The Impact of Intellectual Property Rights on Commercialization of University Research

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Abstract

One of the foundational assumptions of patent law is that imbuing inventions with intellectual property rights (IPR) is necessary to bring forth innovation. We test this foundational assumption by examining the impact of IPR on commercialization of university research. Using the full set of US public firms who patented and conducted research over the period 1976 to 2007, we find little evidence that university research protected by IPR had higher commercialization relative to university research in the public domain. Indeed, if anything, university research in the public domain appears to have slightly greater commercialization.

I. Introduction

One of the foundational assumptions of patent law is that imbuing inventions with intellectual property rights (IPR) is necessary to bring forth innovation[1]. This assumption arises from the fact that knowledge is a public good. Because it is difficult to keep knowledge from diffusing, the innovator bears the cost of innovation, but captures only a fraction of its returns. Given that, the level of innovation may be suboptimal.

Patents are an effort to maintain incentives to innovate, while preserving the diffusion of knowledge necessary to fuel economic growth. Patents provide the inventor temporary rights to the use of an invention in exchange for disclosure of the knowledge underpinning it. Accordingly, in 1980, when the government wanted to increase commercialization of federally-funded research, it enacted the **Bayh–Dole Act (BDA)** or **Patent and Trademark Law Amendments Act** (Pub. L. 96-517). The key provision of the Bayh-Dole Act was to greatly streamline the granting of property rights for government-funded inventions to universities.[2] Until that time, the primary means for diffusing university research was through publications.[3] Since the passage of the BDA, university research has been diffused through both publications and patents. This period of co-existence allows us to evaluate the foundational assumption of patent law—that IPR bring forth greater innovation.

To this end, we examine firms whose patents cite university research. Our treatment is university research disseminated through patents, while our placebo is university research

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[1] Throughout the paper, we follow Mansfield's (1968) distinction between the prescription for a new product or process (invention) and its diffusion (innovation).

[2] Prior to the BDA, many universities had negotiated blanked IP agreements with different funding agencies, or negotiated rights for specific inventions. The BDA created a uniform policy of awarding IPR to universities, including the discretion to license inventions exclusively.

[3] Secondary means for diffusing research were teaching and the movement of personnel, primarily graduate students, from the university to the private sector.

disseminated through publications. Accordingly, we compare firms' commercialization of university patents relative to their commercialization of university publications. While our test is meaningful only after the BDA (when university research was disseminated both through publications and patents), we look separately at firms who cited university research prior to the BDA, and those who began utilizing university research only after BDA. This separation allows for the possibility that firms utilizing university research prior to the BDA were better able to commercialize it after it had greater IPR. If granting IPR is an effective means to increase commercialization of university research, we expect the impact of university patents to be greater than that for university publications, across both groups.

We utilize two measures of commercialization for our tests. The first measure, *total stock market value (tsm)*, captures the market's perception of the economic value of a firm's patents (Kogan, Papanikolaou, Seru and Stoffman, 2017). By construction, *tsm* omits firm inventions protected by other means. Accordingly, we also employ a second measure of commercialization, *R&D contribution* to revenue growth*,* which takes into account both the level of firms' R&D and the productivity of their R&D (RQ). *R&D contribution* thus captures increases in commercialization arising from either greater investment in R&D, higher productivity of that R&D, or both.

We conduct the test for the set of all public firms in Compustat who report R&D, and have been granted patents over the period 1976 to 2007. We find no statistical difference between commercialization of university patents and university publications. Accordingly we can't reject the null hypothesis that university research protected by IPR is equivalent to university in the public domain. Indeed, if anything, university research in the public domain appears to have slightly greater commercialization under both measures of commercialization and for both sets of firms.

The only exception is for the set of firms who began utilizing university research post BDA, and only when using *tsm* as the measure of commercialization. There we find commercialization is slightly higher when utilizing university patents. The fact that university patents increase *tsm* for this group without increasing *R&D contribution*, may indicate these firms substitute licensing of university research for conducting internal R&D.

Taken together, our results offer little support that providing university research with IPR increases commericalization relative to allowing the research to remain in the public domain. This conclusion is reminiscent of Murray and Stern (2007) who found a small but statistically significant decline in forward citations to university research once it became patented.

The paper proceeds as follows. First, we characterize firms' utilization of university research. Second, we discuss our empirical approach for testing the impact of the two forms of dissemination (patents and publications) on firms' commercialization of university research. Third, we present results from those tests. Finally, we offer a summary and conclusions.

II. Firm utilization of university research

Before conducting our empirical tests, we first characterize patterns in firms' utilization of university research. Figure 1 documents that the number of firms with patents, and the number of firms citing university publications or university patents, have all been increasing.[4]

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[4] Note that the apparent decline in patenting after 2004 is an artifact of the Kogen et al database, which ends in 2010.

Insert Figure 1 about here

While Figure 1 presents aggregate patenting for all public firms conducting R&D and patenting, we know industries differ markedly in their reliance on patents (Cohen, Nelson & Walsh 2000). Accordingly, Figure 2 depicts the trends within industrial sectors (1 digit SIC). Consistent with Mowery et al. (2001), there is heterogeneity across industrial sectors in their use of university research, both for citations to university publications (Figures 4a) and citations to university patents (Figure 4b).

Insert Figure 2 about here

While increasing citations to university research suggest firms are making greater use of it, and thereby increasing commercialization, it is possible that firms merely substitute university research for their own. Accordingly, we next look more formally at firms' commercialization of university research.

