University Innovation and the Professor's Privilege*

Hans K. Hvide, University of Bergen and CEPR

Benjamin F. Jones, Kellogg and NBER

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Abstract

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 U.S. model, where the university holds majority rights. Using comprehensive data on Norwegian workers, firms, and patents, we find a 50% 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 literatures on university technology transfer, innovation incentives, and taxes and entrepreneurship are considered.

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I. Introduction

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 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 allows 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 U.S. 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

[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. U.S. 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).

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 U.S. system today (since the 1980 U.S. 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 provides 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, 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% drop in the rate of start-ups by university researchers. This drop appears (1) in a simple pre-post analysis of university start-up rates, (2) when compared to background rates of start-ups in Norway, and (3) 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 U.S. 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 2015). 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 II 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 III introduces the data and identification strategy. Section IV presents the core results for entrepreneurship and patenting.

Section V discusses these findings, including their relevance to broader settings, as well as other margins of response empirically.[2] Section VI concludes.

II. 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 tradeoffs 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 U.S. 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 et al. 2007, Grimaldi et al. 2011, National Academy of Sciences 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]

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[2] 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. Appendix II considers additional empirical findings, studying the publication behavior of university researchers and how this changes with the reform. Appendix III details the results of our university inventor survey, focusing on licensing behavior and individual views of the reform. Appendix IV further details the patent measures. 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 V while the appendices themselves are available online.

[3] Separately, many scholars have addressed whether universities should engage in commercial innovation activity given potential tradeoffs with other activities, especially basic research (e.g., Krimsky 2003, Washburn 2008, National Academy of Sciences 2010). These potential tradeoffs bear on a complete assessment of the welfare consequences of commercialization policy. In prior literature, however, individual-level publishing and patenting appear positively rather than negatively correlated (e.g., Fabrizio and Di Minin 2008, Azoulay et al. 2007, Buenstorf 2009) which suggests that basic research and invention may be complements rather than substitutes. This finding is consistent with conceptualizations of scientific progress based on Pasteur's Quadrant (Stokes 1997), so that the tradeoffs between research and invention may not be so acute (Ahmadpoor and Jones 2017). In Appendix II, we examine publications in the context of our data and confirm a positive correlation between patenting and

The 1980 Bayh-Dole Act is a signal event for researchers and policymakers in this space. The law eliminated U.S. government claims to university-based innovation, giving U.S. 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 et al. 1998), and entrepreneurship (e.g., Shane 2004) among other issues. Interestingly, while U.S. 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 pre-existing trend (Mowery and Sampat 2005).

The acceleration of patenting and licensing from U.S. universities eventually caught the attention of European policymakers, who concluded that European universities lagged their U.S. 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 rights to the university. Notably, although policymakers in Europe were inspired by the post-Bayh-Dole Act environment in the U.S., 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 U.S. post Bayh-Dole.

In contemporaneous studies of the professor's privilege, Czarnitiski et al. (2016) find a decline in university patenting in Germany after the reform there, while Astebro et al. (2016) find lower rates of PhDs leaving universities to start companies in the U.S. 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 V.

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publications at the individual level. We further examine publication output within individual researchers, harnessing the reform as a shock to patenting incentives, and do not find evidence that publications and patents are substitute activities. See Appendix II.

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 startups 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] In the case of patents, university bylaws obligate the university to claim its property rights within six months after the researcher discloses the invention. Should the university decide not to use its option, the rights are returned to the inventor.

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 on net (Czarnitzki et al. 2011). However, as discussed in Section II.A, 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 university-owned IP as the mode of technology transfer from universities. This focus leaves aside the potential for university academics to start companies, rather than license, which is a primary commercialization alternative (e.g., Gans and Stern 2003).

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[4] The non-public higher education sector is very small in Norway. The law change is named Proposition No. 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, were led by a director, and were financed partially by the university itself, partially by the Norwegian Research Council (FORNY program), and partially by the Ministry of Education (Rasmussen et al. 2006).

[6] While Germany included a clause in the new law that the university must share 1/3 of net revenues with the researcher, in Norway this norm was not formally established in the law per se but rather was called for by the parliamentary committee chairman, who stated explicitly at the time the law was passed that a one-third split with the researcher was expected. This norm was then further formally established in university bylaws later in the decade.

[7] The marginal tax rate in Norway is approximately 50% 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%. The increase in effective tax rate is thus approximately 33 percentage points.

As we will show, both patenting and this “other” commercialization mode – new ventures – appear to have been severely affected by the end of the professor’s privilege.[8]

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 & 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 startup areas, and details of the TTOs are provided in 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 U.S. 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 V.

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) provide canonical analysis of innovation contexts where different agents bear private costs but share in future payoffs and emphasize the challenge in effectively balancing incentives across investing

[8] Interestingly, Lissoni et al. (2008) have shown that, in contrast to the U.S. experience where 69% 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 these privately-owned patents are accounted for, university researchers in these three European countries (especially Sweden) show only modestly lower patenting rates than U.S. universities, which undercuts the empirical view that European universities were laggards in commercialization activities in the first place.

parties. These theories suggest that rights should be balanced toward the party whose investment matters more.[9]

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 et al. 2007). For instance, if receiving a patent requires substantial costs in time and money, such costs may limit entry (e.g., Hall 2007, Gans et al. 2008, Baldini 2009). Should the establishment of a TTO reduce entry costs (e.g., via scale advantages in providing commercialization services), it is possible that the professor's privilege reform could encourage more university technology transfer. Universities and their TTOs may also act as useful intermediaries in markets for technology and improve the quality of innovative outcomes (e.g., Macho-Stadler et al. 2007). 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 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. 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

[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).

[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.

pursuit of greater technology transfer (Litan et al. 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 Appendix I). In practice, the appropriate income rights allocation in the university context remains unknown.

The professor's privilege reform might also be motivated in part 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 classic 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 in general appear to have strong tastes for autonomy and other motivational characteristics distinct from income (e.g., Evans and Leighton 1989, Hamilton 2000, Shane et al. 2003). Moreover, studies of university entrepreneurs further suggest the importance of motivations beyond income and distinct traits from other university researchers (Roach and Sauermann 2012). The extent to which university-based innovators, or high-skill innovators more generally, react to effective tax rates appears unknown.

Beyond changing income shares, 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. Beyond issues of how the surplus is ultimately split, disagreement may result in Williamsonian haggling costs that further destroy surplus. Anticipation of such haggling may in turn dissuade effort.

While theories emphasizing rights allocations in the economics of innovation are highly influential, empirical studies examining these theories remain relatively few (Lerner & Merges 1998; Lach and Schankerman 2008, Lerner & 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.

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.

III. Data and Identification

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

A. Data

The startup analysis draws on several Norwegian register databases. The socio-demographic data, compiled by Statistics Norway, covers the Norwegian adult population and consists 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 startup data, collected from the government registry "Bronnoysundregisteret", covers the population of incorporated companies started in Norway between 2000 and 2007, and provides 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% of the company, can be matched to the sociodemographic data, and in this manner we identify new firms started up by university researchers as well as the sociodemographic characteristics of entrepreneurs more generally. The data further contains anonymous ID numbers for the startups, which allows us to match at firm level with longitudinal, yearly, accounting data collected from Dun & Bradstreet. The accounting data runs through 2012; it identifies which sector the startup operates in and contains annual measures of startup performance such as sales, profits and employees.[11]

[11] Note that we focus on incorporated companies, which does not include self-employment. Levine and Rubinstein (2015) show in the U.S. 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 (EUR 13,000) during the study period. Incorporated companies are required to have an external auditor certify annual accounting statements submitted to tax authorities.

The patenting analysis is based on separate data collected from several sources. The Norwegian Patent Office (NPO) data does 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 sociodemograhic information such as gender, age, and PhD 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 U.S. Patent and Trademark Office.[15] Further detail regarding the patent data is given in Appendix IV.

Table 1A provides summary statistics for start-up firms in Norway between 2000 and 2007. In total there were 48,844 startups and 128 of these were started up by individuals with PhDs employed at a university. We define a university startup 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 startups is more similar.[16] University PhD startups tend to be somewhat

[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.
[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, United States, and Japanese patent databases. Patent renewal data comes from the NPO.
[16] Non-surviving firms are defined as those that stop reporting profits or whose sales fall below 50 thousand NOK after their first year.

smaller in employees, sales, and profits than non-university start-ups, with a closer match to non-university PhD startups.[17] Comparing the university PhD start-ups and non-university PhD startups, 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 75th percentile company in each category features 1-3 employees while sales reach 1.2-3.3 million NOK, depending on the population, while the 95th 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 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% 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

[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=.28), sales (p=.61), employees (p=.14), and profits (p=.064).
[19] Guzman and Stern (2015a, 2015b) document the rarity of high-growth entrepreneurship in the U.S. and in the environs of U.S. universities.
[20] Two sample t-tests indicates no significant difference for age (p=.83) or marital status (p=.89) while there is a marginally significant difference for gender (p=.095) and differences for prior year earnings (p=.017) and wealth (p=.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.

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 U.S. Patent and Trademark Office. Although about two-thirds of the university PhD workforce is male, university inventors are 93% male. The background population of Norwegian inventors is estimated to be 94% male. The substantial propensity toward male inventors echoes the similar gender propensity seen in entrepreneurship above.

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%, 39%, and 7% respectively.

B. Econometric Approach

Our analyses primarily consider difference-in-difference 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:

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

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-difference regressions thus generally take the form:[21]

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

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

IV. Results

In this section we present the main results of the paper. We consider entrepreneurship in Section IV.A and patents in Section IV.B.

A. Startups

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 line, left vertical axis) and non-university startups (blue line, right vertical axis) over the sample period.[22] While the non-university startup rate is approximately constant across years, the university startup 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 startups per year, for a drop of 56%.

Figure 1B considers the same data on a per-worker basis for the relevant groups. On average, 0.678% of university researchers started a new firm in a given year prior to the reform, while 0.224% of university researchers started a new firm in a given year after the reform, for a 67% 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.

[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.

Together, these figures show a sharp drop in entrepreneurship by university researchers that is coincident with the professor's privilege reform. By contrast, the start-up rate for the background population is largely flat, increasing 5.9% comparing the post and pre periods (Figure 1A) and increasing 2.1% 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" differences-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% decline (i.e., $1\text{-}e^{-1.102}$) 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 startups by university PhDs, with a 49% 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% 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 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 a pre-period university researchers, even should they leave the university. The difference-in-difference drop in university start-up rates is similarly large and negative across these sector-level specifications.

[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.

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. Non-linear 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 and control groups – either via unobservable, fixed individual level characteristics or several observable and time-varying characteristics – that may explain individual startup 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% 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

[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 non-linear models, the emphasis on the linear probability model in the exposition also appears conservative. Complete results using non-linear 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.

[26] To see this magnitude, consider that the mean of the dependent variable in columns (1)-(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% decline in their prior rate.

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 startup propensities of university researchers compared to this narrower control group. The 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=.11) while non-linear models show greater precision as shown in column (3) (p<.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 startups 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-difference results comparing university and non-university PhDs would be biased against finding effects, i.e., be conservative. One might alternatively imagine sources of non-conservative biases for this control sample, although the plausibility for the reform positively affecting startups by non-university PhDs may be limited.[27]

[27] One mechanism might be as follows. To the extent that non-university PhD startups compete with university PhD startups, the decline in university PhD startups 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 startup rate doesn't go up in absolute terms after the reform, and more generally university researcher startups are a very small percentage of businesses in any sector, which may limit the plausibility of such competition effects.

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 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-difference 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 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 startups, we can also consider the quality of startups 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 differences-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 startups 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" startups while

[28] We take two alternative approaches to studying an exit effect while accounting for underlying exit propensities of university researchers. In one approach, the treated group are 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 reform. Either way, we see no evidence of increased exit by those who seem relatively impacted to the reform.

avoiding upper tail outliers that can otherwise influence the results.[29] The threshold for an upper quartile start-up is 3.3 million NOK in sales and 3 employees at an age of 5 years.[30] The findings in Table 6B broadly echo the above results. The probability that a university startup surpasses the 75th percentile of sales declines by 12 percentage points at conventional significance levels after the reform, compared to other startups. The probability of surpassing the 75th 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 (a) manufacturing sectors that are defined as "low-technology" and (b) 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.

Table 6C column (1) indicates a substantial decline in higher-technology startups by university researchers after the reform when compared to higher-technology startups 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) startups across Norway.[32] Columns (3) and (4) show, removing such ICT startups from the sample, the $Post$ coefficient is no longer large or significant. These columns further show large, negative effects of the decline in (non ICT) technology-oriented startups from university

[29] In general, evidence suggests that successful startups are rare, even in clusters around universities (Guzman and Stern 2015a, 2015b), and the evidence about firm size in Table 1A further suggests the thick upper tail in startup growth, so that mean regression analysis of performance may be driven by outliers.
[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] Startups in "computer and related activities" (NACE code 72) were frequent in the early 2000s in Norway, as they were elsewhere.

researchers, with similar size effects using either control group.[33] Poisson models (not reported) rather than 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-difference decline in technology start-up rates in columns (3) and (4) implies a 71% drop. This decline is larger than the decline for university start-ups generally, indicating that these university technology startups fell proportionately more on average, although this excess decline is not statistically significant.[35]

Related, we can also look at the decline in startup rates among university researchers with science and engineering PhDs as opposed to those with non-technical PhDs. We find that university researchers with non-technical PhDs saw a 39% decline in their startup rates after the reform. Those with science and engineering PhDs, who produced 57% of pre-reform startups, saw a much larger 62.9% decline in their startup rates after the reform. Thus the decline in startups 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 startups by university researchers founded prior to the reform, 12% obtained a patent as the applicant within five years of founding. Among university startups founded after the reform, only 2% percent obtained a patent in this manner within this window. This decline is significant at the 1% level using a simple t-test.

