

University Innovation and the Professor's Privilege^{*}

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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. Finally, we integrated 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 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 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. 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.

This paper is organized as follows. Section II details the institutional setting, reviews relevant literature, and discusses theoretical advantages and problems 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 of the paper. Section V discusses these findings, including their relevance to broader settings, and Section VI concludes.²

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

² In addition, 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.

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., Krinsky 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. In Appendix II, we examine publications in the context of our data and confirm a positive correlation between patenting and publications at the individual level. We further examine publication output within individual researchers, harnessing the reform as a shock to patenting incentives, and find no evidence that publications and patents are substitute activities. See Appendix II.

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 policy makers 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 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

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>.

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). 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

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 pre-reform 100 kroner in commercialization profits 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.

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.

B. Theoretical Perspectives

Several theoretical perspectives could be used to 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 core perspectives in the economics of innovation to better understand the motivations and pitfalls associated with the policy change. The richness of these theories suggests the importance of empirical analysis. The empirical analysis in turn can help limit the set of relevant mechanisms, as we will further discuss in Section V.

Fundamentally, 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 parties. A broad intuition in these theories is that rights should be balanced toward the party whose investment matters more.⁹

A natural mapping to the university-based innovation context is the rights allocation between the researcher and the research institution, where 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, noting potentially substantial costs in time and money to achieve a patent (e.g., Hall 2007, Gans et al. 2008), it can be natural for such costs to limit entry, and university researchers report that they do (e.g., 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

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).

intermediaries in markets for technology and improve the quality of innovative outcomes (e.g., Macho-Stadler et al. 2007).

The professor's privilege reform most directly acts to reallocate income rights. To the extent that investments by both parties matter, 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 model and example. An interesting insight is that strengthening the university's income share (at the expense of the researcher's share) can actually cause the researcher to invest more. This follows when the university's investment raises the marginal product of the researcher investment (i.e., the investments are complements), so that the researcher finds investment more worthwhile even though the researcher's share of the innovation income has declined.

This income rights reasoning, as a potential *a priori* justification for the reform, can also point out potential pitfalls. In particular, one may be skeptical about the value of university-level investments. Some scholars argue that university technology transfer offices (TTOs) have poor capabilities or inappropriate incentives and suggest reallocating rights toward the faculty in pursuit of greater technology transfer (Litan 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 promote innovation (see also Appendix I). In practice, the appropriate income rights allocation in the university context remains unknown.

Looking more closely at researcher interests, the professor's privilege reform might also be motivated in a belief that university researchers may 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 and disinterestedness 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

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.

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, noting that the university gained decision-making authority over knowledge-related assets. Such control rights may matter to the extent that 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 & Merces 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

The patenting analysis is based on separate data collected from several sources. 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).¹² There are 11,905 unique university researchers in this data. In addition to full names, this dataset contains sociodemographic information such as gender, age, and PhD type, as well as the specific university employer. From the Norwegian Patent Office (NPO) we obtained a list of all Norwegian patents issued to inventors in Norway from 1990-2014.¹³ We then matched the names from NIFU with the inventor names in the patent data to determine which patents had university inventors. These matches are based on employment at the university at the time of the

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.

¹² The NIFU list of university researchers is biannual for 1995-2006 and annual for 2007-2010.

¹³ These Norwegian patents include patents that were granted by the European Patent Office and then waived in by the Norwegian Patent Office.

patent application. 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 matched all the NPO patents with the European Patent Office's PATSTAT database, to determine the number of citations each Norwegian patent receives.¹⁴

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.¹⁵ University PhD startups tend to be somewhat smaller in employees, sales, and profits than non-university start-ups, with a closer match to non-university PhD startups.¹⁶ 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.¹⁷ 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.¹⁸

¹⁴ We are indebted to Stefano Breschi for help in matching the NPO and EPO data.

¹⁵ Non-surviving firms are defined as those that stop reporting profits or whose sales fall below 50 thousand NOK after their first year.

¹⁶ 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.

¹⁷ 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).

¹⁸ See Guzman and Stern (2015a, 2015b) for analysis of the rarity of high-growth entrepreneurship in the U.S. and in the environs of U.S. universities.

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.¹⁹

Table 1C provides summary statistics for patents. We see that 431 university researchers produced 750 patents over the 1995-2010 period. 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. Note that we otherwise have little information about the demographics of the Norwegian inventors, as the inventor data (which gives full names) does not link to the Norwegian census data (which uses anonymized identification numbers).

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 period from 2000-2007. 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:

¹⁹ 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.

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

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”. We start by looking simply at the pre-post difference for university start-up rates and patent counts, before introducing control groups (start-up and patenting behavior in Norway more generally) and using the difference-in-difference specification in (1).

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:²⁰

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

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.²¹ While the non-university startup rate is approximately constant across years, the university startup rate drops dramatically from

²⁰ 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.

²¹ The vertical axes in Figure 3 and related figures in the paper begin at 0 so that the percentage changes in the data being compared can be seen visually.

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.

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., $1 - e^{-1.102}$) 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.

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.²² Columns (5) and (6) examine the log start-up count as the dependent variable, and shows broadly similar results using either control group. 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. The difference-in-difference drop in university start-up rates is now 45%.

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.²³ 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.²⁴ 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

²² 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.

²³ 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.

²⁴ 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.

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.²⁵

In Table 1A we see that a small minority of Norwegian entrepreneurs have advanced degrees, especially PhDs. Table 4 thus presents further individual-level analysis, using control samples of workers who share increasingly similar observable characteristics to university researchers. Column (1) of Table 4 limits the control group to those with at least a Master's degree and shows large declines in 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 and more precise effects than before with the linear probability model. 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

²⁵ To see this magnitude, consider that the mean of the dependent variable in columns (1)-(3) is 0.00389 of Table 3. 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.

comparing university and non-university PhDs would be biased against finding effects, i.e., conservatively. 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.²⁶ 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.

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

²⁶ 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.

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.

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 start-up firms and the patenting behavior 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 avoiding upper tail outliers that can otherwise influence the results.²⁷ The threshold for an upper quartile start-up is 3.3 million NOK in sales and 3 employees at an age of 5 years.²⁸ 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

²⁷ 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.

²⁸ 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).

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.”²⁹ 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.³⁰ 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 researchers, with similar size effects using either control group.³¹ 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.³² 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

²⁹ The Eurostat sectoral classifications by technological-intensity can be found at: http://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an2.pdf.

³⁰ Startups in “computer and related activities” (NACE code 72) were frequent in the early 2000s in Norway, as they were elsewhere.

³¹ 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.

³² These further analyses follow those in Tables 3 and 4. Results are available from the authors upon request.

for university start-ups generally, indicating that these university technology startups fell proportionately more on average, although this excess decline is not statistically significant.³³

Lastly, we collected the incorporation documents for all university start-ups to search for patents by these young firms. In particular, we searched the Norwegian Patent Office database for patents where the start-up was listed as either the applicant or the assignee. We found that, among startups by university researchers founded prior to the reform, 12% obtained a patent within five years of founding. Among university startups founded after the reform, only 2% percent obtained a patent within this window. This decline is significant at the 1% level using a simple t-test.