III. Empirical Approach

To evaluate the impact of IPR on commercialization of university research by firms, we compare utilization of university patents (the treatment) to that of university publications (the placebo). If granting IPR increases commercialization of university research, we expect that utilization of university patents leads to greater commercialization than utilization of university publications. This matches the foundational assumption of patent law. Conversely, if granting universities IPR hinders the diffusion of university research, then utilization of patents should exhibit lower commercialization than utilization of publications. IPR might hinder diffusion if 1) licensing royalties paid to universities fully capture firms' value to commercializing university research, 2) firms simply outsource to universities work they might have otherwise done themselves, or 3) IPR increase the transaction costs for accessing university research, relative to accessing it from the public domain.

To assess these predictions, we model commercialization of firm *i* in fiscal year *t+3*, as a function of backward citations to university patents (Equation 1) and university publications (Equation 2), looking separately at two groups, firms who utilized university research prior to the BDA, and those who began utilizing university research only after the BDA. Use of citations allows for comparability across the two forms of university research[5]

$$Commercialization_{it+3} = \beta_1(backward\ citations\ to\ university\ patents)_{it} + \eta_i + \lambda_t + \varepsilon_{it} \quad (1)$$

$$Commercialization_{it+3} = \beta_2(backward\ citations\ to\ university\ publications)_{it} + \eta_i + \lambda_t + \varepsilon_{it} \quad (2)$$

If IPR increases commercialization of university research, we expect to find that the coefficient (β_1) on *backward citations to university patents* (*BCA)* is positive and significant in explaining commercialization. Furthermore, if IPR is a more effective mechanism for commercializing university research than releasing it in the public domain, and if papers and patents on average comprise equivalent units of knowledge[6], we expect the coefficient (β_1) to be greater than that for the coefficient (β_2) on *backward citations to university publications (BCP).* Note there is no foundation for treating the two forms of knowledge as equivalent. Indeed, given the higher prevalence of publication citations relative to patent citations (roughly 3:1 for both

[5] Patent and paper citations are imperfect measures of knowledge flows, in the sense that citations are often added by patent examiners. However, they do capture whether knowledge from the cited patent or paper is embedded in focal patent, even if the inventors were unaware of the source of the knowledge. Post-hoc citations added by examiners or anyone but the inventors would pick up knowledge flows that might otherwise have been transferred to the private sector. This would *increase* the likelihood of measuring an effect. Thus, extra-patent knowledge transfer will make likelihood of not measuring a positive relationship between of reliance on university patents and research productivity smaller. See Corredoira, Goldfarb and Shi (2018) for a related discussion.

[6] Given the higher prevalence of citations to publications relative to patents (roughly 3:1 for both groups), treating th two forms of knowledge as equal biases in favor of re

groups), patents appear to convey more units of knowledge. Accordingly, treating the two forms as equivalent knowedge, biases us in favor of finding that university patents have higher commercialization than university publications.

In testing both conjectures (that $\beta_1 > 0$ and $\beta_1 > \beta_2$), we want to avoid capturing firm factors that are associated with citations to university research and also associated with commercialization. Accordingly, we employ firm and year fixed effects to minimize this concern. Firm fixed effects (η_i) control for unobservable time-invariant firm characteristics, such as the quality of their scientist staff, that might cause both citations and commercialization to increase. Year effects (λ_t) control for macro trends, such as the increase in government biomedical funding that might cause both citations and commercialization to increase. When including these fixed effects, our estimates are identified by changes in a firm's citations to university research rather than by differences in levels of citations across firms and over time. Further, because we run an equivalent analysis for citations to university publications (Equation 2), we control for any broader changes in firms' access to university research, such as the creation of technology transfer offices (TTOs).

Variables

Our dependent variable is commercialization. The challenge is how to measure that. As noted in a recent NIST green paper, "*[m]eaningful effectiveness and efficiency metrics have the potential to assess and improve the ROI that accrues to the American taxpayer. However, current measures … do not accurately reflect the impact or effectiveness of technology because they are counts of outputs…* (NIST 2018:112)."

We utilize two novel measures of commercialization for all tests. Our first measure captures the market's perception of the economic value of a firm's patents. This measure developed by Kogan, Papanikolaou, Seru and Stoffman (2017) is based on the stock market response to a patent grant in a 3-day window following and including the grant date. The firm-level measure, *total stock market value (tsm)*, aggregates across all the patents granted to a firm in a given year. Data for the *tsm* measure come from a dataset made available by Stoffman.[7] To adjust for the likelihood of patent approval, we follow Kogan et al, and multiply *tsm* by 2.27. Whereas Kogan et al normalize each firm-year *tsm* by total assets (which is relevant to their subsequent analysis), we normalize by the firm's R&D spending in the prior year.

Because firms have alternative means to appropriate the returns to their innovations other than patents (Cohen et al 2000), we also employ a second commercialization measure, *R&D contribution* to revenue growth. *R&D contribution* is a composite of the firm's R&D spending, and the productivity of that spending. Accordingly, it captures increases in commercialization reflected in greater investment in R&D, higher productivity of that R&D, or both. It is computed as RQ*ln(R&D), where RQ (short for research quotient) is the *firm-specific output elasticity of R&D* (Knott 2008). RQ is the firm-level equivalent of the most common means used by economists to measure industry-wide returns to research (Hall 1993; Hall, Mairesse and Mohnen 2009) . It is estimated with a random coefficients model using successive 7-year windows of firm financial data. This estimation process and its robustness checks are described in the user manual for the WRDS RQ database, where we obtained the RQ data for our empirics.[8]

[7] https://iu.app.box.com/v/patents

[8] WRDS RQ database. This 13-page manual describes the theory underpinning RQ, the functional form for all variables, as well as the logic behind those functional forms. It then compares estimates for all variables in RQ estimation to those from four other versions of research production function estimation, including attempts to control for endogenous choice of inputs.