[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 startups 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% of university-based start-ups were in higher-technology sectors (41% including ICT); after the reform only 17% of university-based startups were in these sectors (33% including ICT).

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 pre-existing companies. We can test this possibility in two ways. First, the Norwegian registry data identifies 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%) appears in a simple pre-post of university researcher start-up behavior, and it appears similarly large when compared to the background startup 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 startups by university researchers decline, but there are declines in several quality measures for these startups as well.

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

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 III.A). The resulting dataset cannot be linked to the Norwegian registry data; therefore, the patent analysis allows comparisons among inventors only (university vs. 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 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 the 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% of university researchers applied for a patent in a given year prior to the reform, while 0.48% of university researchers applied for patents per year after the reform, for a 49% drop in the per-worker rate. By contrast, the broader Norwegian workforce averaged 0.019% patents per year prior to the reform and 0.016% after the reform, for a 15% 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.

[37] Recall that the Norwegian census and business registry data use an anonymized numerical identifier for each individual, while the Norwegian Patent Office data does not use such identifiers. Thus we do not have socio-demographic 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] We define a patent as a university patent if at least one inventor on the patent 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.

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-difference in Figure 2B, the $Treat_i \times Post_t$ coefficient now indicates a 43% 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%. 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), 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 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

[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% over the 2000-2007 timeframe while the Norwegian workforce grew only 7% (see Section III.A) it is remarkable that the aggregate rate of patents from universities still falls.

[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.

month of December sees the most activity of any month that year, accounting for 20% 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 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-difference 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

[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% of inventors apply for one patent only.

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 end of the professor's privilege.

The Quality of Patenting

Table 10 considers changes in the quality of patenting using various standard measures: citations received, patenting in multiple 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 non-linearities in the quality measures over time.

In Table 10, columns (1)-(3) consider the citations a patent receives, with citation counts to each patent calculated using the PATSTAT database.[44] Column (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=.061) compared to controls. Column (2) considers total citation counts using a Poisson model, which shows an approximate 25% decline in citations received per patent, although this result is not statistically significant at conventional levels (p=.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=.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 Appendix IV considers alternative citation count measures. Overall, the $Treat_i \times Post_t$ coefficients are large and negative regardless of the measure, while

[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 column (4) of Table 7.

[44] Citations received have been shown to be positively correlated with market and social value (e.g., Trajtenberg 1990, Hall et al. 2005). The PATSTAT citation counts consider citations to the patent family, using the DOCDB definition, for the given patent. Appendix IV provides further background on the patent data and metrics.

statistical significance is mixed, with specifications broadly showing p-values in the .05-.15 range.

Columns (4)-(7) examine a different and more 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 more important patents, or 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% 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 U.S. declines by a broadly similar magnitude, as seen in column (5), but this decline is not statistically significant (p=.121). In column (6) we look at whether a patent receives protection in all of Europe, the U.S., 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, US, 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 the 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=. 114). The 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. Interestingly, 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 likely to be maintained compared to non-university patents. The reform acts to substantially offset this advantage (compare the $Treated \times Post$ 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. 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.

There were 63 university inventors who responded to our survey, giving a response rate of 22%. Of the respondents, 36% of inventors with patent application dates prior to the reform licensed these patents at least once, while the corresponding post-reform fraction is 26%. We can reject at the 10% 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% level that mean licensing income is higher after the reform. 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 Shankerman (2008), who studied licensing income across U.S. universities and found lower licensing income in universities where the researchers had lower royalty shares.

[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 V.

Summary

In sum, we see a large drop in patenting by university researchers after the "professor's privilege" reform. This decline is commensurate on many dimensions with the findings for start-ups. The patent rate per worker falls by approximately 45%, 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, 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.

V. Discussion

This section considers the policy experiment and results in light of several existing literatures. After summarizing the core empirical findings, we first discuss additional evidence from cross-country and cross-university empirical studies to help inform potential representativeness for broader settings. We then consider possible tradeoffs 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 potential applications to literatures regarding rights allocations in innovation and taxes and entrepreneurship.

Summary of Empirical Results

University researchers are potential wellsprings of innovative ideas that may deliver substantial social returns. A large literature has sought to understand policies that influence innovative activity by this workforce, and the design of these policies 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 U.S. today. Similar reforms were implemented in several European countries, including Germany.

The empirical findings suggest that the policy reform had several measurable effects. First, there was an approximate 50% drop in the rate of new venture formation by university researchers. Second, there was a similar drop in patenting. Third, the quality of new ventures and patents also appeared to decline. These stark findings appear in sharp contrast to the motivations behind the Norwegian policy reform. The findings may 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 of start-ups and patenting by university researchers would rise substantially, as would the quality of these innovations, should universities give the researchers full rights. More generally, since the post-reform regime looks like the U.S. regime, among others, the interest in the external validity of these findings may broaden further.

Representativeness

As guideposts on the potential generalizability of these results, descriptive facts may be informative. On a cross-country basis, Lissoni (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%, Finland is 8%) compared to countries in Europe that did not feature the professor's privilege over similar time periods (France was 3%, Italy was 4%, and the Netherlands was 4%).[47] Examining licensing income and comparing across universities in the U.S., 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 comparing universities with a one-third researcher share to those with nearly full researcher royalty shares. Thus, while such cross-sectional differences do not control for many possible conflating factors, and do not study behavior at the individual level, the cross-sectional evidence appears broadly consistent with the patent findings in this paper.

[47] The U.S. academic patenting share is not clear, but university-owned patents in the U.S. are 4% of all U.S. patents, and samples suggest that these patents represent perhaps 65-80% of all U.S. patents with academic inventors (Fabrizio and DeMinin 2008, Lissoni 2008). Thus the academic patenting share in the U.S. may also be somewhat less than that in the professor's privilege countries, when the policy was in place.

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. Czarnitski et al. (2016) 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-difference 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 U.S. 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 U.S. academics are, compared to the background rates for non-university PhDs in their respective countries.

Overall, the difference-in-difference estimates established for all new ventures and patents in Norway appear broadly consistent with this other evidence. Countries under the professor's privilege regime have tended to see greater rates of commercialization activity by academics, often by large magnitudes as seen through the Norwegian policy shock. These 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

[48] The quality of patents may have dropped too: although Czarnitski et al. (2016) do not report separate results on patent citations, their citation-weighted difference-in-difference estimate of the reduction in patenting rates is about 24 percent, i.e., larger than the unweighted estimates.

[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 non-profit 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 U.S. 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 U.S., such as UC Berkeley, Wisconsin, and Michigan, are often leaders in academic entrepreneurship.

[50] A system with more heterogeneous royalty structures (i.e., the U.S.) may also allow easier migration of innovation-oriented researchers to universities offering them higher royalty shares, as argued by Lach and

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 different TTOs. Appendix V discusses Norwegian TTOs in greater depth and assesses evidence for quality heterogeneity, finding no strong support for it to the extent we can test this possibility. 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.

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. Tradeoffs 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, National Academy of Sciences 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 tradeoff with other research outputs. This analysis is provided in Appendix II. In line with existing studies (e.g., Fabrizio and Di Minin 2008, Azoulay et al. 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 fixed effects, do not suggest an obvious tradeoff between invention and research when comparing across individuals.

Schankerman (2008). This migration effect could increase the elasticity of innovative activity to the royalty share policy at a given university (by attracting or repelling innovators), yet soften the effect of one university's policies on the broader innovative output of the national system.

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 Appendix II.

In sum, we find little evidence for a tradeoff 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).

Mechanisms and Views of Reform

When considering the quantity and quality of innovative outcomes, conceptually one can consider the innovator'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

[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 et al. (1998) find that the average quality of U.S. 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).

a fixed 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, 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, TTOs might through commercialization expertise and/or reputational functions promote higher quality inventions and new ventures (e.g., Macho-Stadler et al. 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 the ensuing creation of 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. The appropriate allocation of rights between investing parties is a classic question in economics (Holmstrom 1982, Grossman and Hart 1986, Aghion and Tirole 1994, Green and Scotchmer 1995, Hellmann 2007), and the professor's privilege reform is a large shock to the rights regime. In theory, the appropriate balance of rights might emphasize the university's role, and 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.[53] The basic presumption here is that university-level investments are important and cannot be easily replicated by the university researcher. However, it is also natural to imagine that the researcher's investments are especially 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.[54,55] 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.[56]

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 61% reporting a negative effect while only 13% reported a positive effect. Of those who gave comments, views of the TTOs contributions were mixed, with some emphasizing TTO advantages along the theoretical lines above and others emphasizing bureaucratic disadvantages. The main theme, however, 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:

[53] While proportional sharing of the joint surplus cannot provide first-best efforts (Holmstrom 1982), within the class of second-best outcomes, some royalty sharing regimes may be vastly superior to others.

[54] Appendix I takes an income rights perspective. A control rights perspective will also tend to suggest that rights should favor the party whose investment matters more (e.g., Aghion and Tirole 1994).

[55] Some analyses of commercialization practices, putting little store in university capabilities and/or emphasizing incentive conflicts between the parties, have argued for sharply curtailing the role of TTOs and increasing researcher's rights (Litan et al. 2007, Kenney and Patton 2009).

[56] A related feature that could motivate the reform is the view that university researchers do not care (much) for income, so that their investment incentives would be little affected by a loss of income rights. Taking scientific norms of openness seriously, where scientists place the typical fruits of their labor (i.e., research articles) in the public domain (Merton 1973), and in many cases earn far less than in industry, one might imagine that scientists have weak pecuniary interests or otherwise would care little if rights were transferred to the university. The evidence in this paper, by contrast, suggests that the loss of rights severely diminishes the commercialization activity of university researchers. This finding suggests that, at least among those researchers inclined to actually engage in patenting or new ventures, rights matter.

- *"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…"*

Further comments are provided in Appendix III. Overall, these comments appear broadly consistent with the income rights theories discussed above and in Appendix I.[57]

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 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

[57] 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. 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 the university researcher retains 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 have further dissuaded innovative effort by university researchers, with ultimately similar effects on innovation from a commercialization policy perspective.

expected income is associated with an approximate fifty 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 et al. (2016), who study the international migration of inventors in response to top income tax rates and find elasticity estimates of approximately 1. While Akcigit et al. (2016) study a different construct, their results further suggest substantial sensitivity of R&D to workers to income rights. In our policy experiment, the decline in the quantity and quality of startups 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.

VI. 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 U.S. post Bayh-Dole. This paper has considered 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%, 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.

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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Figure 1A: University Startups vs. Non-university Startups