Overall, integrating across performance measures based on accounting data, technology-intensity of the sector, or patenting, these results indicate that start-up performance 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.³⁴

³³ 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).

³⁴ These analyses are available from the authors upon request.

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.

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.³⁵

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.³⁶ We see that the non-university patent rate rises 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

³⁵ 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).

³⁶ We define a patent as a university patent if at least one inventor on the patent matches with a university researcher.

period. Figure 2B considers the same data on a per-worker basis for the relevant groups.³⁷ 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, 1.61% of university researchers applied for a patent in a given year prior to the reform, while 0.75% of university researchers applied for patents per year after the reform, for a 53% drop in the per-worker rate. By contrast, the broader Norwegian workforce averaged 0.0176% patents per year prior to the reform and 0.0152% after the reform, for a 14% drop in the per-worker rate. Together, these figures show a sharp drop in patenting by university researchers that is coincident with the professor's privilege reform.

Table 7 considers regression results, looking at changes in log annual patent counts per year and log annual patent counts per worker. Columns (1) and (2) show that the log number of university patents declines relative to non-university patents. The first column includes a dummy to indicate the post period while the second column includes application year fixed effects to better capture the background dynamics seen in Figure 2. The $Treat_i \times Post_t$ coefficient indicates a 20% decline in patenting by universities. Column (3) repeats the analysis for patents per-worker. Consistent with the larger visual difference-in-difference in Figure 2B, the $Treat_i \times Post_t$ coefficient now indicates a 48% decline in the patenting rate per university worker, compared to the background per-worker rate. Column (4) considers the number of unique inventors per employed worker and finds similarly large declines.

The last two 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.³⁸ This analysis can help account for compositional changes in the technologies receiving patents. Column (5) uses the log patent count as the dependent variable in OLS, while column (6) presents a Poisson count model. We see that these technology-class level analyses and the aggregate count analyses in columns (1) and (2) show similar results.

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

³⁷ For non-university inventors, this normalization is the number of non-university patents divided by the size of the non-university Norwegian workforce.

³⁸ 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.

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.³⁹ 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). Column (4) provides a robustness check by reducing 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 analysis of Table 5, columns (1) and (2) consider “pre-period university researchers”, those individuals employed at universities from 2000-2002, and then tracks patenting by these individuals regardless of whether they remain in university employ. Columns (3) and (4) focus instead on “stayers”, examining whether the patenting decline appears among those who are consistently employed at university in the post period.⁴⁰ 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.

³⁹ 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.

⁴⁰ To match the start-up analysis, we define stayers 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). These results are available upon request.

The Quality of Patenting

Table 10 considers changes in the quality of patenting using a standard proxy measure, the number of citations that a patent receives (Trajtenberg 1990, Hall et al. 2005). 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. The dependent variable is the count of citations each patent has received through 2014 using the PATSTAT database. Given the presence of count data, we consider a Poisson model, negative binomial model, and for comparison OLS in columns (1) through (3), respectively. Application year fixed effects are included to capture non-linearities in the flow of citation counts over time.⁴¹ The final columns further consider the propensity for unusually highly-cited patents, where the dependent variable is an indicator for an upper tail patent according to a given citation threshold. Columns (4)-(6) use the 75th, 90th, and 99th citation thresholds respectively.⁴²

Across specifications, we see a robust decline in citations received by university patents. Using either the Poisson or negative binomial model, there is an approximate 25% decline in citations received per patent. As shown by the OLS model, this change represents an average loss of 2.2 patent citations. Studying upper-tail patents, the final three columns further show large declines in the propensity for university researchers to produce such patents, after the reform.

Interestingly, the treated coefficient in all specifications indicates that, prior to the reform, university patents were more highly cited than non-university patents. The reform acts to largely offset this advantage (compare the *Treated* × *Post* coefficients with the *Treated* coefficients), so that university patents went from being extraordinary to ordinary in their citations.

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-

⁴¹ Patenting later in the period provides less time to be cited, leading to the usual pattern of declining observed citations in more recent application years. Application year fixed effects help account for this dynamic. An alternative approach is to only include citations that come within N years after publication of the focal patent, and end the sample N years prior to 2014. In this approach, citations are only considered when they come within a common length of time. This alternative approach, for various N, yields similar results to those shown in Table 10 (results available from authors upon request).

⁴² The thresholds are determined, by application year, examining the citation distribution across all issued NPO patents with the given application year.

ups. The patent rate per worker falls by approximately 50%, 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, citations received per patent also declined for university patents after the reform. 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 findings 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%, and Norway is 9%) 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%).⁴³ 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.⁴⁴ 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.

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. (2015) study patenting in Germany and find that university researchers patented

⁴³ 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. also appears less than that in the professor's privilege countries, when the policy was in place.

⁴⁴ Lach and Shankerman (2008) study licensing income across universities, a type of data not available in our context (changes in licensing income cannot be easily observed since Norwegian universities did not track licensing income under the professor's privilege regime). Our context looks upstream of licensing income to the patenting itself. The drop in the quantity and quality of patenting after the reform suggests that the pipeline for licensing is substantially diminished.

less after the professor's privilege was eliminated. The decline among university researchers is greater than the decline among researchers in public research organizations that were not affected by the reform, although a puzzling feature in the German case is that the decline in patenting for both groups appears to start 5 years prior to the reform and there is little change in the rate of decline around the reform year (2002) *per se*. 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 other evidence. While the effect of the professor's privilege is difficult to identify using cross-sectional data, and analyses of new ventures are especially few, the existing evidence indicates that professor's privilege countries have tended to see greater rates of commercialization activity by academics, often by similar 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.⁴⁵

Additionally, the effects of a system-wide change may be quite different from the effects of a policy change at a single university.⁴⁶ Thus the results in this paper may generalize more

⁴⁵ 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. Separately, one may make arguments about the relative organizational efficiency of universities, depending on their governance. That said, 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.

⁴⁶ 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 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.

naturally to public university systems, like those in Europe. Second, given that the Norwegian TTOs were born with the 2003 reform, one may imagine that they are not as effective as more experienced TTOs and that their performance might improve with time. That said, there is no 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. 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 a tradeoff between invention and research when comparing across individuals.

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

matched researchers who did not patent in the pre-reform period. While noisy, point estimates suggest if anything a decline in publication outputs after the reform within individuals. 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 creativity 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

For both new ventures and patenting, we find large declines in quantity after the reform. Additional metrics suggest that quality also declined. These findings appear to reject, in our context, several specific mechanisms as driving forces for understanding the results, especially regarding the roles that TTOs may play. First, TTOs might arguably lower the 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. Third, TTOs might through commercialization expertise and/or reputational functions promote higher quality inventions and new ventures (e.g., Macho-Stadler et al. 2007). However, the tendency for quality measures to also decline does not point to an effective TTO function in this regard, 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 the problem of university researcher incentives, and how these 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 and also provides canonical perspectives in studies of innovation (Holmstrom 1982, Grossman and Hart 1986, Aghion and Tirole 1994, Green and Scotchmer 1995, Hellmann 2007). The professor's privilege reform is a large shock to the rights regime.