For both *tsm* and *R&D contribution*, we evaluate commercialization at a three-year lag relative to the citation to university research. In robustness checks we use alternative lags and employ *R&D* and *RQ* as separate measures of commercialization.

Our independent variables capture the two means by which university research is accessed by firms. *Backward citations to university patents*$_{it}$ (BCA) is the 10-year moving window of the total number of university patents cited by patents filed by company *i* in year *t* that were later granted.[9] *Backward citations to scientific publications*$_{it}$ (BCP) is the 10-year moving window of the total number of university publications cited by patents filed by company *i* in year *t* that were later granted.[10] Citations to university publications were identified by parsing each patent's non-patent citations and matching journal names to journal lists from the *Journal Citation Index*. To minimize skewness, we take the natural log of each measure.

Data

Data for the study come from four sources. The data on firm R&D expenditures comes from the Compustat Capital IQ database over the period 1972-2013 for all active and inactive publicly traded firms in the U.S. that had at least one patent and conducted research. The data on firms' RQ comes from the Wharton Research Data Services (WRDS) RQ database over the period 1972-2013. As noted earlier, the data on the economic value of patents comes from Stoffman. The data on firm patenting and citations come from the U.S. patent dataset released by Kogan, Papanikolaou, Seru, and Stoffman (2017) over the period of 1926-2010.[11] To merge

[9] We tested the 5 year moving window of backward citations to university patents, which yielded consistent results.
[10] Scientific journals are limited to those identified by Scimago Journal Rank (https://www.scimagojr.com/journalrank.php)
[11] We cross-validated our results by utilizing a widely used patent dataset (1976-2006), The National Bureau of Economic Research Patent Data Project (NBER PDP) under the leadership of Bronwyn Hall (http://elsa.berkeley.edu/~bhhall/patents.html). The two patent datasets yielded consistent results.

the patent data with the Compustat data, we followed Kogan et al. (2017) and use the CRSP-COMPUSTAT link table in the CRSP/Compustat Merged Database (CCM). The final data set using *R&D contribution* contains 27,319 firm-year observations over the period 1976-2007. However, the dataset using *tsm* has only 16,182 observations. Thus, if the true effects are of similar magnitude, our tests using *tsm* will have lower power than those using *R&D contribution*.

Table 1 presents summary statistics separately for the two firm groups: those who cited university research prior to the BDA (pre-BDA=1), and those who began citing university research only after the BDA (pre-BDA=0). Firms in the pre-BDA group appear to have much greater innovative activity than those in the post BDA group. Their mean R&D is on average 2.7 times larger than for the post-BDA group, and they produce approximately six times as many patents. However, they are less reliant on university patents—on average only 6.0% of the pre-BDA group patents cite academic patents (5.8/97.3), whereas 9.2% of the treatment group patents cite academic patents (1.45/15.79). This suggests that the BDA may have brought forth firms who were attracted to the new IPR for university research. Also worth noting is that both groups rely more heavily on university publications than university patents—the number of citations to publications is roughly three times that to patents for both groups.

Also of note is that both measures of commercialization exhibit a cross-sectional correlation with utilization of university research. For both groups, citations to university patents *log(BCA+1)* and publications *log(BCP+1)* are correlated with both *R&D Contribution* (*RQ* ln(R&D))* and *tsm*. These correlations are stronger for the pre-BDA group than for the post-BDA group. While *R&D spending* is also correlated with both forms of university research for both groups, R&D productivity (*RQ*) is uncorrelated with either form of research for either group.

Table 1 about here

IV. Results

Table 2 presents results for the analysis of Equations 1 and 2 for the full set of firms who patented their inventions. Models 1-6 utilize *R&D contribution* as the measure of commercialization, while Models 7-12 utilize *tsm* as the measure of commercialization. For both sets of models, we first present results for utilization of university publications (ln(BCP+1)), then results for utilization of university patents (ln(BCA+1)), then compare the two. In all pairs of results, the first model is for the pre-BDA group (Pre-BDA=1), the set of firms who utilized university research prior to the BDA, while the second model is for the post-BDA group (Pre-BDA=0), the set of firms who began utilizing university research only after implementation of the BDA.

Looking first at the impact of *academic publications* (the placebo), we see that the coefficient is positive and generally significant for firms in both groups when using *R&D contribution* as the dependent variable (Models 1,2,5, and 6). Results are similar using *tsm* as the dependent variable, though the coefficient estimates are less precise, likely due to the fact that the sample sizes are smaller (Models 7,8,11, and 12). For all models we report the 95% confidence intervals for the magnitude effects. For example, in Model 1 the effect is bounded between 0.01 and 0.12.

Looking next at the impact of *academic patents* (the treatment), we see that coefficients are imprecisely estimated when using either *R&D contribution* as the dependent variable

(Models 3-6) or *tsm* as the dependent variable (Models 9-12). Thus these models provide no evidence that a firm utilization of university patents increases commercialization.

Finally, comparing the impact of *academic patents* to *academic publications*, we consider the models that jointly examine both forms of citations: models 5-6 for *R&D contribution*, and models 11-12 for *tsm*. Note that our independent variables are highly correlated, and hence we cannot rule out the possibility that changes in values moving from independent estimation to joint estimation are due to an omitted common factor (Kalnins, 2018). Having said that, there are no models in which the coefficients for citations to *academic patents* are statistically different from those for citations to *academic publications*. Thus we cannot reject the null hypothesis that university research protected by IPR is equivalent to university research in the public domain.