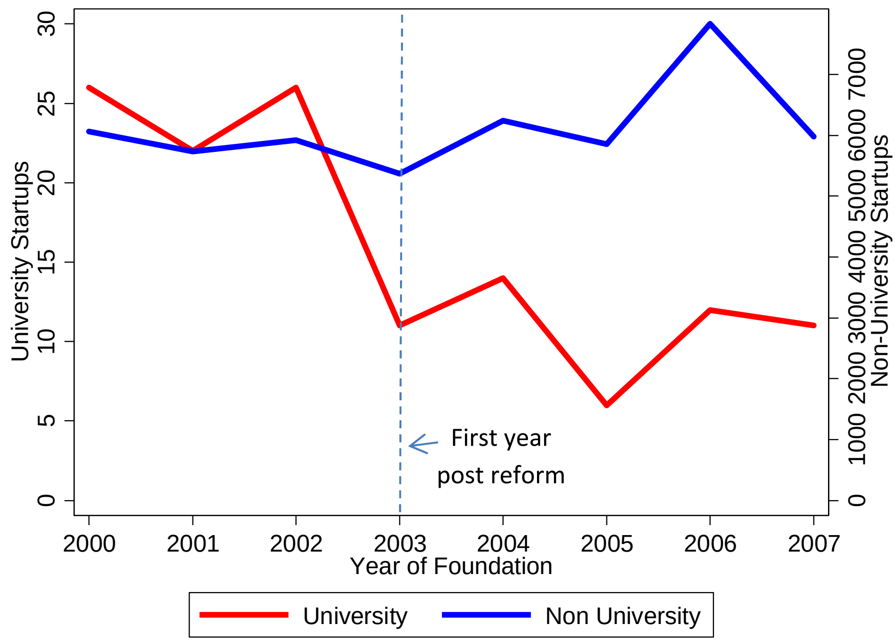


Figure 1B: University vs. Non-university Startups, per Worker

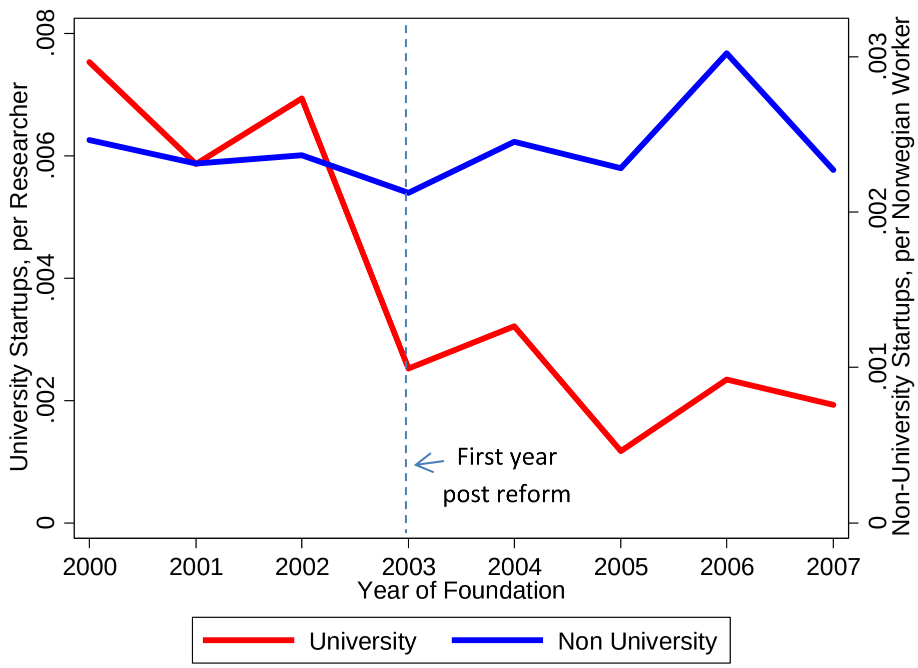


Figure 2A: University Patents vs. Non-university Patents

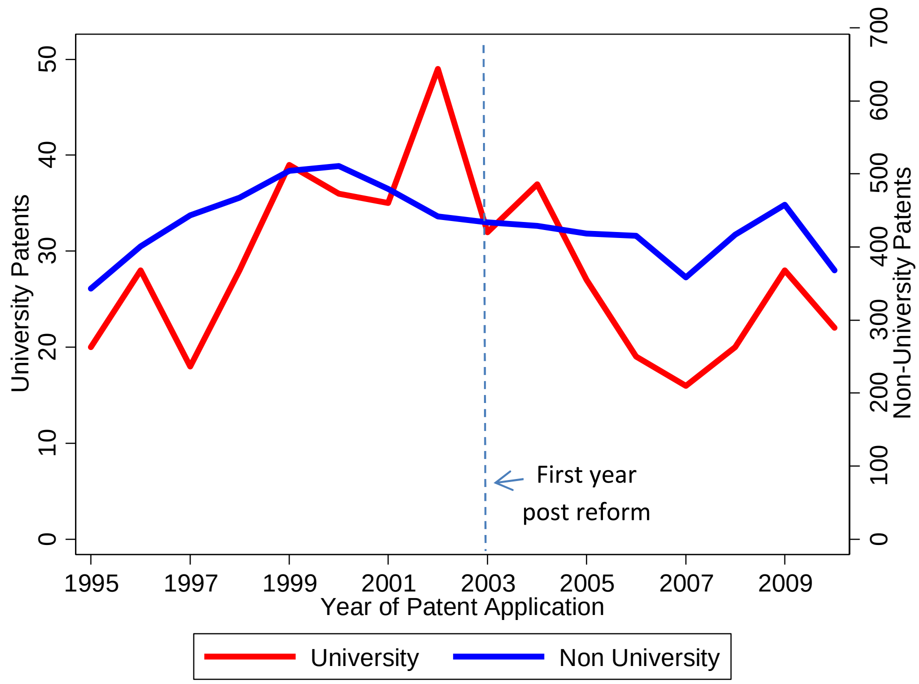


Figure 2B: University Patents vs. Non-university Patents, per Worker

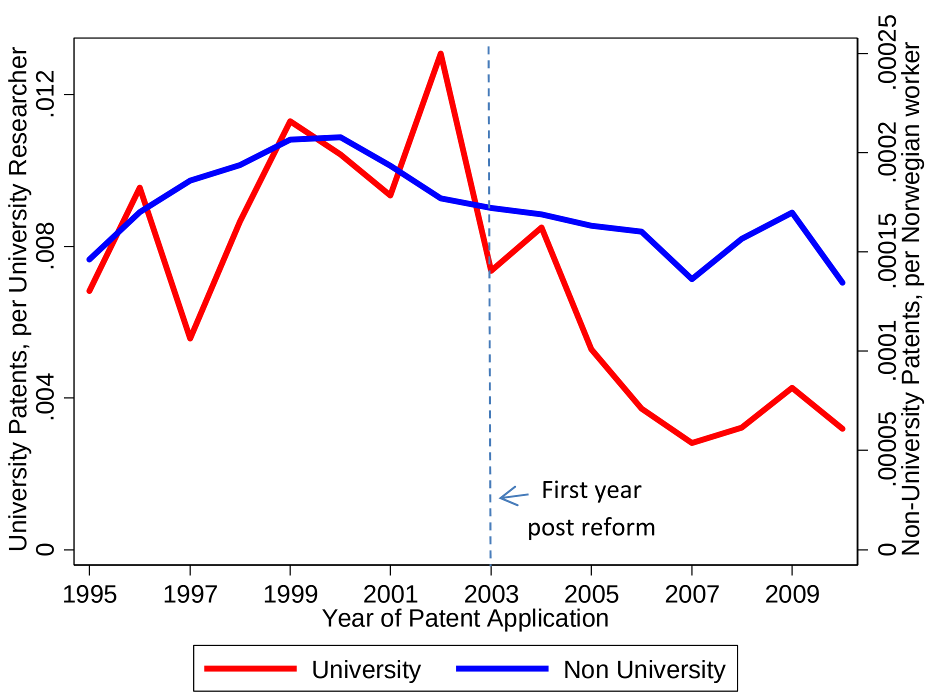


Table 1A: Summary Statistics for Start-Up Firms in Norway, 2000-2007

		Non University	Non University Ph.D.	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
	(St Dev)	(13,282)	(4,777)	(9,934)
	Median	1,751	628	183
	75^{th} ptile	4,834	2,210	1,550
	95^{th} ptile	20,769	10,815	9,374
Employees at 5 years	Mean	3.31	1.68	1.22
	(St Dev)	(7.77)	(3.16)	(2.89)
	Median	1	1	0
	75^{th} ptile	4	2	1
	95^{th} ptile	13	7	5
Profits at 5 years	Mean	198	220	100
	(St Dev)	(554)	(599)	(600)
	Median	43.1	41.2	-6.50
	75^{th} ptile	283	296	215
	95^{th} ptile	1,358	1,555	1,555

Notes: Sales, Employees, and Profits are conditional on survival at year 5. Profits and sales are measured in 1000 NOK.

Table 1B: Summary Statistics for Entrepreneurs in Norway, 2000-2007

	Non University	Non University Ph.D.	University
Number of Entrepreneurs	69,496	413	125
Age of Founder, Mean	41.6	47.4	47.8
(St Dev)	(9.95)	(8.98)	(8.90)
Median	40	46	47
Fraction with highest degree			
Bachelors	0.23	1	1
Masters	0.09	1	1
Ph.D.	0.006	1	1
Income, Mean	422	752	609
(St Dev)	(675)	(513)	(265)
Median	343	631	527
Wealth, Mean	1,520	1,610	1,140
(St Dev)	(12,200)	(2,910)	(1,550)
Median	449	731	581
Marital Status, Mean	0.59	0.74	0.74
(St Dev)	(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 1000 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[(1)]
% Cited at Least Once	53.4%	60.4%
% Patented at EPO, USPTO, or JPO	41.7%	50.2%
Number of Unique Inventors	6,890	268
% Male, workforce	50.4%	65.9%
% Male, Inventors	94.3%[(2)]	92.9%
Period	1995-2010	1995-2010

Notes: [(1)] 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. [(2)] 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. Appendix IV provides further detail on the patent data.

Table 2: Startups, Aggregate and Sector Level Analysis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Aggregate					Sector		
	Log Startups	Log Startups Per Worker	Log Startups	Log Startups Per Worker	Log Startups, Pre Period Individuals	Log Startups	Startups	Startups, Pre Period Individuals
Treated x 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	Norwegian	Norwegian	PhD	PhD	PhD	Norwegian	PhD	PhD
Sample	Workforce	Workforce	workforce	workforce	workforce	Workforce	workforce	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-squared	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)-(8), observations are sector x year for the treatment and control groups, with sector determined by the 1-digit NACE code. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3: Startups, Individual Level, All Workers

	(1) All Workers	(2) All Workers	(3) All Workers	(4) Entrepreneurs only	(5) Entrepreneurs only
Treated x 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-squared	0.000	0.164	0.165	0.029	0.032
Year FE	NO	YES	YES	YES	YES
Individual FE	NO	YES	YES	YES	YES
Age FE	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. Non-linear 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 (*** p<0.01, ** p<0.05, * p<0.1).

Table 4: Startups, Individual Level, Similar Workers

	(1) Masters or more	(2) Ph.D.	(3) Ph.D. Logit	(4) Ph.D. Propensity Score Match	(5) Ph.D. Entrepreneurs only	(6) Ph.D. Entrepreneurs only	(7) Ph.D. Earned pre 2000
Treated x Post	-0.00339***	-0.00231	-0.00177***	-0.00382**	-0.0865***	-0.0878***	-0.00280*
	(0.00114)	(0.00143)	(0.199)	(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-squared	0.173	0.177	--	0.271	0.017	0.030	0.165
Year FE	YES	YES	YES	YES	YES	YES	YES
Individual FE	YES	YES	NO	YES	NO	NO	YES
Age FE	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 Ph.D. 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 Ph.D. type fixed effects, gender, and marital status. Standard errors, in parentheses, are clustered by individual (*** p<0.01, ** p<0.05, * p<0.1).

Table 5: Startups, Individual Level, Intensive Margin

	(1)	(2)	(3)	(4)	(5)	(6)
	Pre-Period University Researchers			Stayers		
	All	Ph.D.	Ph.D., Logit	All	Ph.D.	Ph.D., Logit
Treated x 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-squared	0.153	0.159	--	0.153	0.159	--
Year FE	YES	YES	YES	YES	YES	YES
Individual FE	YES	YES	NO	YES	YES	NO
Age FE	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 (*** p<0.01, ** p<0.05, * p<0.1).

Table 6A: Start-up Performance at Year 5

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Survive	Log Sales	Log Employees	Log Assets	Survive	Log Sales	Log Employees	Log Assets
Treated x 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-squared	0.0419	0.1441	0.0914	0.0437	0.317	0.1657	0.1378	0.1327
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
2-digit sector FE	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 (*** p<0.01, ** p<0.05, * p<0.1).

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

	(1) Sales	(2) Employees	(3) Assets	(4) Sales	(5) Employees	(6) Assets
Treated x 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-squared	0.0591	0.0585	0.0283	0.1197	0.1036	0.0813
Year FE	YES	YES	YES	YES	YES	YES
2-digit sector FE	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 75th percentile of performance in the indicated measure, where the 75th percentile is defined for Norwegian startups as a whole. Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

Table 6C: Start-up Sectors

	(1) Log Startups	(2) Log Startups	(3) Log Startups	(4) Log Startups
Treated x 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-squared	0.987	0.673	0.978	0.386
Control Sample	Norwegian Workforce	PhD workforce	Norwegian Workforce	PhD workforce
Startup 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 startup-type in the last row of table. Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

Table 7: Patents, Annual Rates, Aggregate and Technology Level Analysis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Aggregate					Technology		
	Log Patents	Log Patents per Worker	Log Inventors per Worker	Log Patents, Balanced	Log Patents, Pre Period Individuals	Patents	Log Patents per Worker	Patents, Pre Period Individuals
Treated x 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-squared	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)-(5) we consider balanced panels of university researchers (see text). In columns (6)-(8), observations are technology class x 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)-(8) which cluster standard errors by technology class (*** p<0.01, ** p<0.05, * p<0.1).

Table 8: Patents, Individual Level, Inventors

	Dependent variable: Indicator for patenting in given year			
	(1)	(2)	(3)	(4)
	All Inventors	All Inventors	All Inventors	Rare Names
Treated x 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 FE	NO	YES	YES	YES
Individual FE	NO	NO	YES	YES
R^2	0.00	0.00	0.00	0.00
Obs	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 (* p<0.1; ** p<0.05; *** p<0.01).

Table 9: Patents, Individual Level, Intensive Margin

	Dependent variable: Indicator for patenting in given year			
	(1)	(2)	(3)	(4)
	Pre-Period University Researchers		Stayers	
Treated x 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 FE	NO	YES	NO	YES
Individual FE	NO	YES	NO	YES
R^2	0.00	0.00	0.00	0.00
Obs	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 (* p<0.1; ** p<0.05; *** p<0.01).

Table 10: Patents, Quality Measures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Cited	Citation Count	Citation Count	EPO Patent	US Patent	Triadic Patent	EPO, US, or JPO	In force duration
Treated x 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	--
Obs	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 column (2) and (3) using the integer count. Columns (4)-(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 (* p<0.1; ** p<0.05; *** p<0.01).

Appendix I: A Simple Formalization

Numerous countries maintain systems where the university, not the researcher, receives the majority of commercialization income. To sharpen the ideas behind these policies (which includes Norway after the professor's privilege reform and the U.S. after the Bayh-Dole Act), we introduce a simple formalization in the spirit of Holmstrom (1982). Namely, consider a policymaker that seeks to encourage the flow of commercially-valuable innovations from universities. This policy must balance the incentives of individual researchers with that of the university itself, which may make complementary investments that support successful technology commercialization. The policymaker's lever is rules on the allocation of rights assigned to each party.

To fix ideas, let a researcher have a unit of time of which a share s is devoted to producing a commercially-valuable innovation and the remainder $1 - s$ is used for other tasks (like basic research, teaching, or leisure). The university can also make investments (e.g., through a TTO) that facilitate the discovery and commercialization of technologies. By making an investment x, the university improves the commercial success of a researcher's insight.

Let the expected value of innovations that result be $v(s, x)$, which is increasing and concave in both arguments and where the inputs are complements ($v_{12} \geq 0$). The policy parameter is the portion α that accrues to the individual researcher, leaving a portion $1 - \alpha$ for the university. As Aghion and Tirole (1994) and Scotchmer (2004) have emphasized in innovation contexts, giving all the rights to one party can make the first-best difficult to achieve given the desire to incentivize investment by both parties, and as Holmstrom (1982) emphasized broadly, there can be deep challenges in achieving first-best outcomes via the rent-sharing parameter α.