One key element of the reform is the shock to income rights. Recognizing the potential importance of investments by both the university researcher and the university itself, one can motivate a royalty sharing regime that favors balancing rights across parties rather than giving all royalties to one party, as under the professor's privilege. Appendix I studies these tradeoffs formally and shows circumstances under which the one-third / two-third split, which is prevalent in many countries today, could be (second-best) optimal.⁴⁷ The basic presumption here is that university-level investments are important and cannot be easily replicated by the university researcher. 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.⁴⁸ 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). The empirical analysis in this paper appears broadly consistent with this perspective.

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

⁴⁷ 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.

⁴⁸ 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).

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.

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 expected income is associated with an approximate fifty percent decline in innovative output, for a lower bound tax elasticity of 0.75.

It may also be, however, that university interests and actions create greater commercialization obstacles for the university researcher, rather than providing support. 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. It is difficult in our context to separate control rights effects from income rights effects, although some considerations suggest that control rights may not be the key mechanisms at work here. Ex-post of our empirical analysis, we conducted telephone interviews with the directors of the TTOs at the three largest Norwegian universities.⁴⁹ 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

⁴⁹ These universities are the University of Oslo, the University of Bergen, and the Norwegian University of Science and Technology in Trondheim.

consistent with other literature (e.g., Jensen and Thursby 2001).⁵⁰ The formal contractual incompleteness challenges may also be mitigated here given the ongoing, multi-agent nature of the university's relationships with its researchers, suggesting that relational contracts may limit hold-up problems (Levin 2002). Lastly, to the extent that transaction cost problems would materialize as up-front "haggling costs" between researchers and universities, one might expect that the loss of control rights would (like a fixed cost) cause the quantity of innovative activity to decline but the quality to go up, as only the most worthwhile projects ex-ante would be attempted. The empirical fact that both quantity and quality decline would then reject this view.⁵¹

More generally, and integrating across potential theories, the policy experiment indicates that these university researchers appear very sensitive to their inventive rights. 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

⁵⁰ We also find, consistent with this qualitative view, that university researchers are CEOs of their start-ups at a stable rate (about 40% of cases) before and after the professor's privilege reform. These results are available from the authors on request.

⁵¹ Our findings instead appear consistent with theories emphasizing the decline of commercialization effort by university researchers, leading to a worsening quality distribution of their innovations. With a worsening quality distribution and a fixed cost of commercialization, fewer ideas will be started (the quantity effect). Conditional on commercialization, the average quality would also decline.

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 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. This finding raises 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 in Europe and the potential for formal experimentation in the rights regimes employed by universities are key areas for future research.

References

Aghion, Philippe and Jean Tirole, “The Management of Innovation,” *Quarterly Journal of Economics*, 109, No. 4 (1994), 1185-1209.

Association of University Technology Managers, “Highlights of AUTM’s U.S. Licensing Activity Survey FY2014,” autmvisitors.net/sites/default/files/documents/FY2014%20Highlights.pdf, accessed: January 2016.

Astebro, Thomas, Serguey Braguinsky, Pontus Braunerhjelm, and Anders Brostrom, “Bayh-Dole versus the Professor’s Privilege,” mimeo, HEC Paris, 2015.

Azoulay, Pierre, Waverly Ding, and Toby Stuart. “The Effect of Academic Patenting on the Rate, Quality, and Direction of (Public) Research Output,” *Journal of Industrial Economics*, 57, No. 4 (2009), 637-676.

Baldini, Nicola, “University Patenting: Patterns of Faculty Motivations,” *Technology Analysis and Strategic Management*, 23, (2011), 103-121.

Buenstorf, Guido, “Is Commercialization Good or Bad for Science? Individual-level Evidence from the Max Planck Society,” *Research Policy*, 38, no. 2 (2009), 281-292.

Bruce, Donald and Tami Gurley, “Taxes and Entrepreneurial Activity: An Empirical Investigation Using Longitudinal Tax Return Data,” *Small Business Research Summary*, No. 252 (2005), 1-51.

- Czarnitzki, Dirk, Katrin Hussinger, and Cédric Schneider, “Commercializing Academic Research: The Quality of Faculty Patenting,” *Industrial and Corporate Change*, 20, (2011), 1403-1437.
- Czarnitzki, Dirk, Thorsten Doherr, Katrin Hussinger, Paula Schliessler, and Andrew A. Toole, “Individual versus Institutional Ownership of University-discovered Inventions,” ZEW Discussion paper, no. 15-007 (2015).
- Debackere, Koenraad, and Reinhilde Veugelers, “The role of academic technology transfer organizations in improving industry science links,” *Research Policy*, 34, (2005), 321-342.
- Evans, David S. and Linda S. Leighton, “Some Empirical Aspects of Entrepreneurship,” *American Economic Review*, 79, no. 3 (1989), 519-535.
- Fabrizio, Kira, and Alberto Di Minin, “Commercializing the laboratory: Faculty patenting and the open science environment,” *Research Policy*, 37, (2008), 914–931.
- Gans, Joshua S. and Scott Stern, “The Product Market and the Market for ‘Ideas’: Commercialization Strategies for Technology Entrepreneurs,” *Research Policy*, 32 (2003), 333-350.
- Gans, Joshua, David H. Hsu, and Scott Stern, “The Impact of Uncertain Intellectual Property Rights on the Market for Ideas: Evidence from Patent Grant Delays,” *Management Science*, 54, (2008), 982-997.
- Gentry, William M. and R. Glenn Hubbard, “Tax Policy and Entrepreneurial Entry,” *American Economic Review*, 90, no. 2 (2000), 283-287.
- Geuna, Aldo and Federica Rossi, “Changes to University IPR Regulations in Europe and the Impact on Academic Patenting,” *Research Policy*, 40 (2011), 1068-1076.
- Glaeser, Edward L., “Entrepreneurship and The City,” NBER Working Paper No. 13551 (2007).
- Green, Jerry R. and Suzanne Scotchmer, “On the Division of Profit in Sequential Innovation,” *RAND Journal of Economics*, 26, no. 1 (1995), 20-33.
- Grimaldi, Rosa, Martin Kenney, Donald S. Siegel and, Mike Wright, “30 Years after Bayh-Dole: Reassessing Academic Entrepreneurship,” *Research Policy*, 40 (2011), 1045-1057.
- Grossman, Sanford and Hart, Oliver, “The Costs and Benefits of Ownership: A Theory of Lateral and Vertical Integration’, *Journal of Political Economy*, 94, (1986), 691-719.
- Guzman, Jorge, and Scott Stern, “Where is Silicon Valley?” *Science*, 347 (2015a), 606-609.
- Guzman, Jorge, and Scott Stern, “Nowcasting and Placecasting Entrepreneurial Quality and Performance” NBER Working Paper No. 20954 (2015b).