One observation that is not statistically significant, but nevertheless interesting because it deviates from other results, is that the coefficient on *academic patents* is greater than that for *academic publications* for the post-BDA group when using *tsm* as the measure of commercialization. When combined with the result that reliance on *academic patents* has no impact on *R&D contribution*, suggests these firms may have a different innovation strategy than firms who began utilizing university research prior to the BDA. In particular, they may substitute licensing university research for conducting internal R&D.

Insert Table 2 about here

The models in Table 2 present aggregate results for all public firms conducting research and patenting. As noted previously, industries differ markedly in their reliance on patents (Cohen, Nelson and Walsh 2000). For example, SIC 2, includes pharmaceuticals, and special purpose machines, while SIC 3 includes medical equipment. To create greater insight into these differences we replicated models 1-6 for each industrial sector (1 digit SIC). Since there are only meaningful patenting levels in SIC codes 2, 3, and 7, we only report analyses for these in Table 3.[12] Qualitatively, there is little difference between the results in these three subsamples and the general population. There is some evidence that the positive effect of utilizing *academic publications* is due to firms in SIC 3 (Manufacturing). However, we find little evidence of a clear positive relationship between utilization of *academic patents* and commercialization. Thus, both at the aggregate level as well as the sector level, we see little evidence that granting university research IPR increases its commercialization by firms, when using our measures of commercialization.

Insert Table 3 about here

Robustness checks

A central concern is that while we might hypothesize a positive relationship between IPR and commercialization of university research, there is no strong guidance on how to measure commercialization. For example, in the specifications above, we assume a logged form of the dependent and independent variables. However, there is no theoretical justification for this functional form assumption. More specifically, the results presented above reflect a host of empirical specification decisions not particularly germane to the underlying theory. For instance, the citation-based measures are highly skewed, as such, we might wish to winsorize the independent variables, as opposed to using natural logs. On the other hand, there is much

[12] SIC 7 should be viewed cautiously as there are only 12 unique firms that relied on university patents prior to 1980.

reason to suspect that outliers matter materially as a few firms may provide significant benefits associated with some university technologies. Hence, we might wish to retain a linear form of the dependent or independent variables. We have assumed a 3-year time lag between citation and commercialization. Perhaps this lag is too long, and 1 or 2 years might be more appropriate. We have used a single year of citations to past articles or patents. Perhaps we should use a multi-year moving average.

With this in mind, we evaluate the sensitivity of our results to these assumptions. We employ user-written Stata routines, *specreg* and *specmap* that estimate all combinations of control variables and functional forms across pre-specified controls and functional form possibilities (King, Goldfarb & Simcoe, forthcoming). This allows the readers to evaluate which assumptions have a strong effect on the conclusions.

The epistemic maps are depicted in Figure 3 (using *R&D contribution* as the measure of commercialization) and Figure 4 (using *tsm* as the measure of commercialization). Each map reflects iterations over all combinations of the dependent variables lagged 1, 2 and 3 years. For each dependent variable (DV), we iterate over the following functional forms of the independent variables (IV) of interest: the log and linear forms of the variables, and the winsorized linear variable. For each DV-IV specification, we include variables for the corresponding functional form of the second independent variable, as well as a control for whether the firm patented in year t, and include a linear or fixed year effects. The sets include models where all controls are omitted. We break out the models by independent variable (citations to *academic patents* and *academic publications*), and by firm group (Pre-BDA=1 and Pre-BDA=0). In all, we run 171 regressions for each group. The four panels in each figure capture respectively, the pre-BDA group with the placebo (citations to *academic publications*) (panel 1), and with the treatment (citations to *academic publications*) (panel B), the post-BDA group with the placebo (panel 3) and with the treatment (panel 4). Since we iterate over different functional forms, the coefficient estimates are not strictly comparable. For this reason, we normalize each estimate by its standard error, and graph the standardized 95% confidence intervals. The estimates are ordered from highest to lowest.

Insert Figures 3 and 4 about here

The epistemic maps using *R&D contribution* as the measure of commercialization (Figure 3) indicate that for both the placebo (Panels 1 and 2) and the treatment (Panels 3 and 4), there appears to be no consistent relationship between citations to publications or patents, and commercialization for either the firms who utilized university research prior to the BDA (panels 1 and 3) or those who only began utilizing university research after the BDA (panels 2 and 4). In contrast, the epistemic maps using *tsm* as the measure of commercialization (Figure 4) indicate that in general, there is a positive relationship between university research and commercialization for both the placebo (Panels 1 and 2) and the treatment (Panels 3 and 4) across both groups of firms.

Thus, depending on the specification, we might conclude that there is a positive, negative or no meaningful relationship between reliance on university research and commercialization. Since we have little ex-ante reason to prefer one specification over the other, we conclude that there is no robust evidence that granting IPR for university research increases its commercialization.

V. Discussion and Conclusions

Patent laws, and legislation exploiting them, such as the BDA, and the National Institute of Standards and Technology (NIST)'s recent Return on Investment Initiative for Unleashing American Innovation[13], rely on an assumption that IPR bring forth greater innovation (the commercialization of inventions). We failed to find strong evidence supporting that assumption.

We examined the impact of IPR on commercialization of university research by comparing the commercialization of academic patents (the treatment) to commercialization of academic publications (the placebo). We looked separately at firms who utilized university research before it was protected by IPR, and firms who began utilizing university research only after some of it was protected by IPR, and therefore might have been induced to utilize university research by its IPR provision.