In particular, given a researcher investing s in commercialization activities, the university solves the problem

$$\hat{x} = argmax_x[(1 - \alpha)v(s, x) - rx] \qquad \text{(A1)}$$

where the cost per unit of investment is r. The university's investment level is thus sensitive to their expected share of income, $1 - \alpha$.

Meanwhile, let the individual researcher have quasi-linear preferences in income so that, for a given x, the researcher solves the problem

$$\hat{s} = argmax_s[\alpha v(s,x) + G - \theta s] \quad \text{(A2)}$$

The researcher earns $\alpha v(s,x) + G$, where G represents the individual's academic salary or other non-commercialization income.[58] The disutility of commercialization effort (i.e. the loss of time for basic research, leisure, or other activities) is given by θs.[59]

With this simple approach, we can now examine the Nash equilibrium that emerges where the researcher and university make their choices, $\hat{s}$ and $\hat{x}$, as above, given the policy environment α. A key observation is that, with complementarities between university and researcher investments, innovative output may not be maximized at $\alpha = 1$, i.e. with a "professor's privilege".[60] Moreover, taking some rent share from one party may not only create more innovation but also encourage the party with the declining rent share to exert *more* effort.

To understand the role of such complementarities, consider a standard labor supply diagram for the researcher (see Figure A3) and consider how the researcher's budget constraint rotates in the presence of changes in the researcher's rent share. In a normal labor supply problem, increasing the tax rate on earned income will rotate the budget constraint counter-clockwise around the point C. This rotation generally creates two effects: the substitution effect will dissuade effort at the task, while the income effect pushes the other way, leading to the standard theoretical ambiguity linking tax rates and labor effort. Here, however, we have turned off income effects given the quasi-linear preferences of (A2), so the substitution effect will determine the worker's response. Nonetheless, the presence of complementarities in investment makes the direction of the rotation itself ambiguous. The slope of the budget set at an interior solution is $\alpha v_1(\hat{s}, \hat{x})$ (see point B in Figure A3). Since the equilibrium investment of the university is a function of α, i.e., $\hat{x}(\alpha)$, there is both a direct effect of reducing the researcher share, rotating the budget line

[58] For simplicity and to focus on the issue of complementarity, we take quasi-linear preferences, which turn off income effects and also remove considerations of risk aversion.
[59] For simplicity, we will consider the model taking θ as fixed, although more generally this could be considered as a taste parameter drawn from a distribution $F(\theta)$. Thus, in general, some fraction of researchers may participate in commercialization activities while others may not.
[60] For example, this result appears directly for a Cobb-Douglas production function or more generally where each input is necessary to positive production ($v(s,0) = v(0,x) = 0$). In such cases, either $\alpha = 1$ or $\alpha = 0$ would not produce positive commercialization output, as one party would not invest.

counterclockwise (like a standard tax), and an indirect effect, via changes in the university investment, that can rotate the budget line clockwise (via complementary investment). Formally,

Lemma. *Researcher investment is increasing in* α *if and only if* $v_1(\hat{s},\hat{x}) + \alpha v_{12}(\hat{s},\hat{x})\hat{x}'(\alpha) > 0$. *Moreoever, for the professor's privilege,* $\hat{x}'(\alpha) \leq 0$ *at* $\alpha = 1$.

Proof. By the first order condition for the university researcher, $\hat{s}$ is chosen such that $\alpha v_1(\hat{s},x) = \theta$. Totally differentiating this condition with respect to α we have

$$\hat{s}'(\alpha) = \frac{v_1(\hat{s},\hat{x}) + \alpha v_{12}(\hat{s},\hat{x})\hat{x}'(\alpha)}{\alpha v_{11}}$$

Noting that $v_{11} < 0$, it follows that $\hat{s}'(\alpha) > 0$ iff $v_1(\hat{s},\hat{x}) + \alpha v_{12}(\hat{s},\hat{x})\hat{x}'(\alpha) > 0$. Hence the first part of the Lemma. From the maximization problem for the university (see (1)), it follows by inspection that $\hat{x} = 0$ at $\alpha = 1$. Thus, $\hat{x}$ must be weakly larger for $\alpha < 1$. Therefore $\hat{x}'(\alpha) \leq 0$ *at* $\alpha = 1$.

The first term in the Lemma, v_1, represents the "tax effect" from α, while the second term, $\alpha v_{12}\hat{x}'(\alpha)$, captures the "complementarity effect" from α, operating through the university's investment decision. By inspection, in the absence of complementarities ($v_{12} = 0$), researcher investment increases in the researcher's rent share.[61] However, in the presence of complementarities ($v_{12} > 0$), and where the university's investment is increasing in the university's rent share ($\hat{x}'(\alpha) < 0$), researcher effort may actually decline in the researcher's rent share. Indeed, starting with a "professor's privilege" where the researcher has all rights to an innovation ($\alpha = 1$), the university does not invest: increasing the rent share to the university can then encourage greater university investment, and this in turn may encourage more (complementary) investment by the researcher -- even as the researcher's share of the pie is declining.

An Example that Can Motivate the Reform

A simple example can further illustrate the potentially non-monotonic relationship between a party's rent share and their equilibrium effort level. In particular, consider a CES production function

[61] Recall again that we are turning off income effects, for focus. If preferences were not linear in income, then taxing a researcher more could alternatively encourage more effort via a sufficiently strong income effect.

$$v(s,x) = [A_s s^\rho + A_x x^\rho]^{\varphi/\rho} \quad \text{(A3)}$$

with returns-to-scale parameter φ and elasticity of substitution $\sigma = \frac{1}{1-\rho}$. Equilibrium investment levels and innovative income are shown in Figure A4 as a function of the policy α for illustrative parameters.[62] We see that both researcher and university investments increase as one initially moves away from the professor's privilege. Indeed, this example is constructed to show a case where net innovation income from university-based researchers peaks at $\alpha \approx 1/3$. Thus, emphasizing complementarities in investment may provide a natural logic for reforming the "professor's privilege" in the vein of several European countries – and the similar balance between researcher and university rent shares often found in the United States today.

Of course, given that the empirical findings show a decline in the quantity and quality of both start-up activity and patenting, the candidate theoretical example in Figure A4 appears rejected by the data. Alternative examples in the income rights framework that match the findings are similarly easy to construct. For example, while the example in Figure A4 assumed that the productivity of the researcher and the university are equivalent ($A_s = A_x$), an alternative where the researcher's role is substantially more important ($A_s \gg A_x$) and the inputs are gross substitutes can push the commercialization peak to the corner solution where the professor is given full rights, as in the pre-reform regime.

Application to Tax Rates

This income rights framework can also generate an implication for the effect of taxation. Namely, the decline in α can be thought of in part as increasing the tax rate on researcher's commercialization income. The policy change (lowering α) acts both as a tax on researcher income and an incentive for complementary investments by the university which may, ceteris paribus, raise the return to the researcher's investment. The additional effect on university investment distinguishes the experiment from a narrower tax experiment on the university researcher's commercialization income. However, under the conditions of the model, the shift in α provides a lower bound on the effect of an equivalent tax.

[62] Namely, for this illustration we set $A_s = A_x = 1$ so that the inventor and university are equally productive in their investments; $\varphi = 0.5$ so that there is decreasing returns to scale; $\theta = 1$ and $r = 0.1$ so that the costs of investment are higher for the individual than the university; and $\rho = 1/3$ so that the inputs are complements but neither input is necessary for positive output.

To see this application formally, define a tax rate on earned income, $1-\tau$, so that a researcher's after tax income is

$$y=\tau(\alpha v(s,x)+G) \tag{A4}$$

Write the equilibrium commercialization effort of the individual researcher as $\hat{s}(\alpha,\tau)$. Now compare two policy regimes, a tax regime where $(\alpha,\tau)\ =\ (1,c)$ and a rent-sharing regime where $(\alpha,\tau)\ =\ (c,1)$, so that the tax rate and rent-sharing rate are of equivalent size.

Lemma. $\hat{s}(1,\tau)\leq\hat{s}(\alpha,1)$ for $\alpha=\tau$.

Proof. By the first order condition for the university researcher, $\hat{s}$ is chosen such that $\tau\alpha v_1(\hat{s},x)=\theta$. The first order condition for the "tax" case where $(\alpha,\tau)\ =\ (1,c)$ is then $cv_1\big(\hat{s}(1,c),x(1,c)\big)=\theta$. The first order condition for the "property rights allocation" case where $(\alpha,\tau)\ =\ (c,1)$ is then $cv_1\big(\hat{s}(c,1),x(c,1)\big)=\theta$. It therefore follows that

$$v_1\big(\hat{s}(1,c),x(1,c)\big)=v_1\big(\hat{s}(c,1),x(c,1)\big). \tag{A5}$$

Now note that $x(c,1)\geq x(1,c)=0$, since the university does not invest when it has no rights (see (A1)). Therefore, with $v_{12}\geq 0$ (i.e. maintaining the assumption that investments are complements), (A5) can only hold if $\hat{s}(1,c)\leq\hat{s}(c,1)$. Hence the Lemma.

Based on this reasoning, university researchers appear very sensitive to the effective tax rates on their expected income. Noting that α in the policy experiment is increased by two-thirds and that the ensuing decline in start-up and patenting rates is approximately one-half to two-thirds, the implied elasticity to an equivalent tax rate τ has a lower bound of 0.75.

Appendix II: Analysis of Publications

The end of the professor's privilege may separately affect university researchers' publication behavior. To the extent that marketplace innovation becomes less appealing, the individual university researcher may shift effort toward other activities, including basic research, teaching, or leisure. The university commercialization literature has been concerned particularly with the balance between commercialization effort and research effort, noting potential welfare tradeoffs should patenting or start-up behavior come at the expense of basic research (e.g., National Academy of Sciences 2010).

To inform this issue, we collected all Web of Science (WOS) publications with at least one Norwegian address and then matched this data, based on author name, to the NIFU database of university researchers. This approach allows us to integrate publication data and patent data for the university researchers. Further, the NIFU database incorporates demographic information about university researchers, including doctoral field, PhD cohort, age, and gender among other observables.[63]

In assessing potential tradeoffs between commercialization and research activities, a central question is whether these activities are substitutes or complements. On the one hand, viewed from the perspective of a budget constraint (in time and/or money) effort at one task may seem to detract inevitably from the other. However, to the extent that the researcher substitutes commercialization activity against leisure or other non-research activities, commercialization activity need not come at the expense of basic research. On the other hand, viewed from the perspective of the knowledge production function, innovative and basic research activities may be complements. For example, effort in creating patentable inventions may spark an individual's research insights, which in turn increases an individual's publication output (e.g., Stokes 1997, Azoulay et al. 2009).

[63] The WOS provides an author's last name and first initial only. Given the potential increased matching noise with the limited information on first name, the analysis below focuses on the sample of individuals with low frequency names in Norway. These are individuals for whom the full name (from the NIFU data) appears three or less times in Norway as a whole. In practice, this drops 20% of the matched sample. Using the full sample shows similar results.

To shed light on these issues, we first analyze whether university researchers who patent ("university inventors") tend to publish more or less than university researchers who do not patent. We find strong evidence that university inventors tend to publish substantially more papers and also more highly-cited papers. Table A2 column 1 shows that university inventors average an additional 0.67 journal publications per year. Given an average publication rate of 1.08 publications per year for university researchers, the publication rate of the inventors appears about 60% greater. Column 2 shows that the publication advantage of university inventors is robust to controlling for year, PhD cohort, university, and doctoral field fixed effects, as well as gender. The robustness to doctoral field fixed effects shows that the heightened publication activity of university inventors is not due to the differences between, say, material science and economics, but rather appears within the same field. Columns 3 and 4 reconsider publication volume counting "fractional publications", where an author receives 1/N credit for a paper, where N is the number of authors. The increased publication rate of university inventors is robust to this alternative accounting. Columns 5 and 6 consider mean citations received per publication and show that the average citation impact of university inventors' papers is substantially higher than the citation impact for other university researchers. Collectively, these findings suggest that university inventors are especially productive researchers, producing both more papers and more highly-cited papers than their non-patenting counterparts. This finding appears both across and within fields.

The greater publication output of university inventors may suggest that patenting and publication activities are complements in production (e.g., Fabrizio and Di Minin 2008, Azoulay et al. 2009, Buenstorf 2009). However, the positive correlations in Table A2 may also be driven by an individual-level effect, where some researchers are simply more productive at both tasks. Then patenting and publications may still be substitutes within a given individual. The question of whether patents and publications are complements or substitutes at the individual level is thus unclear – and remains an important question for assessing potential tradeoffs with basic research that may emerge from university commercialization policies.

The professor's privilege reform provides an opportunity to further investigate this issue by looking at how the publications within individuals respond when the incentives to patent change.[64] We again take a differences-in-difference approach, but face a limitation. Namely, publications outside universities are rare in Norway, which makes control groups outside the university context (and hence unaffected by the reform) difficult to find.[65] Nonetheless, we may proceed on a different tack, noting that patenting is sequestered within a relatively small number of disciplines within universities so that a change in patent incentives may naturally affect some university researchers far more than others. A regression approach can then study publications by asking whether a treated group, for whom patenting matters relatively strongly, changes their publication output compared to other university researchers, who would presumably be less affected by the reform.