Hall, Bronwyn H., Adam Jaffe, and Manuel Trajtenberg, "Market Value and Patent Citations." *RAND Journal of Economics* 36, no. 1 (2005), 16-38.

Hall, Bronwyn, "Patents and Patent Policy," *Oxford Review of Economic Policy*, 23, (2007), 1–20.

Hamilton, Barton H., "Does Entrepreneurship Pay? An Empirical Analysis of the Returns to Self-Employment," *Journal of Political Economy*, 108, no. 3 (2000), 604-631.

Hellmann, Thomas, "When Do Employees Become Entrepreneurs?" *Management Science*, 53, no. 6, (2007), 919-933.

Holmstrom, Bengt, "Moral Hazard in Teams," *Bell Journal of Economics*, 13, no. 2, (1982), 324-340.

Holtz-Eakin, Douglas, David Joulfaian, and Harvey S. Rosen, "Entrepreneurial Decisions and Liquidity Constraints," *NBER Working Paper No. 4526*, 1993.

Hurst, Erik and Annamaria Lusardi, "Liquidity Constraints, Household Wealth, and Entrepreneurship," *Journal of Political Economy*, 112, no. 2 (2004), 319-347.

Iversen, Eric J., Magnus Gulbrandsen, and Antje Klitkou, "A Baseline for the Impact of Academic Patenting Legislation in Norway," *Scientometrics*, 70, no. 2 (2007), 393-414.

Jensen, Richard and Marie Thursby, "Proofs and Prototypes for Sale: The Licensing of University Inventions," *American Economic Review*, 91, no. 1 (2001), 240-259.

Kenney, Martin and Donald Patton, "Reconsidering the Bayh-Dole Act and the Current University Invention Ownership Model," *Research Policy*, 38 (2009), 1407-1422.

Krimsky, Sheldon, 2003, *Science in the Private Interest: Has the Lure of Profits Corrupted Biomedical Research?* Rowman & Littlefield, Lanham, Maryland, 2003.

Lacetera, Nicola, "Academic Entrepreneurship," *Managerial and Decision Economics*, 30 (2009), 443-464.

Lach, Saul and Mark Schankerman, "Incentives and Invention in Universities," *RAND Journal of Economics*, 39, no. 2 (2008), 403-433.

Lerner, Josh and Ulrike Malmendier, "Contractibility and the Design of Research Agreements," *American Economic Review*, 100, no. 1 (2010), 214-246.

_____, and Robert P. Merges, "The Control of Technology Alliances: An Empirical Analysis of the Biotechnology Industry," *Journal of Industrial Economics*, 46, no. 2 (1998), 125-156.

- Levin, Jonathan, "Multilateral contracting and the employment relationship," *Quarterly Journal of Economics*, (2002), 1075-1103.
- Levine, Ross and Yona Rubinstein, "Smart and Illicit: Who Becomes an Entrepreneur and Does it Pay?" NBER Working Paper No. 19276 (2013).
- Lindh, Thomas and Henry Ohlsson, "Self-Employment and Windfall Gains: Evidence from the Swedish Lottery," *Economic Journal*, 106, no. 439 (1996), 1515-1526.
- Lissoni, Francesco, Patrick Llerena, Maureen McKelvey and Bulat Sanditov, "Academic Patenting in Europe: New Evidence from the KEINS Database," *Research Evaluation*, 17, no. 2 (2008), 87-102.
- Litan, Robert, Lesa Mitchell, and E.J. Reedy, "The University as Innovator: Bumps in the Road," *Issues in Science and Technology*, 23, (2007), 57-66.
- Lockett, Andy, Donald Siegel, Mike Wright, and Michael D. Ensley, "The Creation of Spin-off Firms at Public Research Institutions: Managerial and Policy Implications," *Research Policy*, 34, no. 7 (2005), 981-993.
- Macho-Stadler, Ines, David Pérez-Castrillo and Reinhilde Veugelers, "Licensing of university inventions: The role of a technology transfer office," *International Journal of Industrial Organization*, 25, (2007) 483–510.
- Merrill, Stephen and Anne-Marie Mazza (editors), *Managing University Intellectual Property in the Public Interest*, Committee on Management of University Intellectual Property, National Research Council, National Academies Press: Washington DC, 2010.
- Merton, Robert K., "Priorities in Scientific Discovery: A Chapter in the Sociology of Science." *American Sociological Review*, 22 no. 6 (1957), 635-659.
- _____, *The Sociology of Science: Theoretical and Empirical Investigation*. Chicago, IL: University of Chicago Press, 1973.
- Mowery, David C., Richard R. Nelson, Bhaven N. Sampat, and Arvids A. Ziedonis, "The Growth of Patenting and Licensing by U.S. Universities: An Assessment of the Effects of the Bayh-Dole Act of 1980," *Research Policy*, 30 (2001), 99-119.
- Mowery, David, and Bhaven Sampat, "The Bayh-Dole Act of 1980 and University-Industry Technology Transfer: A Model for Other OECD Governments?" *Journal of Technology Transfer*, 30, (2005), 115–127.
- Murray, Fiona, and Scott Stern, "Do formal intellectual property rights hinder the free flow of scientific knowledge? An empirical test of the anti-commons hypothesis," *Journal of Economic Behavior and Organization*, 63 (2007) 648–687.

- O'Shea, Rory P., Thomas J. Allen, Arnaud Chevalier, and Frank Roche, "Entrepreneurial Orientation, Technology Transfer and Spinoff Performance of U.S. Universities," *Research Policy*, 34 (2005), 994-1009.
- Rasmussen, Einar, Øystein Moen, and Magnus Gulbrandsen, "Initiatives to Promote Commercialization of University Knowledge," *Technovation*, 26 (2006) 518-533.
- Rothaermel, Frank T. Shanti D. Agung, and Lin Jiang, "University Entrepreneurship: A Taxonomy of the Literature," *Industrial and Corporate Change*, 16, no. 4 (2007), 691-791.
- Sampat, Bhaven N., "Patenting and US Academic Research in the 20th Century: The World Before and After Bayh-Dole," *Research Policy*, 35 (2006), 772-789.
- Sauermann, Henry and Michael Roach, "Taste for Science, Taste for Commercialization, and Hybrid Scientists," Mimeo, Druid Society, DRUID 2012.
- Scotchmer, Suzanne, *Innovation and Incentives*, MIT Press: Cambridge, MA, 2004.
- Shane, Scott A., *Academic Entrepreneurship: University Spinoffs and Wealth Creation*, Glos, UK: Edward Elgar Publishing, 2004a.
- _____, "Encouraging University Entrepreneurship? The Effect of the Bayh-Dole Act on University Patenting in the United States," *Journal of Business Venturing*, 19 (2004b), 127-151.
- _____, Edwin A. Locke, and Christopher J. Collins, "Entrepreneurial Motivation," *Human Resource Management Review*, 13 (2003), 257-279.
- Stern, Scott, "Do Scientists Pay to Be Scientists?" *Management Science*, 50, no. 6 (2004), 835-853.
- Stokes, Donald. *Pasteur's Quadrant: Basic Science and Technological Innovation*, The Brookings Institution, Washington, D.C., 1997.
- Thursby, Jerry G. and Marie C. Thursby, "University Licensing and the Bayh-Dole Act," *Science*, 301 (2003), 1052.
- Toole, Andrew A. and Dirk Czarnitzki, "Biomedical Academic Entrepreneurship Through the SBIR Program," *Journal of Economic Behavior & Organization*, 63 (2007), 716-738.
- Trajtenberg, Manuel, "A Penny for Your Quotes: Patent Citations and the Value of Innovations," *RAND Journal of Economics*, 21, no. 1 (1990), 172-187.
- Washburn, Jennifer. *University Inc.: The Corporate Corruption of Higher Education*, New York: Basic Books, 2008.