We found no strong evidence that IPR increases commercialization of university research. This was true for two types of firms, using two separate measures of commercialization, under an exhaustive set of plausible functional form and lag assumptions of the dependent and independent variables, and for specifications with and without control variables. There was, at best, evidence of a small positive association between utilization of academic publications and commercialization, and a small negative association between utilization of academic patents and commercialization. However, these results were subject to particular specification assumptions.

Taken together, the results fail to provide robust evidence that granting university research IPR increases its commercialization. Indeed, if anything, utilization of university

[13] https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1234.pdf

research in the public domain (publications) appears to have slightly greater commercialization. This result resembles that of Murray and Stern (2007) who found a small but statistically significant decline in forward citations to university research following patenting of that research.

The question is why vesting university research with IPR appears to have no obvious advantage over allowing research to remain in the public domain? One possible explanation is that firms substitute university research for their own research. If so, then R&D investment that formerly went to in-house research, where it enhances the firm's capability to do research, is now going to universities in the form of licensing fees. Indeed the result for the post-BDA group that utilization of university patents increases *tsm*, but has no effect on *R&D contribution*, is consistent with that conjecture, at least in that group.

An alternative explanation is that absorbing the knowledge underlying university patents is more difficult than absorbing knowledge in the public domain (publications). Perhaps university research that has been patented is more likely to be embodied knowledge that requires co-development rather than arms-length acquisition.[14]

A final explanation is that creating a fence around the commons of university research makes its knowledge less accessible – a hypothesis consistent with the findings of Murray and Stern (2007). Indeed, informal interviews with two Chief Technology Officers indicated that working with TTOs is cumbersome.

There are caveats to these results. First, we study public firms for whom research is observable. Thus, it is possible we miss innovation by private firms utilizing university patents.

[14] We explored this conjecture in greater detail in a single industry (pharmaceuticals). We utilized a web search to determine which firms funded university research (as an indicator of knowledge co-development). While we were only able to code one-third of the firms, our preliminary results went in the wrong direction—the coefficient on BCA for firms who funded university research was more negative than those who did not.

For example, Google's initial patent was licensed from Stanford University. To the extent that many of Google's subsequent patents did not cite the original Stanford-owned patent, or their commewe might fail to pick up the link to the original university research.

Similarly, the Cohen-Boyer recombinant DNA patent, which sits at the foundation of the modern biotechnology industry, was very enriching to Stanford University, but was also licensed non-exclusively for a small fee (Godar, 2015). Thus, it did not provide exclusionary IPR, and might have acheived greater commercialization if the technology had been in the public domain from inception.

A second caveat is that our analysis is restricted to firms who patent. Thus we miss commercialization of university research by the 50% of firms who conduct R&D, but protect their innovations by other means (Cooper, Knott and Yang 2019). It is unclear ex ante whether firms who do not patent themselves utilize inventions patented by others.

Third, we look only at the impact of IPR on commercialization. There may be other social returns to university research that increase when it is protected by IPR. However social returns to patented inventions are likely correlated with commercialization, since the main reason to seek IPR is to exclude others from appropriating its value. The ability to exclude others is therefore only valuable under commercialization.

Finally, our main conclusions and this discussion pertain to aggregate results. It is worth noting that there is some heterogeneity in results across sectors. Exploration of those differences may provide greater insight into why firms' success with university patents differs from that with university publications. In addition, the differences suggest innovation policy may want to vary across sectors.

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Table 1. Data Summary

PreBD==0 Firms not citing university research prior to BDA (1529 firms, 9046 observations)

	Mean	S.D.	Min	Max	Year	R&D	RQ	RQ*log (R&D) t+3	tsm/ book value t+3	fNpats	No. of Annual Patents	log (BCP+1)	log (BCA+1)
Year	1996.33	8.25	1976.00	2007.00	1.000								
R&D	151.56	578.15	0.07	10092.58	0.179	1.000							
RQ	0.13	0.06	0.00	1.94	-0.225	-0.064	1.000						
RQ*log(R&D)t+3	0.4	0.26	0.00	3.54	0.263	0.338	0.199	1.000					
tsm/book value	328.46	2733.60	0.00	109970.91	0.075	0.334	-0.011	0.183	1.000				
fNpats	24.99	96.08	1.00	1841.00	0.158	0.483	-0.084	0.202	0.328	1.000			
Number of Annual Patents	30.85	115.64	1.00	3130.00	0.127	0.436	-0.057	0.228	0.436	0.779	1.000		
log(BCP+1)	1.3	1.77	0.00	10.02	0.335	0.355	-0.079	0.384	0.237	0.394	0.441	1.000	
log(BCA+1)	0.69	1.10	0.00	6.34	0.317	0.341	-0.082	0.324	0.289	0.463	0.533	0.788	1.000

Correlations if PreBD==1 Firms citing university research prior to BDA (476 firms, 7222 observations)

	Mean	S.D.	Min	Max	Year	R&D	RQ	RQ*log (R&D) t+3	tsm/ book value t+3	fNpats	No. of Annual Patents	log (BCP+1)	log (BCA+1)
Year	1988.82	8.83	1976.00	2007.00	1.000								
R&D	315.32	821.93	0.40	12183.00	0.321	1.000							
RQ	0.13	0.05	0.00	0.42	-0.412	-0.085	1.000						
RQ*log(R&D) t+3	0.51	0.28	0.01	2.17	0.033	0.404	0.239	1.000					
tsm/book value	851.8	3596.48	0.02	114215.38	0.247	0.477	-0.087	0.214	1.000				
fNpats	101.22	259.66	1.00	3963.00	0.224	0.658	-0.053	0.346	0.345	1.000			
Number of Annual Patents	113.26	309.52	1.00	4556.00	0.203	0.633	-0.050	0.332	0.371	0.909	1.000		
log(BCP+1)	1.85	1.97	0.00	7.95	0.374	0.547	-0.082	0.518	0.407	0.531	0.532	1.000	
log(BCA+1)	0.94	1.33	0.00	6.25	0.446	0.607	-0.142	0.432	0.453	0.609	0.625	0.839	1.000