We consider two types of analyses along these lines. First, organizing the 35 different PhD disciplines in the Norwegian data, we find 15 disciplines for which university researchers never patent between 1995 and 2010. By contrast, in the top 5 PhD disciplines by patent propensity, university researchers produce patents in 1.2% of researcher-years. Table A3 considers regressions that compare individual researchers in the top 5 patenting PhD disciplines (the treated group) with those in PhD disciplines where patenting has not occurred (the control group). The regressions include individual fixed effects which allow us to focus on within individual changes. In column 1, we first consider the tendency to patent. In line with the analysis in Section IV.B, patenting rates declines after the reform for individuals in the patent-heavy disciplines. The following columns investigate publication measures. The findings indicate that individual university researchers in patent-heavy fields do not measurably change their publication rates after the reform compared to university researchers in patent-free fields. The potential exception is that average citation impact appears to decline within individual researchers in patent-heavy fields, after the reform. The statistical significance of this finding is, however, not robust to other reasonable specifications along these lines, including those below.

[64] Note that this analysis examines the interplay of patenting and publications; entrepreneurship may show a different relationship with research output. Recall that we cannot link publications to the university entrepreneurs, because the entrepreneurship analysis uses anonymized personal identifiers in Norwegian registry datasets (i.e., we do not know the entrepreneurs' names).

[65] In particular, examining WOS publications with Norwegian authors that do not match to university researcher names, we see that these authors only publish once in ten years, on average, which is also about one-tenth the publication rate for university researchers. It is thus difficult to find a relevant non-university control group for publications in Norway.

A possible difficulty with the analysis in Table A3 is that, even in patent-heavy fields, most researchers do not patent. Therefore, any publication effects on "patent-sensitive" researchers may go undetected by mixing them together with those who have no intention to patent. An alternative approach then is to focus explicitly on university researchers with a demonstrated interest in patenting; i.e., individuals who patented before the reform. We can then ask whether these specific university inventors, upon the reform, changed their publication behavior. Table A4 considers this analysis. In columns 1-4, the control group is all other university researchers. In columns 5-8, the control group is constructed from the two nearest neighbors for each pre-reform university inventor, where the nearest neighbors share the same PhD discipline as the university inventor and have the closest average number of publications per year in the pre-period. Columns 1 and 5 consider patenting to confirm that the patenting behavior of these individual inventors drops substantially after the reform. The remaining columns, which consider publication measures as indicated in the table, show no statistically significant changes. If anything, the coefficients tend to be negative, suggesting that publications of university inventors may have relatively declined.

Together, these analyses do not indicate that an increase in publications acted as a kind of "silver lining", offsetting the decline in university-based innovation detailed in main text. On net, the publications do not appear clearly as either complements or substitutes for more applied innovative activities. A tradeoff between inventive activity and publication activity does not visibly emerge at the individual level.

Appendix III: University Inventor Survey

We conducted a survey of university inventors in our data, with two purposes. First, the survey allowed us to investigate licensing behavior and thereby inform this additional feature of commercialization. Second, the survey allowed us to gather qualitative insights from the university inventors themselves about the professor's privilege reform and thereby further inform potential mechanisms.

The survey, which was web-based, was conducted from November 2016 through January 2017. The 20 survey questions are reproduced below. We performed online searches of current university homepages to find the email addresses for 282 university inventors. Of these 282 university inventors, 63 individuals completed the survey, which gave a response rate of 22.3%.

Table A5 reports summary statistics on all relevant survey questions. The 20 survey questions themselves are included at the end of this Appendix. Below we discuss the main findings.

Licensing Activity

Licensing activity can build on the creation of the underlying intellectual property to generate potentially important channels to marketplace commercialization. In the survey, 36% of inventors with an application date prior to the reform report licensing at least once (Q7), while the post-reform fraction is 26% (Q12). Using a one-tailed t-test, we can reject at the 10% confidence level that the fraction of 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 (Q8) than for post-reform patents (Q13). With the caveat that licensing income is skewed and hence sensitive to outliers, a one-sided t-test rejects at the 10% level that mean licensing income is higher after the reform. These results are consistent with the finding in Section IV, where measures for the quality of the underlying patents dropped after the reform.

Prior to the reform, the university inventors report that the university played some role in licensing for 30% of the cases (Q9), while the corresponding number after the reform is 33% (Q15), which is only slightly larger and not significantly different. It is somewhat surprising that the universities do not contribute more regularly after the reform, given that they invest substantial resources in TTOs. On the other hand, this result is again consistent with the lower quality of patents, where the university has less to work with and does not succeed in licensing lower quality patents. This finding may also be a statistical artifact. Notably, all the post-reform inventors (40 of 40 individuals) responded on whether the university played a role but only 57% of the pre-reform inventors (27 of 47 individuals) responded to this question (see Table A5). It is unclear whether non-response is due to imperfect recall or due to it being “obvious” that the university played little or no role pre-reform. If one interprets non-response as indicating the latter, then the fraction where the university played a role pre-reform would be 17%. In this view, one could interpret the licensing survey findings as indicating that the reform did lead to an increase in university support for licensing, but licensing activity didn’t increase on net as the quantity and quality of the underlying intellectual property declines.

Mechanisms and Views of Reform

The survey also asked the researchers for their views on the reform. Two survey questions asked how the reform affected the individual’s “interest in patenting, entrepreneurship, or other commercialization activities.” To allow a quantitative categorization, the first question asked whether the reform had a positive, negative, or neutral influence (Q16). To allow more qualitative assessment and gather potential ideas about mechanisms, the next question asked for an open-ended comment on “what role the reform played” (Q17).

Of the 56 university inventors who responded to first question, 61% reported that the reform had a negative effect on their interest in commercialization activity, 27% reported no effect, and 13% reported a positive effect. While not unanimous, the respondents’ answers were therefore strongly in the direction or viewing the reform negatively.

Written comments were provided by 20 respondents as to how the reform affect their interest in commercialization activity. As seen below, the majority of comments (10 of 20) were negative, while some comments (6 of 20) were positive and a few (4 of 20) appeared neutral. The positive comments typically pointed to useful features of the TTOs, while the negative comments typically mentioned the dilution of the individual’s income rights.

Regarding the 6 positive comments, the full texts were as follows:[66]

1) "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"
2) "Better support, better integration with institutional policy, interests etc and less potential conflict of interest situations"
3) "I got support in the judicial work around patenting"
4) "The TTO established itself as an active partner which supports in commercialization. Without such support very few researchers have resources or capacity to commercialize by themselves"
5) "Without the TTO, no patent or further developments"
6) "Became more orderly and less random"

Regarding the 10 negative comments, the full texts were as follows:

7) "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"
8) "The university had nothing that added value compared to personal network. The reform became in practice a complicating factor and removed much of the incentives to commercialize as a university researcher"
9) "The university contributed little, but was entitled to a substantial income share"
10) "We experience that the university does not contribute substantially and the motivation drops when one loses two-thirds of ownership shares on startup."
11) "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 startup and must rely on other actors, who from experience do not need to have much competence on neither technology or management

[66] When given in Norwegian (the majority of cases), the comments below have been translated into English.

of startups. Furthermore a low ownership share also means limited upside. The most important feature, however, is that the entrepreneur loses control over the startup. This creates a lot of uncertainty and I would not start up a company under this model. Before the reform I started up a company and had good control over the first six years. This was critical for the substantial success it made. NTNU has a budget of about 2 billion kroner and does not need to flay entrepreneurs for several millions through the TTO. NTNU should rather be rewarded by the government ministries for having spun out a company."

12) "I, and others I know in the same situation, do what they can to avoid the university system because we think they do not have enough to offer"
13) "TTOs at the universities does not function well. Too much bureaucracy"
14) "The TTO has so far not contributed to developing patents, I work with many ideas but there is no support to perform such work in the future. The innovations get stuck in a vacuum, without being able to develop"
15) "None. I was not active as inventor back then. I was negative to the reform"
16) "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." [Authors' note: This person goes on to describe two very high-growth companies that have emerged from this person's research and inventions; to preserve anonymity, we do not present this information.]

Overall, many comments emphasize the problems of dilution for the university researchers' commercialization incentives (comments 7, 8, 9, 10, 11, and 16). Further, there are both positive comments (numbers 1, 4, and 5, and possibly 2 and 3) and negative comments (numbers 13, 14, and 16 and possibly 8 and 11) about the TTOs. Notably, several comments explicitly balance the value of the TTO's or university's contribution weighed against loss of inventor rights and all these are negative about the reform (comments 7, 8, 9, 10, 11, and 16).

Putting these qualitative results together with the econometric results in the paper, one may then imagine that TTOs can play useful roles but that that the dilution experienced by the university researcher is the major effect, leading to less effort and success at commercialization. While the survey results are only a sample of the university inventors, the reactions to the reform and licensing results appear consistent with an overall decline in the quality and quantity of new ventures and patenting documented in the paper. The emphasis on income incentives, which appears in a number of comments above (and very strongly in some) provides further qualitative support for rent-sharing perspectives discussed in the text and presented formally in Appendix I.

Addendum: Survey Questions

Each university inventor received an email with a link to an online survey, which was hosted by NSD (Norwegian Centre for Research Data). By clicking on the link, each respondent was taken to the NSD survey webpage and then guided through the following questions. Depending on the answer to any given question, the survey was coded to move to the next question as indicated in square brackets below.

1. Which language do you prefer/hvilket språk foretrekker du? (tick one box)
    a. Norwegian/norsk
    b. English/engelsk
2. Through data from Norsk Patentkontor, we have identified you as an inventor of at least one patent. Is this information correct? (tick one box)
    a. Yes [to Q3]
    b. No [to end]
3. For how many patents were you an inventor? (two digit number box)
4. Were you employed full-time at a Norwegian university at any time between 1995 and 2010? (tick one box)
    a. Yes [to Q5]
    b. No [to end]
5. Which years? (two four digit boxes)
   Start year (four digit box)
   End year (four digit box)

<u>Pre 2003 patents</u>

6. Were you an inventor on any patent with application date before 2003? (tick one box)
    a. Yes [to Q7]
    b. No [to Q11]
7. For all your patents with application date before 2003, how many licenses were issued (excluding any licenses issued to companies you own)? (tick one box)
    a. 0 [to Q9]
    b. 1 [to Q8]
8. For any patent with application date before 2003, how much income in kroner was generated from licensing in total (excluding any licenses issues to companies you own)? (eight digit box)
9. For any patent with application date before 2003, what role did the university play in finding licensees and/or negotiating licensing agreements? (tick one box)
    a. None [to Q11]
    b. Slight [to Q10]
    c. Substantial [to Q10]
10. For any patent with application date before 2003, please comment on what role the university played in your licensing activities.
    (text box)

<u>Post 2003 patents</u>

11. Were you an inventor on any patent with application date in 2003 or after? (tick one box)
    a. Yes [to Q12]
    b. No [to Q16]
12. For any patent with application date in 2003 or after, how many licenses were issued (excluding any licenses issued to companies you own)? (tick one box)
    a. 0 [to Q14]
    b. 1 or more [to Q13]
13. For any patent with application date in 2003 or after, how much income in kroner was generated from licensing in total?

(eight digit box)

14. For any patent with application date in 2003 or after, what role did the university play in finding licensees and/or negotiating licensing agreements? (tick one box)
    a. None [to Q16]
    b. Slight [to Q15]
    c. Substantial [to Q15]
15. For any patent with application date in 2003 or after, please comment on what role the university played in your licensing activities.
    (text box)

In 2003, the Norwegian Parliament abolished the so-called "Lærerunntaket" (Professor's privilege) which meant that researcher-inventors after the reform received a lower fraction of commercialization income than before, and the university more. At the same time, the reform created Technology Transfer Offices at each university, to assist in commercialization. The following four questions are about the effect of this reform.

16. Did the reform have any influence on your interest in patenting, entrepreneurship, or other commercialization activities? (tick one box)
    a. Negative effect [to Q17]
    b. No effect [to Q18]
    c. Positive effect [to Q17]
17. Please comment on what role the reform played in your interest in patenting, entrepreneurship, or other commercialization activities
    (text box)
18. Did the reform have any impact on your colleagues interest in patenting, entrepreneurship, or other commercialization activities? (tick one box)
    a. Negative effect [to Q19]
    b. No effect [to Q20]
    c. Positive effect [to Q19]
    d. I do not know [to Q20]

19. Please comment on what role the reform played in your colleagues' interest in patenting, entrepreneurship, or other commercialization activities
    (text box)
20. May we follow up by email or phone to ask further questions about your experience?
    (tick one box)
    a. Yes
    b. No

Thanks for your participation!

Appendix IV: Patent Measures

The core patent data is provided by the Norwegian Patent Office (NPO). The data includes all patents issued by the NPO where at least one inventor has a Norwegian address. The data include patents issued in Norway that were initially patented in other jurisdictions.[67] The NPO data covers all granted patents with applications in the period 1995-2010.[68] The NPO data provides each inventor's full name and address as well as the patent number and technology classification. Names are given in the Norwegian alphabet, which is important for matching correctly to the NIFU university employee database. The data further include the legal status for each patent, including whether that patent remains in force as of 2014 and, if not, the date at which the patent right lapsed. We use this information to construct the duration each patent lasted as one of our patent quality measures.

For other patent quality measures, including citations received and whether the patent received protection in other jurisdictions, we use the PATSTAT database as of spring 2015. The Norwegian patents are linked by their application identification number to the relevant patent family in PATSTAT. We use the DOCDB definition of patent family, as defined by the European Patent Office.[69] Matching each NPO patent to its patent family provides indicators for NPO patents that are also patented in any of the European Patent Office, United States Patent and Trademark Office, and/or Japanese Patent Office. For citation counts, we use citations in PATSTAT to the given patent family.