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

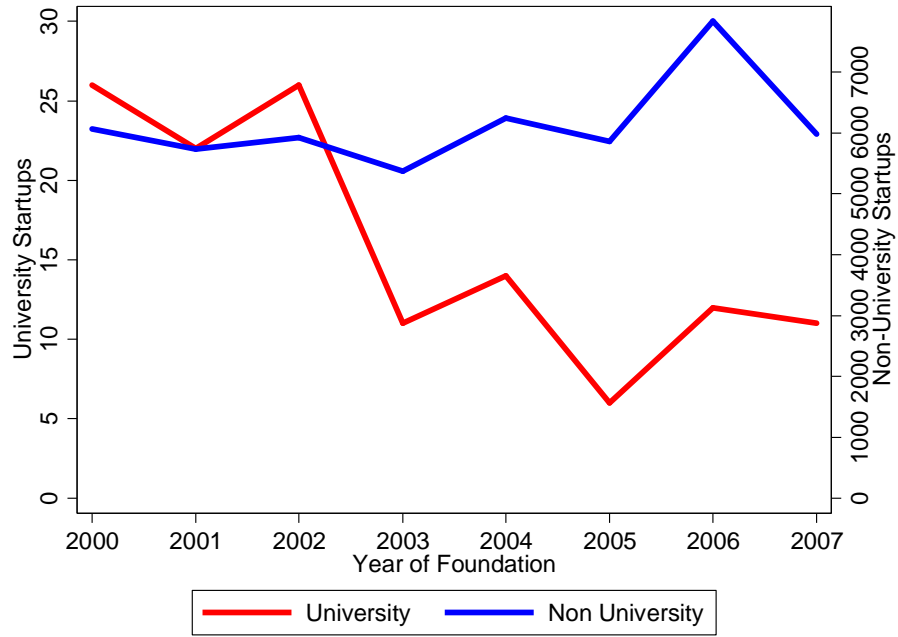


Figure 1B: University vs. Non-university Startups, per Worker

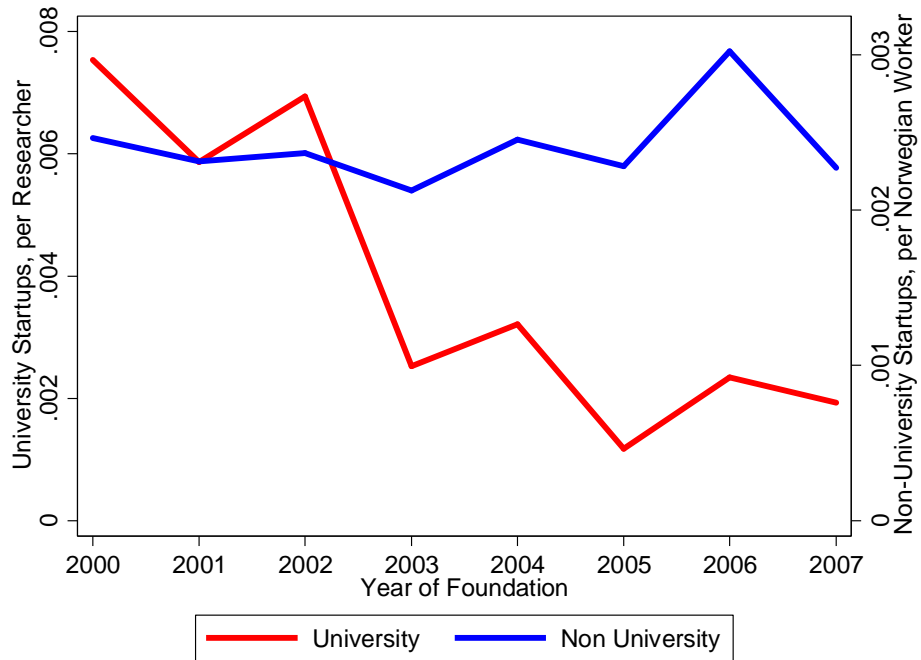


Figure 2A: University Patents vs. Non-university Patents

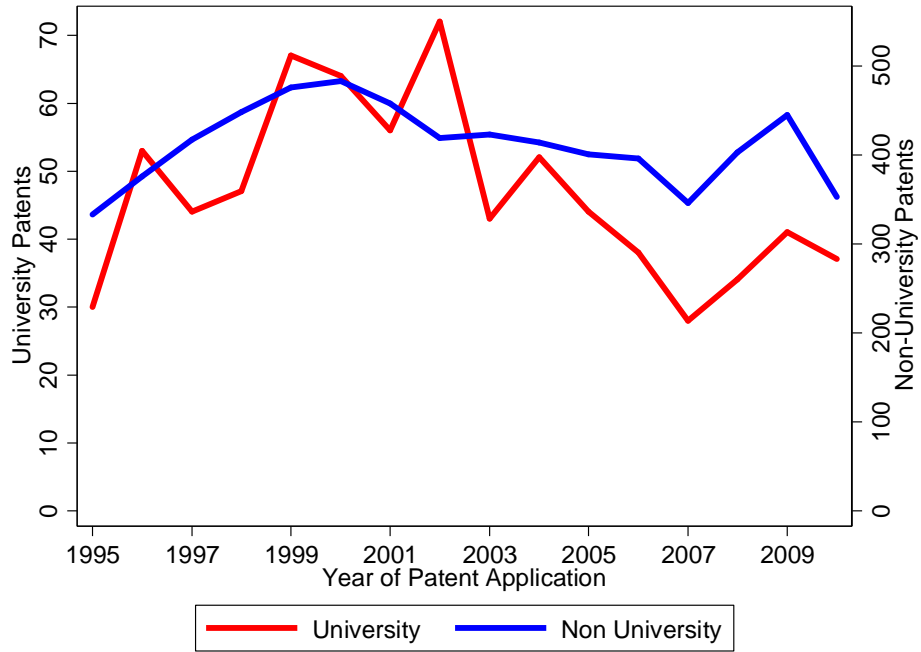


Figure 2B: University Patents vs. Non-university Patents, per Worker

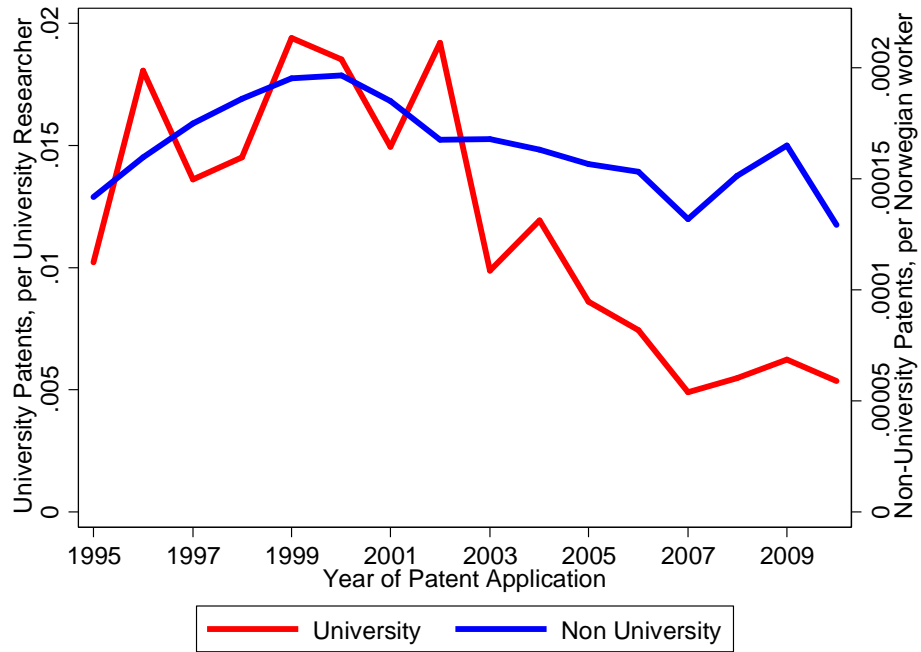


Table 1A: Summary Statistics for Start-Up Firms in Norway, 2000-2007

| | | 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 |
| | Mean (St Dev) | 5,160 (13,282) | 2,308 (4,777) | 2,659 (9,934) |
| Sales at 5 years | Median | 1,751 | 628 | 183 |
| | 75 th ptile | 4,834 | 2,210 | 1,550 |
| | 95 th ptile | 20,769 | 10,815 | 9,374 |
| | Mean (St Dev) | 3.31 (7.77) | 1.68 (3.16) | 1.22 (2.89) |
| Employees at 5 years | Median | 1 | 1 | 0 |
| | 75 th ptile | 4 | 2 | 1 |
| | 95 th ptile | 13 | 7 | 5 |
| | Mean (St Dev) | 198 (554) | 220 (599) | 100 (600) |
| Profits at 5 years | 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 | 7,341 | 750 |
| Number of Unique Inventors | 6,890 | 431 |
| Percentage Male, workforce | 50.4% | 65.9% |
| Percentage Male, Inventors | 94.3%* | 92.8% |
| Period | 1995-2010 | 1995-2010 |

Notes: *Male percentage for all inventors is estimated using gender for common names in Norway. (Other gender calculations are not estimates; gender for university sample is given directly by NIFU database and for Norwegian workforce from census data.)

Table 2: Startups, Aggregate and Sector Level Analysis

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|-----------------------------|-------------------------------------|-------------------------------------|-----------------------------------|----------------------------------|-------------------------------------|-------------------------------|-------------------------------|
| | Aggregate | | | | Sector | | |
| | Log Startups | Log Startups Per Worker | Log Startups | Log Startups Per Worker | Log Startups | Log Startups | Startups |
| Treated x Post | -0.912*** (0.172) | -1.102*** (0.179) | -0.603** (0.232) | -0.667** (0.242) | -0.504* (0.265) | -0.431* (0.224) | -0.591*** (0.206) |
| Treated | -5.477*** (0.0546) | 1.167*** (0.0614) | -0.961*** (0.110) | -0.998 (0.128) | -5.214*** (0.229) | -1.450*** (0.250) | -0.969*** (0.103) |
| Post | 0.0517 (0.0671) | 0.0163 (0.0650) | -0.258 (0.170) | -0.478** (0.113) | -- | -- | -- |
| Year FE | -- | -- | -- | -- | Yes | Yes | Yes |
| Sector FE | -- | -- | -- | -- | Yes | Yes | Yes |
| Control Sample Period | Norwegian Workforce 2000-2007 | Norwegian Workforce 2000-2007 | PhD workforce 2000- 2007 | PhD workforce 2000-2007 | Norwegian Workforce 2000-2007 | PhD workforce 2000-2007 | PhD workforce 2000-2007 |
| Model | OLS | OLS | OLS | OLS | OLS | OLS | Poisson |
| Observations | 16 | 16 | 16 | 16 | 120 | 108 | 160 |
| R-squared | 0.997 | 0.849 | 0.909 | 0.800 | 0.97 | 0.78 | -- |

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 columns (5)-(7), 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*** (0.000974) | -0.00457*** (0.00110) | -0.00431*** (0.00111) | -0.131*** (0.0283) | -0.114*** (0.0285) |