Table 2. Results for test of impact of university research on commercialization of firms' research

	DV: RQ*Log(R&D) in year t+3						DV: tsm*2.27/R&D in year t+3					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
ALL INDUSTRIES	Pre_BD=1	Pre_BD=0	Pre_BD=1	Pre_BD=0	Pre_BD=1	Pre_BD=0	Pre_BD=1	Pre_BD=0	Pre_BD=1	Pre_BD=0	Pre_BD=1	Pre_BD=0
log(Backward Citations to	0.010	0.005			0.012	0.006	0.83	0.90			0.67	0.56
Publications+1)	[0.002,0.019]	[-0.001,0.011]			[0.004,0.020]	[0.000,0.012]	[0.44,1.22]	[0.52,1.29]			[0.32,1.03]	[0.12,1.01]
log(Backward Citations to			0.005	0.002	-0.004	-0.004			0.81	1.28	0.35	0.85
Academic Patents + 1)			[-0.007,0.017	[-0.006,0.009	[-0.016,0.008	[-0.011,0.004]			[0.22,1.41]	[0.80,1.76]	[-0.25,0.95]	[0.31,1.39]
Firm Fixed Effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year Fixed Effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Controls for no.patent in year t	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	8545	18774	8545	18774	8545	18774	5919	6251	5919	6251	5919	6251
F	41.71	68.44	41.86	68.26	41.48	66.47	7.7	5.26	7.65	5.23	7.49	5.28
df_m	32	32	32	32	33	33	29	29	29	29	30	30
df_r	503	2716	503	2716	503	2716	411	1068	411	1068	411	1068
Adjusted R Squared	0.15	0.13	0.15	0.12	0.15	0.13	0.17	0.12	0.17	0.12	0.17	0.12
R Squared Between	0.07	0.08	0.00	0.06	0.07	0.07	0.15	0.08	0.1	0.08	0.15	0.09
R Squared Within	0.16	0.13	0.15	0.13	0.16	0.13	0.18	0.12	0.17	0.12	0.18	0.12
Effect Bounds:Backward Citations	[.01 , .12]	[-.01 , .07]	-	-	[.03 , .13]	[.0 , .08]	[.09 , .24]	[.08 , .21]	-	-	[.06 , .21]	[.02 , .17]
Effect Bounds:Backward Citations	-	-	[-.03 , .07]	[-.02 , .04]	[-.06 , .03]	[-.04 , .02]	-	-	[.03 , .19]	[.08 , .18]	[-.04 , .13]	[.03 , .14]
95% CIs in brackets, Standard Errors Clustered at Firm												

Table 3. Heterogeneity in the impact of university research across sectors

Panel A: Firms in SIC2 (e.g., Pharmaceutical firms)

	Model 1 Pre-BDA=1	Model 2 Pre-BDA=0	Model 3 Pre-BDA=1	Model 4 Pre-BDA=0	Model 5 Pre-BDA=1	Model 6 Pre-BDA=0
log(Backward Citations to Publications+1)	0.007 [-0.006,0.021]	0.001 [-0.009,0.011]			0.01 [-0.003,0.024]	0.005 [-0.008,0.017]
log(Backward Citations to University Patents + 1)			-0.001 [-0.018,0.017]	-0.006 [-0.021,0.008]	-0.008 [-0.025,0.009]	-0.01 [-0.028,0.008]
No patent in year t	0.021 [-0.026,0.067]	0 [-0.016,0.016]	0.015 [-0.029,0.059]	-0.002 [-0.018,0.014]	0.021 [-0.025,0.066]	0.001 [-0.015,0.017]
Observations	2738	3413	2738	3413	2738	3413
F	20.3	16.21	20.54	16.22	19.73	15.87
df_m	32	32	32	32	33	33
df_r	157	475	157	475	157	475
Adjusted R Squared	0.17	0.2	0.17	0.2	0.17	0.2
R2 Between	0.1	0.05	0.001	0.03	0.09	0.04
R2 Within	0.18	0.2	0.18	0.2	0.18	0.21
FirmFE	yes	yes	yes	yes	yes	yes
YearFE	yes	yes	yes	yes	yes	yes
Effect Bounds:BCP	[-.04 , .15]	[-.07 , .08]	-	-	[-.03 , .01]	[-.06 , .01]
Effect Bounds:BCA	-	-	[-.07 , .01]	[-.08 , .03]	[-.1 , .04]	[-.11 , .03]

Notes: 95% CIs in brackets, Standard Errors Clustered at Firm

Table 3 (Cont'd).