A potential challenge in the patent data is that recent patent applications have had less time to accumulate citations or be renewed. The delay between application and grant, which averages 2.7 years in the NPO over our sample period, further curtails the time period after which granted patents can be seen. For example, patent applications in the year 2010, with grants typically coming three years later, face short time windows ex-post of issuance. Given this issue, quality

[67] We thank Bjarne Kvam and the Norwegian Patent Bureau for providing this data. The NPO data includes all patents that were granted by the EPO and then registered in Norway, which became possible in Norway starting in January 2008, as well as patents applied for in any other jurisdictions, so long as the patent sought protection in Norway. Starting in 2008, 13.6% of NPO patents were granted by the EPO and then registered in Norway.
[68] These application years are those that match the data availability of the NIFU database of university employees (see text), which is what allows us to determine whether a given inventor is employed at university.
[69] The DOCDB patent family measure is constructed by EPO patent examiners; it is a standard, expert-validated patent family measure based on the principle that a patent family represents multi-jurisdictional patents that contain the same technical content.

measures based on multi-jurisdictional patenting may be favored in our analysis, as these patent families see similar filing dates and do not require substantial post-issuance windows to construct the measure.

Table 10 in the main text investigates various patent quality measures, using application year fixed effects to account for differential opportunities to accumulate citations or renew patents as time progresses. Table A6 considers further specifications to capture these dynamics in alternative ways. In addition to different construction of the quality measures, the regression specifications also consider alternatives with grant year fixed effects (to capture dynamics related to grant year, which may better capture the time window for citations and patent renewals) as well as technology class fixed effects, to account for potential differential dynamics across technology areas.

In Table A6 columns (1)-(2) we consider citations received within 5 years of application. The idea here is to create a common time window over which citations can be counted regardless of when in the sample period the patent application came. Column (1) uses application year fixed effects while column (2) further includes grant year and technology class fixed effects. We see that the coefficient is negative and quite large but not statistically significant.

Columns (3)-(4) return to the first measure in Table 10, which is a simple indicator for whether the patent is cited at least once. This indicator provides a common range of the dependent variable regardless of the application year, with time fixed effects adjusting for the larger opportunity for a citation among older patents. Column (3) adds grant year and technology class fixed effects and shows similar results in magnitude and statistical significance as Table 10 column 1. Column (4) considers the same specification but restricts the sample to patents that are granted by 2010, which provides at least a five-year window since application to observe citations after each patent. This specification shows larger effects.

Columns (5)-(8) consider alternative indicators, here considering the propensity for unusually highly-cited patents. The dependent variable is an indicator for an upper tail patent according to a given percentile citation threshold for that grant year. By construction, these measures show the same mean regardless of year of patent issuance and thus provide another approach to dealing with citation dynamics. Columns (5)-(6) use the 75^{th} percentile citation threshold and

Columns (7)-(8) use the 95th percentile citation threshold. These results also show large, negative declines in the quality measure, with statistical significance at standard levels except for column (8), which is not quite significant (p=.120).

Columns (9)-(10) further consider patent renewal measures. In column (9), the dependent variable is an indicator for the patent still being in force in the year 2015. Column (10) considers an indicator for whether the NPO patent is still in force 5 years after the patent is issued, restricting the sample to patents issued by 2010. Both measures show a large, negative difference-in-difference estimate although the results are not statistically significant.

Overall, integrating across the quality measures based on citation counts or patent renewals, we see that all tend to show large and negative coefficients. Statistical significance depends on the specification, with results typically either statistically significant at conventional measures or close to such significance thresholds. To the extent that these measures face challenges given limited time windows for later application years, one may emphasize instead the metrics based on multi-jurisdictional patenting (see main text, Section IV.B). These metrics also show large, negative effects, and typically with greater precision.

Appendix V: Further Background on the Norwegian Innovation System and TTOs

This appendix provides further institutional detail and analysis of the Norwegian innovation system, with an emphasis on leading businesses and technology areas.[70] We further provide additional detail and analysis of the Technology Transfer Offices (TTOs)

The Norwegian Innovation System

We describe here the orientation of business, patenting, startups, and research in Norway. A distinguishing feature of the Norwegian economy is a large energy sector, with about one-third of the market capitalization at Oslo Stock Exchange based on energy companies. The largest such company is Statoil with a market value of approximately $50 billion. From the 1970s onwards, numerous inventions in Norway's oil & gas sector have advanced North Sea production, and Statoil was one of the early developers and users of the horizontal drilling technology, which later revolutionized shale gas and oil production in the U.S. and elsewhere. Other leading Norwegian firms include Norsk Hydro, a global aluminum supplier with a market cap of approximately $10 billion and Yara, a chemicals firm that is the world's largest supplier of mineral fertilizer and has a market cap of around $10 billion. Other large technology companies on the Oslo Stock Exchange include Telenor (telecommunications) and the Kongsberg group (weapons technology, as well as marine navigation and systems).

Table A7 provides information on the industrial composition and firm size distribution in Norway, using 2-digit NACE codes. Distinctive sectors of the economy include oil and gas extraction and related services (NACE code 11) as well as health and social work (NACE code 85). Many sectors are dominated by large firms, defined as firms with at least 500 employees based on their consolidated accounting statements in Norway. Manufacturing sectors in which Norway is relatively prevalent includes chemicals, which is dominated by large firms, and fabricated metals and machinery, which are more balanced toward small firms. Computer and related activities occupy 2% of the workforce, with employment balanced toward smaller firms. See Table A7 for further detail.

[70] Each year, Statistics Norway publishes a broad overview of the Norwegian innovation system, see https://www.forskningsradet.no/prognett-indikatorrapporten/Indikatorrapporten_2016/1254018195927.

In the last two decades, Norway has not produced prominent, consumer-facing tech startup successes like those in Sweden (Skype, Spotify). The most successful such information technology startup in Norway is arguably Opera Software, which has a current market capitalization of approximately $600 million and has developed a multiplatform browser with hundreds of millions of users globally. Norway's venture capital investment as a percentage of GDP is above the EU average (Statistics Norway, 2015). For both university researchers and non-university PhDs, the top startup sectors are: NACE 72 (computer and related activities), NACE 73 (research and development), NACE 74 (other business activities), and NACE 85 (health and social work). In terms of notable companies that have grown substantially, prominent technology startups by university researchers have been related to offshore oil and gas services (such as logistics software and drilling analysis firms) as well as biopharma and medical device companies.

For Norway as a whole, the highest frequency technology classes are related to marine technology, communications, machine engineering, agriculture, and medicine.[71] For university patenting in Norway, the highest frequency technology classes are related to biomedicine, mining, physics instrumentation, organic chemistry, agriculture, and naval transport.[72] Looking at the Web of Science, biomedicine accounts for 49% of journal articles in Norway, which is a similarly large share of biomedical research as seen in the United States. Outside of biomedicine, the largest Web of Science research fields are Physics, Physical Chemistry; Geoscience, Geochemistry, and Geophysics; Marine and Freshwater Biology; Oceanography; Environmental Sciences; Food Science; Meterology and Atmospheric Science; Chemical Engineering; and Physics, Particles and Fields.

[71] The top 5 IPC patent classes are B63 (Ships or Other Waterborne Vessels; Related Equipment), F16 (Engineering Elements Or Units; General Measures For Producing And Maintaining Effective Functioning Of Machines Or Installations; Thermal Insulation In General); H04 (Electric Communication Technique); A01 (Agriculture; Forestry; Animal Husbandry; Hunting; Trapping; Fishing); and A61 (Medical or Veterinary Science).

[72] Among university researchers, the top 10 IPC patent classes are A61 (Medical or Veterinary Science), E21 (Earth drilling; mining), G01 (Physics: Measuring, Testing), A01 (Agriculture; Forestry; Animal Husbandry; Hunting; Trapping; Fishing), A23 (Foodstuffs, tobacco), G05 (Physics: instruments), B01 (Physical or chemical processes or apparatus), B63 (Ships or Other Waterborne Vessels; Related Equipment), C07 (Organic Chemistry), and F03 (Machines Or Engines For Liquids; Wind, Spring Weight And Miscellaneous Motors; Producing Mechanical Power; Or A Reactive Propulsive Thrust).

The Norwegian government's innovation support system is focused around Innovation Norway, which runs a number of networking, seed funding, and subsidized loan programs, with offices in all the Norwegian counties. The major innovation hubs and largest research universities are in Oslo (Univesity of Oslo), Bergen (University of Bergen), Trondheim (Norwegian University of Science and Technology), and Stavanger (University of Stavanger). Gulbrandsen and Smeby (2003) and Gulbrandsen (2003) provide examinations of industry-university linkages and Statistics Norway (2015) gives an overview of industry-public sector linkages.

Technology Transfer Offices

Upon the reform of the professor's privilege, each Norwegian university established a technology transfer office (TTO). With the exception of University of Stavanger (which was founded in 2004 through a merger of pre-existing institutions but had a TTO-like unit, Prekubator, in operation since 2002) all TTOs were founded in 2003. Most TTOs were based on precursor technology offices that were financed by the Norwegian Research Council since 1996. In this sense, the TTOs were not wholly de novo entities at the time of the reform, but rather with the reform they became substantially larger entities. As of 2005, the TTO offices typically had about ten employees, led by a director, and were partially financed by the university itself, partially by the Norwegian Research Council (FORNY program), and partially by the Ministry of Education (see Rasmussen et al. 2006 for further description).[73]

In interpreting the empirical findings, one may ask whether the TTOs did not function well. For example, upon the advent of the formal TTOs, perhaps these entities didn't start with effective teams or cultures or perhaps there will be learning by doing. To the extent that TTOs are heterogeneous across time or across universities, there may be substantial room to improve TTO functioning in the future. Related, TTO heterogeneity can also bear on representativeness of the findings outside Norway, should TTOs in other jurisdictions be more effective in some general fashion.

[73] In terms of daily commercialization activities, such as assessing ideas, contacting potential investors, and so on, the TTO offices will be running the show. In the case of startups, the TTO will approve its establishment, and may be engaged in formulating an R&D plan, IP strategy, and financing plan. There is to our knowledge no formal requirement that a TTO employee sit on the board of the startup.

While TTO quality (and variation therein) is difficult to assess conclusively, we can consider two features of our data to help inform this issue. The first observation involves time dynamics. Were TTOs initially bad but then improved with time, we may expect to see, other things equal, larger initial drops in startup and entrepreneurship activity followed by convergence back toward controls as the TTOs improve. However, looking at the start up results (Fig. 1) or patenting results (Fig. 2), it is clear visually that the gap between universities commercialization activities and the background rates are widening rather than narrowing.[74] Related, Figures A1 and A2 present regression findings by year after the reform. The point estimates, echoing the raw data in Figures 1 and 2, also suggest that the gap is widening rather than narrowing with time.

A perhaps more sensitive test for TTO heterogeneity is to examine whether specific universities reacted differently to the law change. That is, we can look for heterogeneous treatment effects across Norwegian universities as evidence that TTOs have performed differently in different settings. To implement this estimation strategy, we separate out the three largest Norwegian universities – Oslo, Bergen, and Trondheim, each of which see substantial new venture and patenting activity on their own. We then run again difference-in-difference regressions from the main text but now with indicators for each of these three universities and interactions of treated x post with these indicators. We can then look at the t-statistics for these triple interactions to see if any of these three universities had statistically different treatment effects from the overall treatment effect in Norway. Separately, we can use an F-test to test for collective differences of these university-specific treatment effects from the overall treatment effect.

Table A8 shows the results for both new ventures and patenting. Columns (1)-(2) extend core specifications from Table 3 (startups), while columns (3)-(4) extend core specifications from Table 8 (patents). For startups, examining the triple-interaction coefficients, we see no evidence that any of Oslo, Bergen, and Trondheim experience a differentially positive or negative effect compared to the background treatment effect. Nor do we see any evidence for a collective difference for these universities when examining the F-statistic p-value (see last role of table).

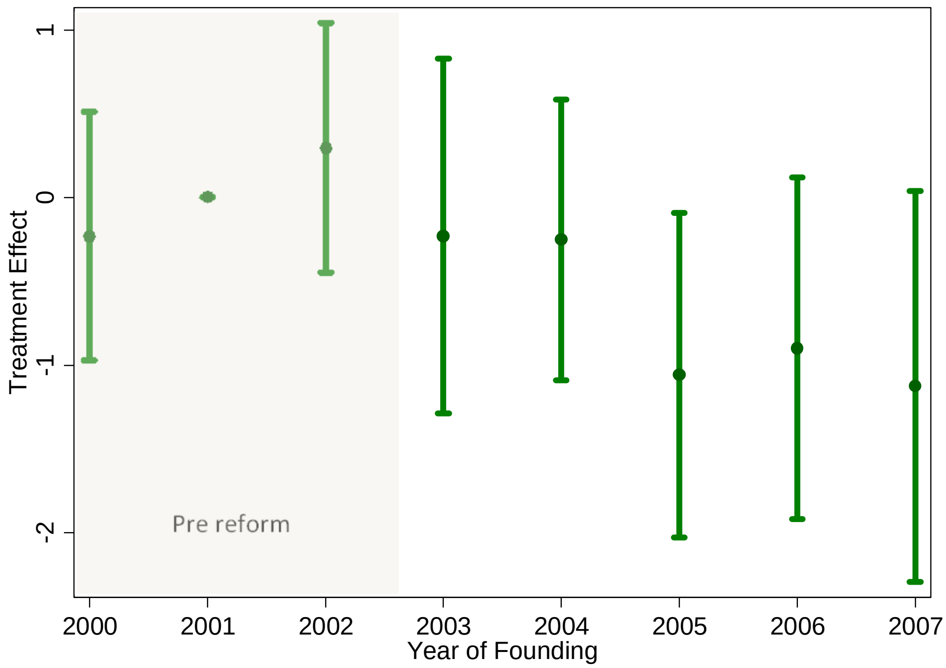
[74] The reverse dynamic is consistent with, for example, weakening in researchers' commercialization investment (e.g., due to the income rights interpretation – see Section V) coupled with TTOs having some initial advantage due to latent intellectual property (a one-shot "searching the closets" effect) or a momentum effect where individual researchers are initially completing commercialization investments they had already begun in the pre-reform period.