| Treated | 0.00358*** (0.000914) | 0.000343 (0.00156) | -0.000142 (0.00160) | -0.000436 (0.0440) | -0.0136 (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) | (2) | (3) | (4) | (5) | (6) | (7) |
|----------------------------------|--------------------------|-----------------------|------------------------|------------------------------|--------------------------|--------------------------|-----------------------|
| | Masters or more | Ph.D. | Ph.D. Logit | Ph.D. Propensity Score Match | Ph.D. Entrepreneurs only | Ph.D. Entrepreneurs only | Ph.D. Earned pre 2000 |
| Treated x Post | -0.00339*** (0.00114) | -0.00231 (0.00143) | -0.00177*** (0.199) | -0.00382** (0.00190) | -0.0865*** (0.0284) | -0.0878*** (0.0288) | -0.0028* (0.0015) |
| Treated | -0.00072 (0.00165) | -0.00135 (0.00190) | -0.00006 (0.0005) | -0.00142 (0.00267) | 0.0478** (0.01999) | 0.0474** (0.0200) | -0.0011 (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 All | University Researchers Ph.D. | Ph.D., Logit | All | Stayers Ph.D. | Ph.D., Logit |
| Treated x Post | -0.00495*** (0.00130) | -0.00302* (0.00165) | -0.00240*** (0.000616) | -0.00502*** (0.00138) | -0.00305* (0.00173) | -0.00248*** (0.000625) |
| Treated | -- | -- | 0.000134 (0.000722) | -- | -- | 0.000134 (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) | (2) | (3) | (4) | (5) | (6) |
|-------------------|-----------|------------|----------|-------------|-------------|-------------|
| | Sales | Employees | Assets | Sales | Employees | 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) | (2) | (3) | (4) |
|----------------|------------------------|---------------------|------------------------|------------------------|
| | Log Startups | Log Startups | Log Startups | Log Startups |
| Treated x Post | -0.727** (0.322) | -0.277 (0.391) | -1.239*** (0.352) | -1.245* (0.632) |
| Treated | -4.046*** (0.263) | -0.484* (0.243) | -3.201*** (0.265) | 0.520 (0.434) |
| Post | -0.252* (0.117) | -0.701** (0.251) | -0.0305 (0.0809) | -0.0240 (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) |
|---------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| | Aggregate | | | Technology | | |
| | Log Patents | Log Patents | Log Patents per Worker | Log Inventors per Worker | Log Patents | Patents |
| Treated x Post | -0.228* (0.131) | -0.228** (0.089) | -0.647*** (0.111) | -0.728*** (0.208) | -0.257* (0.137) | -0.242*** (0.057) |
| Treated | -2.089*** (0.110) | -2.089*** (0.073) | 4.499*** (0.063) | 7.614*** (0.099) | -2.060*** (0.103) | -2.064*** (0.173) |
| Post | -0.066 (0.054) | -- | -- | -- | -- | -- |
| Application Year FE | NO | YES | YES | YES | YES | YES |
| Tech Class FE | -- | -- | -- | -- | YES | YES |
| Control Sample | 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 |
| Observations | 32 | 32 | 32 | 32 | 236 | 256 |
| R-squared | 0.98 | 0.99 | 0.99 | 0.99 | 0.87 | -- |
| Period | 1995-2010 | 1995-2010 | 1995-2010 | 1995-2010 | 1995-2010 | 1995-2010 |