Panel B: Firms in SIC3 (e.g., Medical device)

	Model 1 Pre-BDA=1	Model 2 Pre-BDA=0	Model 3 Pre-BDA=1	Model 4 Pre-BDA=0	Model 5 Pre-BDA=1	Model 6 Pre-BDA=0
log(Backward Citations to Publications+1)	0.009 [-0.002,0.020]	0.006 [-0.002,0.014]			0.008 [-0.001,0.017]	0.007 [0.000,0.014]
log(Backward Citations to University Patents + 1)			0.007 [-0.009,0.024]	0.003 [-0.007,0.013]	0.001 [-0.014,0.016]	-0.003 [-0.012,0.006]
No patent in year t	-0.011 [-0.036,0.014]	-0.008 [-0.016,-0.000]	-0.014 [-0.039,0.011]	-0.01 [-0.018,-0.002]	-0.011 [-0.036,0.014]	-0.009 [-0.016,-0.001]
Observations	4988	11616	4988	11616	4988	11616
F	30.33	41.74	30.38	41.59	29.66	40.52
df_m	32	32	32	32	33	33
df_r	295	1507	295	1507	295	1507
Adjusted R Squared	0.14	0.11	0.14	0.11	0.14	0.11
R2 Between	0.06	0.08	0.01	0.06	0.06	0.08
R2 Within	0.14	0.12	0.14	0.12	0.14	0.12
FirmFE	yes	yes	yes	yes	yes	yes
YearFE	yes	yes	yes	yes	yes	yes
Effect Bounds:BCP	[-.02 , .12]	[-.01 , .08]	-	-	[0 , .01]	[0 , 0]
Effect Bounds:BCA	-	-	[-.04 , .01]	[-.03 , .05]	[-.06 , .07]	[-.05 , .03]

Notes: 95% CIs in brackets, Standard Errors Clustered at Firm

Table 3 (Cont'd).

Panel C. Firms in SIC7 (e.g., Computer software)

	Model 1 Pre-BDA=1	Model 2 Pre-BDA=0	Model 3 Pre-BDA=1	Model 4 Pre-BDA=0	Model 5 Pre-BDA=1	Model 6 Pre-BDA=0
log(Backward Citations to Publications+1)	0.009 [-0.002,0.020]	0.006 [-0.002,0.014]			0.008 [-0.001,0.017]	0.007 [0.000,0.014]
log(Backward Citations to University Patents + 1)			0.007 [-0.009,0.024]	0.003 [-0.007,0.013]	0.001 [-0.014,0.016]	-0.003 [-0.012,0.006]
No patent in year t	-0.011 [-0.036,0.014]	-0.008 [-0.016,-0.000]	-0.014 [-0.039,0.011]	-0.01 [-0.018,-0.002]	-0.011 [-0.036,0.014]	-0.009 [-0.016,-0.001]
Observations	4988	11616	4988	11616	4988	11616
F	30.33	41.74	30.38	41.59	29.66	40.52
df_m	32	32	32	32	33	33
df_r	295	1507	295	1507	295	1507
Adjusted R Squared	0.14	0.11	0.14	0.11	0.14	0.11
R2 Between	0.06	0.08	0.01	0.06	0.06	0.08
R2 Within	0.14	0.12	0.14	0.12	0.14	0.12
FirmFE	yes	yes	yes	yes	yes	yes
YearFE	yes	yes	yes	yes	yes	yes
Effect Bounds:BCP	[-.02 , .12]	[-.01 , .08]	-	-	[0 , .01]	[0 , 0]
Effect Bounds:BCA	-	-	[-.04 , .01]	[-.03 , .05]	[-.06 , .07]	[-.05 , .03]

Notes: 95% CIs in brackets, Standard Errors Clustered at Firm

Table 4. Sector definitions

SIC code	Sector
0100-0999	Agriculture, Forestry and Fishing
1000-1499	Mining
1500-1799	Construction
1800-1999	Not used
2000-3999	Manufacturing
4000-4999	Transportation, Communications, Electric, Gas and Sanitary service
5000-5199	Wholesale Trade
5200-5999	Retail Trade
6000-6799	Finance, Insurance and Real Estate
7000-8999	Services
9100-9729	Public Administration
9900-9999	Nonclassifiable