For patents, we see some evidence in the point estimates of column (3) that the effects were somewhat more negative in Oslo and Bergen, with marginal statistical significance for Oslo. When looking at the refined set of inventors with rarer names, for whom the individual identifiers are cleanest, the evidence for any differential effects weaken. In either specification, there is no collective significance to the treatment effects for these three universities.

Overall, we see no evidence of heterogeneous treatment effects for startups. For patents, we see at most weak evidence, limited to Oslo and itself not robust, for a differential effect. Furthermore, testing collectively for heterogeneous treatment effects among these large universities shows no statistical significance. This evidence, in tandem with the dynamic pattern, thus provides little evidence for interpretations based on differential TTO quality, to the extent one would expect the TTOs to either improve over time or differ substantially across institutions. That said, it is possible that TTOs in Norway improve beyond the horizon of our data or will do so in the future. Regarding heterogeneous treatment effects, one caveat is that universities are very much public sector in Norway, and the universities have similar governance structure and bylaws. Although there were some differences in how the reform was implemented, these differences may be relatively small (Gulbrandsen et al. 2006). Notably, Trondheim's institutional setup was somewhat different, and we see no differential treatment effect for Trondheim, but more generally the institutional setting in Norway may have limited potential for differences across TTOs.[75]

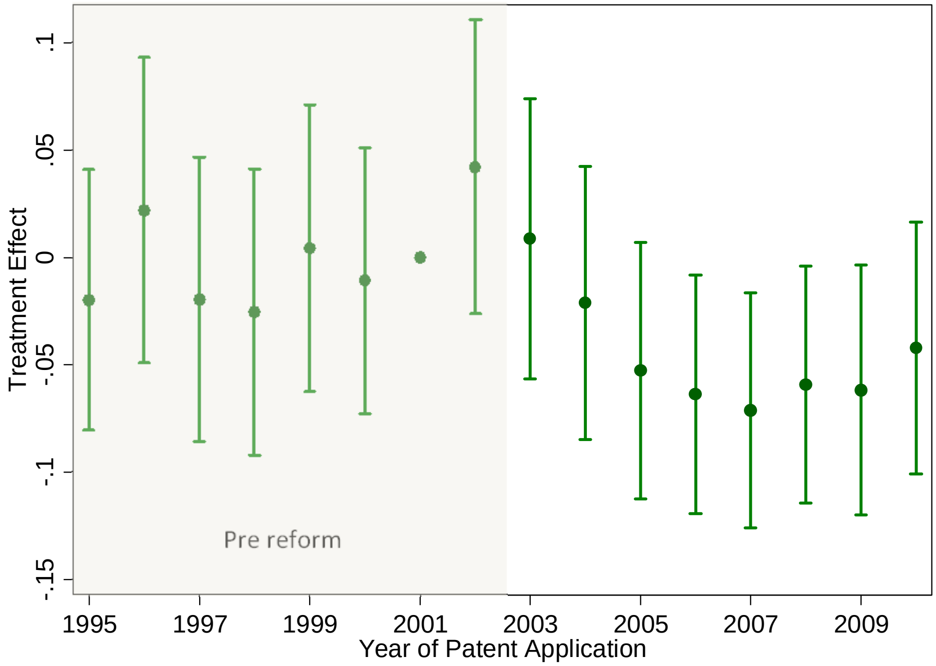
[75] The differences were to a large degree concerning the role division between the university and the TTO. For example, the University of Trondheim (NTNU) keeps the control and ownership rights of commercialization, while the other universities to a larger extent transfer the rights to the TTO (Rasmussen et al, 2006). The TTOs are at any extent controlled by the universities, so these differences are unlikely to play a large role for the incentives of the individual researcher.

Figure A1: Startup Treatment Effects by Year, Individual Level Analysis



Notes: The regression is at the individual level panel as in Table 5. We analyze a balanced panel of Norwegian PhDs over the 2000-20007 period, with interactions between treatment status and year for each founding year. Estimates are logit, with 95% confidence intervals shown. We visualize the 0 baseline using 2001 (two years prior to the reform) to better allow visualization of any potential racing to start firms in the year prior to reform.

Figure A2: Patent Treatment Effects by Year, Individual Level Analysis



Notes: The regression is at the individual level as in Table 8, now with interactions between treatment status and year for each application year. Estimates are the linear probability model, with 95% confidence intervals shown. We visualize the 0 baseline using 2001 (two years prior to the reform) to better allow visualization of any potential racing to start firms in the year prior to reform, for which there is some evidence in the patenting case.

Figure A3: Researcher Utility Maximization and Effort at Commercial Innovation

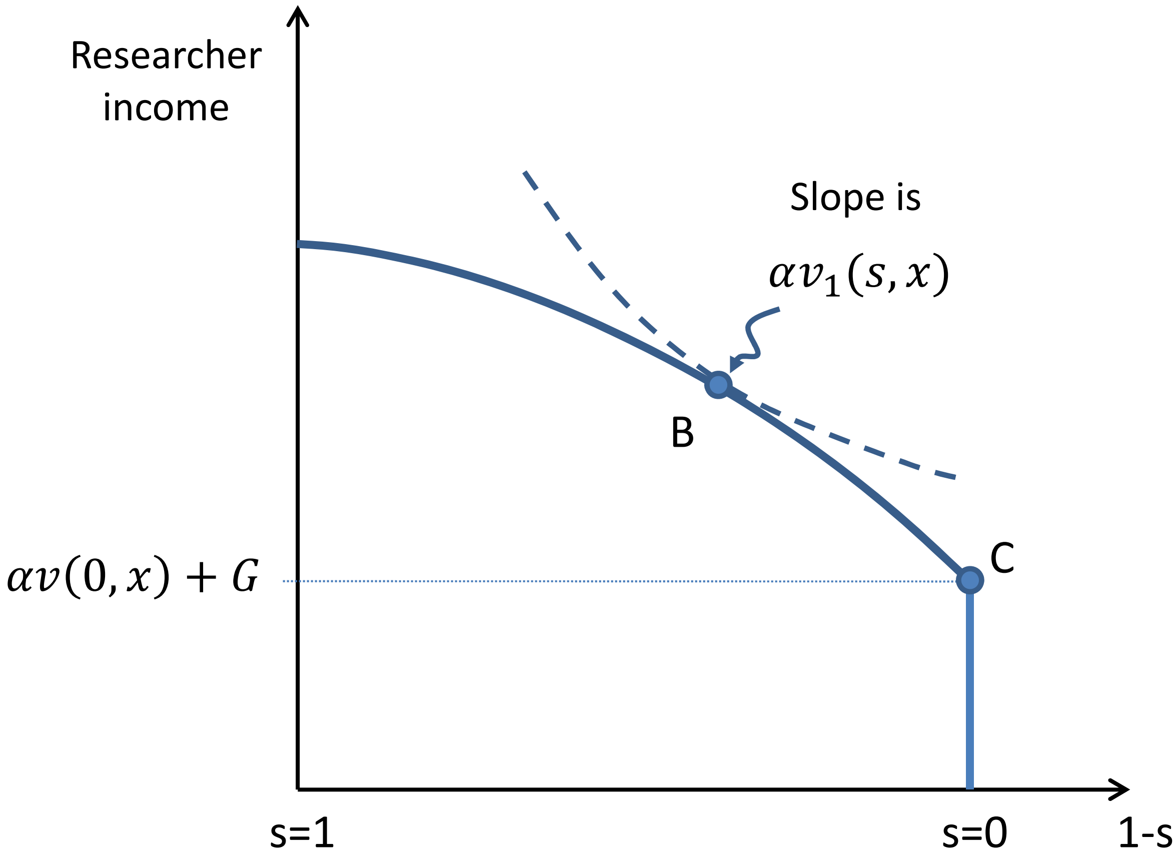
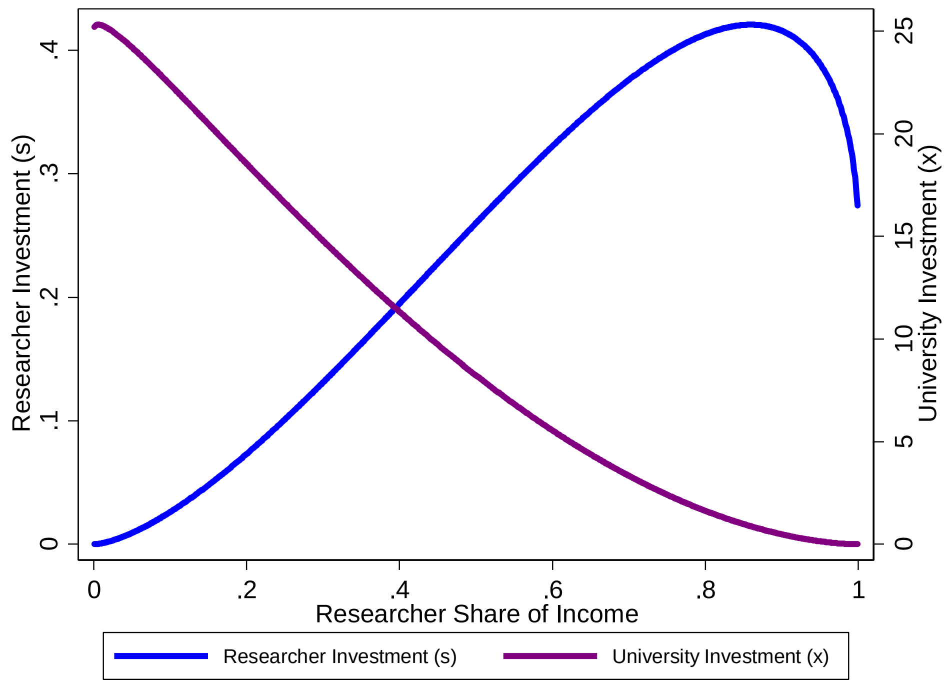
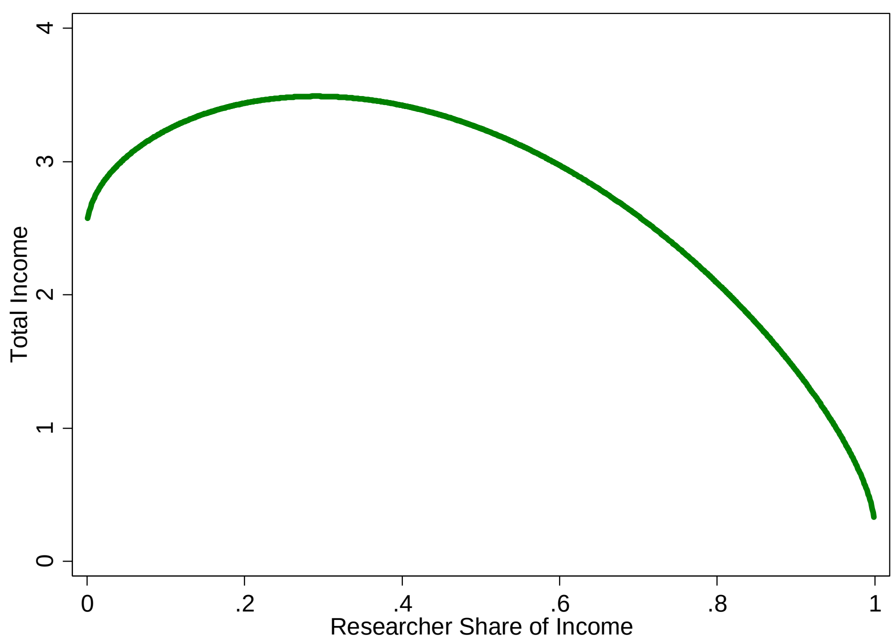


Figure A4: Investment and Innovation as Function of Researcher Rent Share (α)

CES Example





Notes: Example is CES (see equation (A3)). Parameters are $A_s = A_x = 1$, $\varphi = 0.5$, $\theta = 1$, $r = 0.1$, and $\rho = 1/3$.

Table A1: Exit Rates of Technical PhDs after the Reform

	(1) Exit	(2) Exit	(3) Exit
Treated x Post	-0.00989	-0.00815	-0.0303
	(0.00719)	(0.00834)	(0.0425)
Treated	0.00455	--	--
	(0.00656)		
Post	0.000700	--	--
	(0.00452)		
Observations	21,302	21,302	8,289
R-squared	0.000	0.272	0.257
Year FE	NO	YES	YES
Individual FE	NO	YES	YES
Age FE	NO	YES	YES
Sociodemographic controls	NO	YES	YES
Sample	University Phds	University Phds	Technical Phds

Notes: In columns (1)-(2), the sample consists of Phds employed at a university in 2000. The treated group are those with a science and engineering Phd and the control group are those with a non-technical Phd. The dependent variable, exit, equals 1 if the individual leaves the university sector in that year and zero if not. The mean of the dependent variable indicates a 5% probability of exit from (all) university employment each year. In column (3) the treated group are university science and engineering Phds who start a company in the pre-reform period, and the control group are university science and engineering Phds who do not start up a firm in the pre-reform period. Results are for the linear probability model, Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

Table A2: The Publication Output of University Inventors

	(1) Publications	(2) Publications	(3) Fractional Publications	(4) Fractional Publications	(5) Mean Citations	(6) Mean Citations
University Inventor	0.668***	0.487***	0.177***	0.131***	3.317***	1.945**
	(0.188)	(0.185)	(0.051)	(0.051)	(0.976)	(0.979)
Doctoral Field FE	No	Yes	No	Yes	No	Yes
PhD Year FE	No	Yes	No	Yes	No	Yes
Year FE	No	Yes	No	Yes	No	Yes
University FE	No	Yes	No	Yes	No	Yes
Gender	No	Yes	No	Yes	No	Yes
R^2	0.00	0.08	0.07	0.00	0.05	0.04
Obs	49,640	49,640	49,640	49,640	49,640	49,640

Notes: Regressions are OLS. Observations are individual name by year. The sample mean of the dependent variables are 1.08 (publications), 0.30 (fractional publications), and 6.06 (mean citations). Doctoral field fixed effects account for differences between 35 different fields. The sample is limited to university researchers with rare names, though using entire sample produces similar results. Standard errors clustered by individual (* p<0.1; ** p<0.05; *** p<0.01).