Notes: In columns (1)-(4), observations consider aggregate patent counts for the treatment and control groups, by year. In columns (1)-(2) we consider log annual patent counts, while columns (3)-(4) consider log 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 (5)-(6), 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, which allows incorporation of zero counts. Robust standard errors in parentheses, except column (6) which clusters 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*** (0.011) | -0.044*** (0.011) | -0.045*** (0.011) | -0.037** (0.016) |
| Treated | 0.049*** (0.009) | 0.048*** (0.009) | 0.042*** (0.012) | 0.040** (0.017) |
| Post | -0.006*** (0.002) | -- | -- | 0.017*** |
| 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*** (0.012) | -0.045*** (0.012) | -0.047*** (0.015) | -0.046*** (0.015) |
| Treated | 0.047*** (0.009) | -- | 0.049*** (0.012) | -- |
| Post | -0.005** (0.002) | -- | -0.005** (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, Citations Received

| | (1) | (2) | (3) | (4) | (5) | (6) |
|------------------------|---------------------|----------------------|---------------------|--|--|--|
| | Citation Count | Citation Count | Citation Count | 75 th percentile patent | 90 th percentile patent | 99 th percentile patent |
| Treated x Post | -0.250* (0.152) | -0.292** (0.149) | -2.245** (0.900) | -0.474*** (0.178) | -0.386* (0.231) | -1.574* (0.810) |
| Treated | 0.341*** (0.099) | 0.348*** (0.098) | 2.516*** (0.827) | 0.527*** (0.107) | 0.533*** (0.144) | 1.022*** (0.355) |
| Application Year FE | YES | YES | YES | YES | YES | YES |
| Regression Model | Poisson | Negative binomial | OLS | Logit | Logit | Logit |
| R ² | -- | -- | 0.04 | -- | -- | -- |
| Obs | 7,162 | 7,162 | 7,162 | 6,831 | 7,162 | 7,162 |

Notes: In columns (1)-(3) the dependent variable is the count of citations received by each patent. Columns (4)-(6) examine the propensity to produce unusually highly-cited patents. The dependent variable in these columns is an indicator equal to 1 if the patent receives citations at or above the indicated threshold. 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

$$\hat{x} = \operatorname{argmax}_x [(1 - \alpha)v(s, x) - rx] \quad (\text{A1})$$

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

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

The researcher earns $\alpha v(s, x) + G$, where G represents the individual's academic salary or other non-commercialization income.⁵² The disutility of commercialization effort (i.e. the loss of time for basic research, leisure, or other activities) is given by θs .⁵³

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”.⁵⁴ 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 A.1) 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 A.1). 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

⁵² 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.

⁵³ 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.

⁵⁴ 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 $v_1(\hat{s}, \hat{x}) + \alpha v_{12}(\hat{s}, \hat{x})\hat{x}'(\alpha) > 0$. Moreover, 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.⁵⁵ 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

⁵⁵ 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 A.2 as a function of the policy α for illustrative parameters.⁵⁶ 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 A.2 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 A.2 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.

⁵⁶ 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

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

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 $c v_1(\hat{s}(1, c), x(1, c)) = \theta$. The first order condition for the “property rights allocation” case where $(\alpha, \tau) = (c, 1)$ is then $c v_1(\hat{s}(c, 1), x(c, 1)) = \theta$. It therefore follows that

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

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.⁵⁷

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).

⁵⁷ 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. In any case, 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 A.1 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 A.1 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.⁵⁸ 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.⁵⁹ 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 A.2 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.

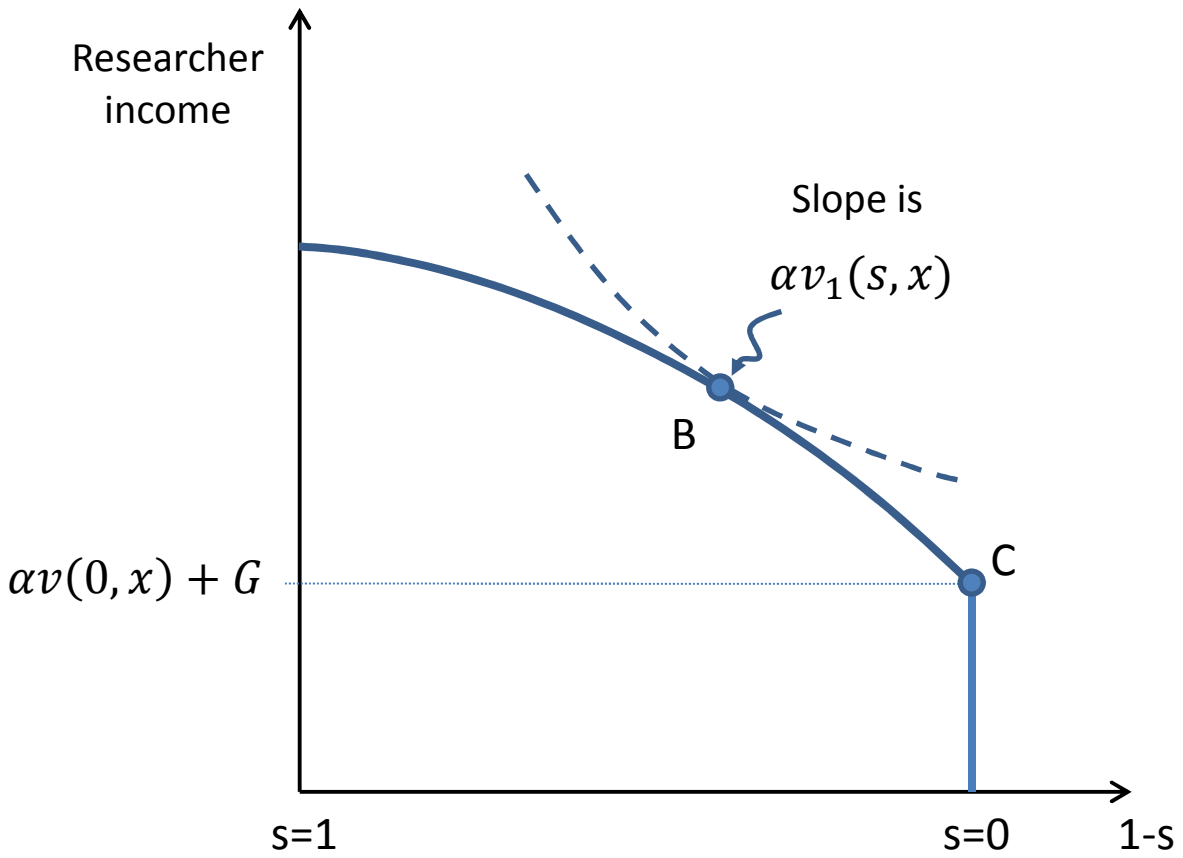
⁵⁸ Note that this analysis examines the interplay of patenting and publications; entrepreneurship may show a different relationship with research output. Recall that we cannot link publications to the university entrepreneurs, because the entrepreneurship analysis uses anonymized personal identifiers in Norwegian registry datasets (i.e., we do not know the entrepreneurs' names).

