do not suggest an emphasis on changing entry costs. Rather these movements are consistent with a decline in the expected value of ideas. If declining effort leads to lower value ideas (a worsening quality distribution) then the presence of a given entry cost would imply both that fewer ideas would be commercialized and that the average quality of commercialized ideas would fall. Declines in effort in producing innovative ideas may thus provide a logically consistent interpretation of the empirical findings.

This perspective may help inform more specific theories in the literature on university-based innovation. For example, the empirical findings appear to diminish, in our context, the importance of several forces that TTOs may bring to bear. First,

[51] While noisy, point estimates suggest if anything a decline in publication outputs after the reform within individuals.

[52] In the context of Bayh-Dole, a period around which patent rates increased, Henderson, Jaffe, and Trajtenberg (1998) find that the average quality of US university patents goes down. Rising patent rates and declining average quality can follow if Bayh-Dole lowered the fixed costs of entry, which may be a natural interpretation of the reform, which removed the government from the bargaining. By contrast, the professor's privilege substantially removed the rights of a key investing party, the inventor, and thus could dissuade effort at patenting, resulting in a quantity down and quality down outcome, as we find. Interpreting the patent rate dynamics around Bayh-Dole requires care however (Mowery and Sampat 2005).

TTOs might arguably lower the entry costs of commercialization, thus helping university researchers overcome the hurdles of patent applications and new venture market entry (e.g., Debackere and Veugelers 2005). However, lowering entry costs would be associated with more innovative entry, not less, which the empirical findings appear to strongly reject. Related, TTOs may perform an important function "searching the closets" for latent applied research ideas to increase technology transfer. However, were this mechanism the driving force, we would expect the quantity of innovative output from the universities to go up, not down. Second, through commercialization expertise and/or reputational functions, TTOs might promote higher quality inventions and new ventures (e.g., Macho-Stadler, Pérez-Castrillo, and Veugelers 2007), acting to screen our lower quality ideas. However, the tendency for quality measures to also decline does not point in this direction, at least in our context. In sum, theories whereby giving the university rights and deploying TTOs will unleash substantial additional innovation, either by improving search, selection, or lowering entry costs, appear inconsistent with our empirical findings. The TTOs may still perform these functions at some level, but if so the benefits therein are being overwhelmed by other forces.

A richer perspective, which may explain the findings, emphasizes both university and researcher incentives, and how rights given to the researcher can be balanced with any rights given to the university itself. In theory, the appropriate balance of rights might emphasize the university's role, as discussed in Section IB. The basic presumption here is that university-level investments are important and cannot be easily replicated by the university researcher.[53] However, it is also natural to imagine that the researcher's investments are particularly important, especially viewing the individual researcher as the creative engine. Under circumstances where the university-level investments are much less important than researcher-level investments, royalty shares would be optimally balanced toward the university researcher. The empirical analysis in this paper appears broadly consistent with such an income rights perspective, where shifting rights away from the researchers substantially reduced their investment incentives.

In our survey of university inventors, we collected views on the reform itself. The inventors' responses tend to echo the empirical findings and often point toward an income rights interpretation as a mechanism. When asked whether the reform had a positive, neutral, or negative effect on their interests in commercialization, 56 university inventors responded, with the majority (34) expressing no effect, while negative effect (15) was expressed twice as often as positive effect (7).[54] When asked how their colleagues viewed the reform, the inventors usually said they did not know; however, they again expressed a negative effect (10) about twice as often as a positive effect (4). See Table 11 and online Appendix III for further detail.

Given the opportunity to comment, respondents provided substantial additional color about the mechanisms at work, and these comments were again balanced toward negative viewpoints. Views about the TTOs contributions specifically were

[53] Online Appendix I provides a formal example under which the one-third/two-third split, which is prevalent in many countries today, could be (second-best) optimal, if university-level investments matter enough.

[54] Among the 63 respondents to the survey overall, 56 individuals answered this particular question. Online Appendix III provides response rates to each question in the survey.

mixed, with some emphasizing TTO advantages along the theoretical lines above and others emphasizing bureaucratic disadvantages. Positive comments about TTOs include:

- *"The technology transfer office did a realistic evaluation of an idea for patent that I had. The conclusion was that the idea/concept was not patentable. That saved me for a lot of unnecessary work.*"
- *"I got support in the judicial work around patenting."*

However, most comments were negative. The main theme was the dilution of the university inventor's rights, which was often seen as a fundamental problem and not counterbalanced by the TTO's contributions. Some representative comments include:

- "*Less attractive to work with entrepreneurship when you as an inventor only get a marginal portion of the ownership. The services that TTO provides does not justify their high portion of ownership.*"
- "*The university contributed little, but was entitled to a substantial income share.*"
- "*The new rules have made it significantly less attractive to develop patents as a university employee. The new rules typically provide a significant initial dilution, which may be a problem in financing, and a company founded on IP in the form of patents also need to carry the burden of a significant bureaucracy in the form of the TTOs. It is claimed that the TTOs provide a useful service, but this is not my experience…*"
- "*I would never start up a company in the current system. In the current system, the TTO has a large ownership fraction and a dominating position from the start, and the entrepreneur has for example 33%. With venture financing, venture gets about 50% at every stage. It is common with 2–3 stages. Thus, the entrepreneur will have 16.6% after the first stage, 8% after two stages, and 4% after three stages. The entrepreneur early onwards loses control over the start-up and must rely on other actors, who from experience do not need to have much competence on neither technology nor management of start-ups. Furthermore a low ownership share also means limited upside…*"

The complete set of positive and negative comments is provided in online Appendix III. Overall, these comments appear broadly consistent with the income rights theories discussed above and in online Appendix I.[55]

[55] The professor's privilege reform, in giving majority income rights to the university, also gave the university control rights, and control rights perspectives, emphasizing contractual incompleteness and the possibility of hold-up by the university, may additionally dissuade university researchers from undertaking innovative activities (see Section IB). That said, several considerations suggest that control rights may not be the key mechanisms at work here. First, only one comment in the inventor survey emphasizes control issues, while many (including the one that mentions control) point directly to income issues. Second, ex post of our empirical analysis, we conducted telephone interviews with the directors of the TTOs at the three largest Norwegian universities (Oslo, Bergen, and Trondheim). These TTO directors emphasized that university researchers retain important de facto control where the ongoing involvement of the researcher is essential to commercialization prospects, which is consistent with other literature (e.g., Jensen and Thursby 2001). Related, relational contracts may limit hold-up problems, especially with many agents watching (Levin 2002). Nonetheless, it is possible that control rights considerations

Taking an income rights view, the policy shock may also provide some insight on the link between taxation and entrepreneurship among a class of highly-skilled knowledge workers. In particular, the loss of income rights can be thought of in part as increasing the tax rate on researcher's commercialization income. While the additional effect on university investment distinguishes the experiment from a narrower tax experiment on the university researcher, an income rights perspective suggests that the policy reform provides a lower bound on the effect of an equivalent tax. Intuitively, should the university investments be at least weakly complementary to the researcher's investments, the taxation effect on the researcher's income incentives is offset to some extent by the benefit of university-level support. This argument is shown formally in online Appendix I. Based on this reasoning, university researchers appear very sensitive to the effective tax rates on their expected income, where a loss of two-thirds of pre-tax expected income is associated with an approximate 50 percent decline in innovative output, for a lower bound tax elasticity of 0.75.

Highly-elastic responses of R&D workers to income taxes appears separately in the natural experiments of Akcigit, Baslandze, and Stantcheva (2016), who study the international migration of inventors in response to top income tax rates and find elasticity estimates of approximately 1. While Akcigit, Baslandze, and Stantcheva (2016) study a different construct, their results further suggest substantial sensitivity of R&D to workers to income rights.[56] In our policy experiment, the decline in the quantity and quality of start-ups and patents is consistent with declining effort by university researchers, who often highlighted the loss of their income rights in our survey amidst a broadly negative view of the reform. While scientists might broadly value freedom over income and operate largely according to scientific norms that emphasize open access to their ideas (Merton 1973; Stern 2004), there is at least a subset of university researchers (those on the margin of important technology transfer avenues) who respond with high elasticity to their rights allocations.

V. Conclusion

Following a pan-European policy debate in the 1990s, many European countries abolished the "professor's privilege" in order to boost commercialization activities from universities, and moved to a policy regime similar to the United States post Bayh-Dole. This paper considers the policy reform in Norway, deploying registry data and other datasets that allow us to comprehensively study new ventures and patenting. The policy change transferred two-thirds of the income rights enjoyed by university researchers to their university employer. The basic empirical finding is a large decline, by approximately 50 percent, in the quantity of both start-ups and patenting by university researchers. We also see declines in measures of quality for start-ups and patents. The declines are robust to using various control groups for the natural experiment and are broadly similar when looking across both start-ups and patents.

further dissuaded innovative effort by university researchers, with ultimately similar effects on innovation from a commercialization policy perspective.

[56] See also Moretti and Wilson (2017) and Widmann (2017), which demonstrate high migration elasticities of inventors to tax rates in more local contexts.

The paper further discusses potential implications of these findings for university commercialization policy. Broader interpretations in light of literatures on rights allocations in innovation and taxes and entrepreneurship are also considered. The basic empirical finding is that the "professor's privilege" policy regime in Norway saw far more university-based start-ups and patenting than the regime where the university owns the rights and gives one-third of the income to the researcher. In addition, a survey of university inventors suggests that the dilution of their income rights was a serious concern, providing further insight on mechanisms. Overall, the findings raise fundamental questions about whether much of the world, which uses university commercialization policies that look like the ex post regime in this study, are producing much less university-based innovation than they could and that many policymakers desire. Studies of additional policy reforms and the potential for formal experimentation in the rights regimes are key areas for future research as the search for the correct policy mix continues.

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