Table A3: The Change in Publication Output within Individuals - Patent-Heavy vs. Patent-Free Research Disciplines

	(1) Patents	(2) Publications	(3) Fractional Publications	(4) Mean Citations
Patent-Heavy x Post	-0.006**	0.025	-0.034	-1.971***
	(0.003)	(0.107)	(0.024)	(0.657)
Individual FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R^2	0.25	0.00	0.64	0.00
Obs	17,329	17,329	17,329	17,329

Notes: Regressions are OLS. The patent-heavy and post terms are absorbed by the individual and year fixed effects, respectively. Patent-heavy fields are the top 5 (of 35) PhD disciplines by patent propensity on a per-person and per-year basis. Patent-free fields are the 15 (of 35) PhD disciplines with zero patents by university researchers from 1995-2010. Observations are individual name by year. The sample is limited to university researchers with rare names, though using the entire sample produces similar results. Standard errors clustered by individual (* p<0.1; ** p<0.05; *** p<0.01).

Table A4: The Change in Publication Output within Individuals - University Inventors vs. Non-Inventors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Control Group: All Other University Researchers				Control Group: Nearest Neighbors			
	Patents	Publications	Fractional Publications	Mean Citations	Patents	Publications	Fractional Publications	Mean Citations
Inventor x Post	-0.120***	-0.122	-0.073	-1.774	-0.123***	-0.177	-0.050	0.583
	(0.018)	(0.194)	(0.057)	(1.414)	(0.018)	(0.275)	(0.073)	(1.982)
Indiv FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.26	0.75	0.64	0.32	0.23	0.77	0.61	0.35
Obs	49,640	49,640	49,640	49,640	3,694	3,694	3,694	3,694

Notes: Regressions are OLS. The inventor and post terms are absorbed by the individual and year fixed effects, respectively. Inventors are those university researchers who patented prior to the reform. In columns (1)-(4) the control group is all other university researchers. In columns (5)-(8) the control group are the two nearest neighbors to the inventor based on pre-reform publication rates, conditional on being in the same PhD field. Observations are individual name by year. The sample is limited to university researchers with rare names, though using the entire sample produces similar results. Standard errors clustered by individual (* p<0.1; ** p<0.05; *** p<0.01).

Table A5: Results from Survey of University Inventors

	(1) mean	(2) sd	(3) p50	(4) min	(5) max	(6) N
Q3. Number of patents between 1995 and 2010	4.46	6.10	3	1	40	63
Q5. Start year university	1,997	3.95	1,995	1,986	2,008	64
Q5. End year university	2,009	3.26	2,010	1,999	2,017	64
Q6. Inventor on any patent with application date before 2003. Fraction yes	0.80	0.41	1	0	1	59
Q7. At least one license on patents with application date before 2003	0.36	0.49	0	0	1	44
Q8. NOK in patenting income on patents with application date before 2003	423,438	1.25e+06	0	0	5.00e+06	16
Q9. University played at least some role on patents with application before 2003	0.30	0.47	0	0	1	27
Q11. Inventor on any patent with application date 2003 or after. Fraction yes	0.71	0.46	1	0	1	56
Q12. At least one license on patents with application date 2003 or after	0.23	0.42	0	0	1	40
Q13. NOK in patenting income on patents with application date 2003 or after	2,222	6,667	0	0	20,000	9
Q14. University played at least some role on patents with application 2003 or after	0.33	0.47	0	0	1	40
Q16. No effect on individual	0.61	0.49	1	0	1	56
Q16. Negative effect on individual	0.27	0.45	0	0	1	56
Q16. Positive effect on individual	0.13	0.33	0	0	1	56
Q18. Reform had no effect on colleagues	0.18	0.39	0	0	1	56
Q18. Reform had negative effect on colleagues	0.18	0.39	0	0	1	56
Q18. Reform had positive effect on colleagues	0.071	0.26	0	0	1	56
Q18. Reform had unknown effect on colleagues	0.57	0.50	1	0	1	56

Notes: The table reports summary statistics of a survey sent to university researchers that were inventors between 1995 and 2000. The survey was sent out by email and had a response rate of 22%. The survey did not require respondents to answer each question; the number of respondents for each question is given in column (6). For those that reported that they licensed a patent but did not report licensing income we imputed a zero income (6 respondents pre-reform and 4 respondents post-reform).

Table A6: Additional Patent Quality Specifications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Cites Within 5 Years	Cites Within 5 Years	Cited at Least Once	Cited at Least Once	Upper 75th Cites	Upper 75th Cites	Upper 95th Cites	Upper 95th Cites	In Force Patent	Renew for 5+ Years
Treated x Post	-0.320	-0.169	-0.078*	-0.135**	-0.108**	-0.074*	-0.053**	-0.039	-0.062	-0.047
	(0.223)	(0.212)	(0.047)	(0.055)	(0.046)	(0.044)	(0.027)	(0.025)	(0.042)	(0.045)
Treated	0.469**	0.310**	0.082***	0.086***	0.137***	0.099***	0.066***	0.046**	0.024	0.031
	(0.154)	(0.141)	(0.030)	(0.031)	(0.032)	(0.031)	(0.021)	(0.020)	(0.031)	(0.028)
Application Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grant Year FE	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Technology Class FE	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Sample	Full	Full	Full	Granted by 2010	Full	Full	Full	Full	Full	Granted by 2010
Estimator	Poisson	Poisson	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
R^2	.	.	0.06	0.04	0.02	0.07	0.01	0.07	0.26	0.20
Obs	7,162	7,162	7,339	6,075	7,341	7,339	7,341	7,339	7,339	6,038

Notes: The table reports additional patent quality measures for citation counts and patent renewals. See discussion in Appendix IV.

Table A7: Norwegian Firm Size Distributions by 2-Digit NACE Industry

Industry		Firm Size Distribution by number of employees			Share of Work-force	Industry		Firm Size Distribution by number of employees			Share of Work-force
Code	Name	Small	Med.	Large		Code	Name	Small	Med.	Large	
1	Agriculture, hunting and related service activities	0.59	0.33	0.08	0.00	40	Electricity, gas, steam and hot water supply	0.05	0.10	0.84	0.01
2	Forestry, logging and related service activities	0.53	0.13	0.34	0.00	41	Collection, purification and distribution of water	0.27	0.17	0.56	0.00
5	Fishing, operation of fish hatcheries and fish farms service activities incidental to fishing	0.57	0.29	0.15	0.01	45	Construction	0.53	0.32	0.15	0.08
11	Extraction of crude petroleum and natural gas service activities incidental to oil and gas extraction,	0.01	0.01	0.98	0.04	50	Sale, maintenance and repair of motor vehicles and motorcycles retail sale of automotive fuel	0.63	0.29	0.08	0.03
13	Mining of metal ores	0.02	0.00	0.98	0.00	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles	0.47	0.22	0.31	0.06
14	Other mining and quarrying	0.42	0.19	0.39	0.00	52	Retail trade, except of motor vehicles and motorcycles repair of personal and household goods	0.47	0.19	0.33	0.11
15	Manufacture of food products and beverages	0.14	0.22	0.64	0.03	55	Hotels and restaurants	0.45	0.37	0.18	0.04
17	Manufacture of textiles	0.33	0.30	0.37	0.00	60	Land transport transport via pipelines	0.31	0.16	0.53	0.03
18	Manufacture of wearing apparel dressing and dyeing of fur	0.40	0.60	0.00	0.00	61	Water transport	0.10	0.08	0.82	0.02
19	Tanning and dressing of leather manufacture of luggage, handbags, saddlery, harness and footwear	0.82	0.18	0.00	0.00	62	Air transport	0.06	0.10	0.85	0.00
20	Manufacture of wood and of products of wood and cork, except furniture manufacture of articles of	0.36	0.31	0.33	0.01	63	Supporting and auxiliary transport activities activities of travel agencies	0.27	0.17	0.56	0.02
21	Manufacture of pulp, paper and paper products	0.03	0.03	0.93	0.01	64	Post and telecommunications	0.25	0.32	0.43	0.00
22	Publishing, printing and reproduction of recorded media	0.29	0.14	0.57	0.02	65	Financial intermediation, except insurance and pension funding	0.04	0.14	0.82	0.02
24	Manufacture of chemicals and chemical products	0.05	0.05	0.89	0.01	66	Insurance and pension funding, except compulsory social security	0.03	0.02	0.94	0.01
25	Manufacture of rubber and plastic products	0.34	0.39	0.26	0.00	67	Activities auxiliary to financial intermediation	0.39	0.16	0.45	0.00
26	Manufacture of other non-metallic mineral products	0.28	0.22	0.50	0.00	70	Real estate activities	0.61	0.18	0.21	0.02
27	Manufacture of basic metals	0.07	0.08	0.85	0.00	71	Renting of machinery and equipment without operator and of personal and household goods	0.50	0.14	0.35	0.00
28	Manufacture of fabricated	0.39	0.40	0.21	0.01	72	Computer and related	0.45	0.26	0.30	0.02

	metal products, except machinery and equipment						activities				
29	Manufacture of machinery and equipment n.e.c.	0.34	0.23	0.43	0.01	73	Research and development	0.05	0.09	0.86	0.01
30	Manufacture of office machinery and computers	0.26	0.12	0.62	0.00	74	Other business activities	0.45	0.17	0.38	0.09
31	Manufacture of electrical machinery and apparatus n.e.c.	0.32	0.21	0.47	0.00	75	Public administration and defence compulsory social security	0.04	0.15	0.81	0.00
32	Manufacture of radio, television and communication equipment and apparatus	0.14	0.36	0.50	0.00	80	Education	0.32	0.31	0.37	0.01
33	Manufacture of medical, precision and optical instruments, watches and clocks	0.34	0.24	0.42	0.00	85	Health and social work	0.07	0.05	0.88	0.16
34	Manufacture of motor vehicles, trailers and semi-trailers	0.20	0.33	0.47	0.00	90	Sewage and refuse disposal, sanitation and similar activities	0.37	0.36	0.27	0.00
35	Manufacture of other transport equipment	0.16	0.22	0.63	0.01	91	Activities of membership organizations n.e.c.	0.05	0.09	0.86	0.02
36	Manufacture of furniture manufacturing n.e.c.	0.30	0.23	0.47	0.01	92	Recreational, cultural and sporting activities	0.25	0.13	0.62	0.02
37	Recycling	0.42	0.58	0.00	0.00	93	Other service activities	0.64	0.28	0.08	0.01

Notes: For each NACE industry code, the firm size distribution indicates the employment-weighted share of firms in the NACE code that are small, medium, or large, where small is defined as firms with 15 or less employees, large is defined as firms with 500 or more employees, and medium is defined as firms in between these other two categories. For each NACE industry code, the last column (share of workforce) is the employment share of that 2-digit NACE code among all full time workers in Norway.

Table A8: TTO Heterogeneity

	(1)	(2)	(3)	(4)
	Startups, All Workers	Startups, Entrepreneurs Only	Patents, All Inventors	Patents, Rare Names
Treated x Post x Oslo	0.000746	0.0116	-0.055*	-0.050
	(0.00252)	(0.0805)	(0.031)	(0.043)
Treated x Post x Bergen	-0.000973	-0.0269	-0.036	0.007
	(0.00291)	(0.0864)	(0.038)	(0.056)
Treated x Post x Trondheim	-0.00274	0.0312	-0.005	0.003
	(0.00337)	(0.0717)	(0.028)	(0.040)
Treated x Post	-0.00402**	-0.141***	-0.027	-0.028
	(0.00180)	(0.0528)	(0.019)	(0.033)
Oslo	-9.23e-05	0.0212	0.021	-0.012
	(0.00275)	(0.101)	(0.031)	(0.042)
Bergen	0.000195	-0.0166	0.024	0.003
	(0.00238)	(0.126)	(0.037)	(0.058)
Trondheim	0.000450	-0.0144	0.022	0.019
	(0.00261)	(0.0782)	(0.026)	(0.035)
Treated	0.000299	0.00332	0.028	0.039
	(0.00223)	(0.0673)	(0.019)	(0.029)
Year FE	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
R^2	0.164	0.029	0.002	0.002
Obs	19,937,044	535,039	108,752	75,008
F-Test, p-value	0.751	0.916	0.287	0.449

Notes: These panel regressions follow the individual-level specifications in Tables 3 and 8 of the main text. For the startup regressions, the dependent variable is an indicator for whether the individual started a company that year. For the patent regressions, the dependent variable is an indicator for whether the individual patented at least once that year. Estimates are the linear probability model. The F-test tests the joint significance of Treated x Post x Oslo, Treated x Post x Bergen, and Treated x Post x Trondheim. Standard errors clustered by individual. (* p<0.1; ** p<0.05; *** p<0.01)