⁵⁹ . 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 A.2 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 A.3 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.

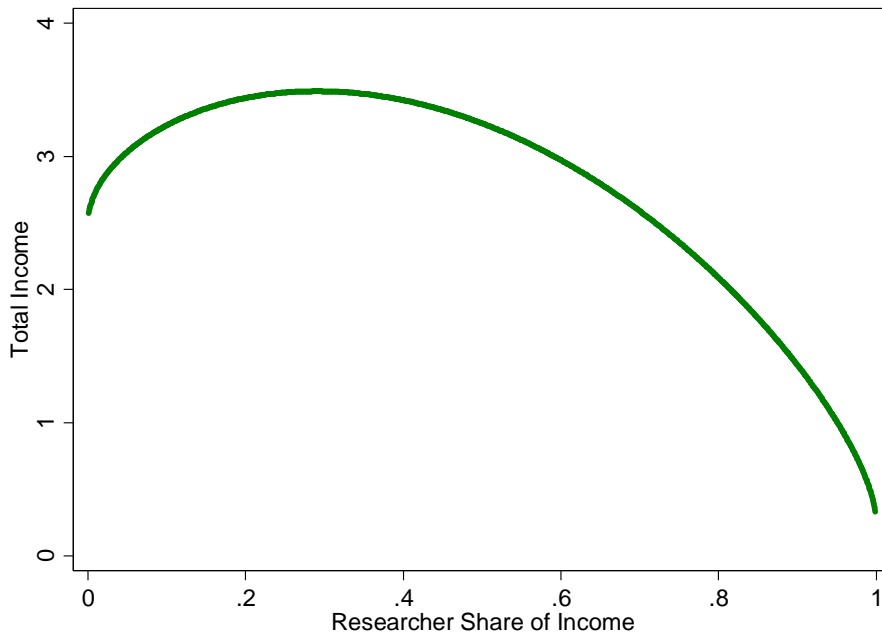
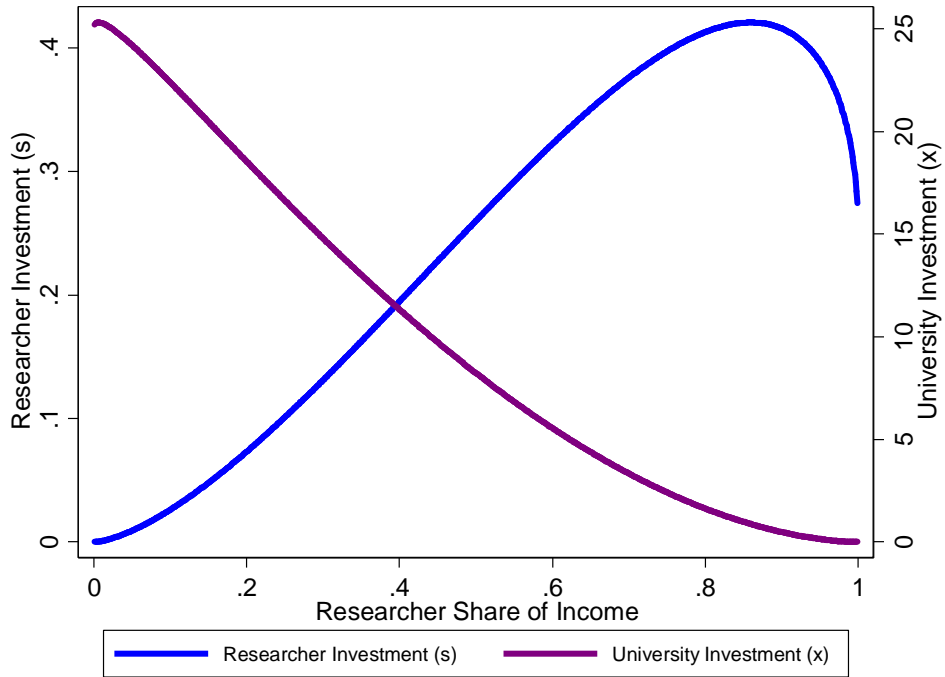
Together, these analyses show no indication that an increase in publications acted as a kind of “silver lining”, offsetting the decline in university-based innovation detailed in main text. On net, the publications do not appear clearly as either complements or substitutes for more applied innovative activities. A tradeoff between inventive activity and publication activity does not visibly emerge at the individual level, which calls into question the concern that university commercialization activity comes at the expense of basic research.

Figure A.1: Researcher Utility Maximization and Effort at Commercial Innovation



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Figure A.2: 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 A.1: The Publication Output of University Inventors

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---------------------|---------------------|---------------------|-------------------------|-------------------------|---------------------|--------------------|
| | Publications | Publications | Fractional Publications | Fractional Publications | Mean Citations | Mean Citations |
| University Inventor | 0.668*** (0.188) | 0.487*** (0.185) | 0.177*** (0.051) | 0.131*** (0.051) | 3.317*** (0.976) | 1.945** (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 A.2: The Change in Publication Output within Individuals - Patent-Heavy vs. Patent-Free Research Disciplines

| | (1) | (2) | (3) | (4) |
|---------------------|---------------------|------------------|-------------------------|----------------------|
| | Patents | Publications | Fractional Publications | Mean Citations |
| Patent-Heavy x Post | -0.006** (0.003) | 0.025 (0.107) | -0.034 (0.024) | -1.971*** (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 A.3: 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 | -0.120*** | -0.122 | -0.073 | -1.774 | -0.123*** | -0.177 | -0.050 | 0.583 |
| x Post | (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 (* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$).