Figure 1. Trends in Firm Patenting

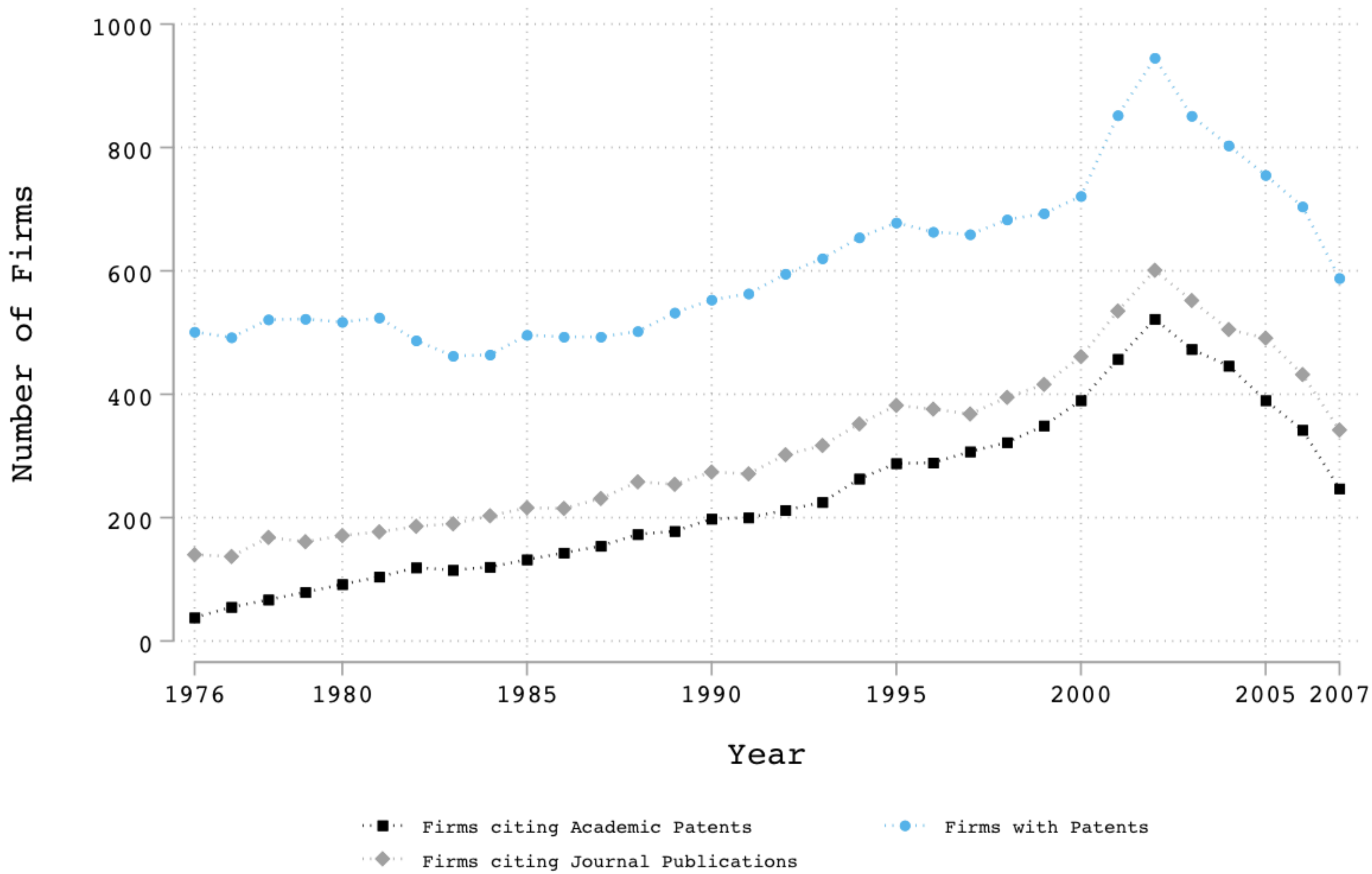
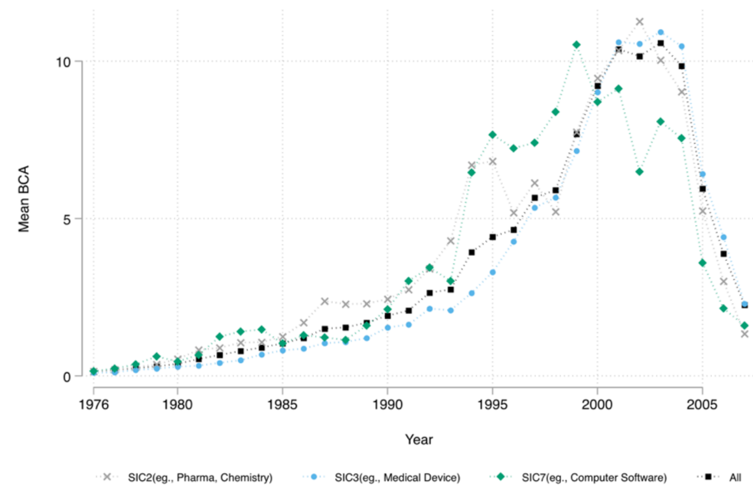


Figure 2. Differences in use of university research across sectors



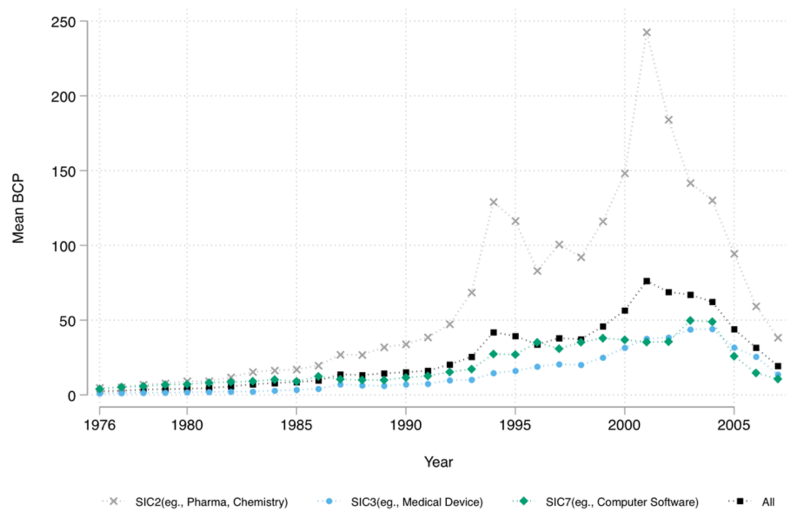
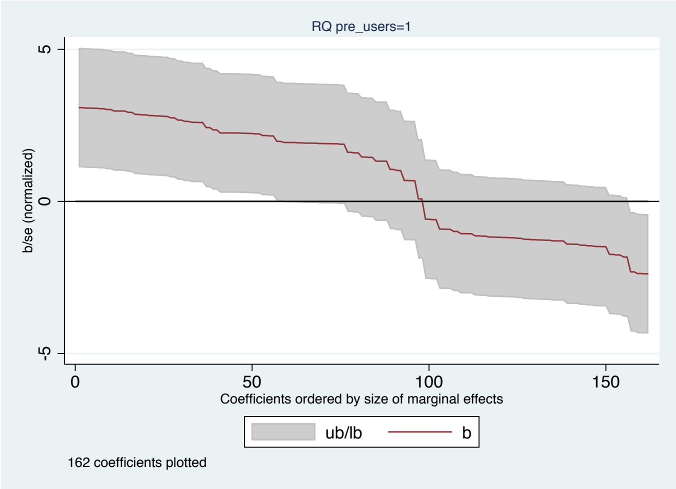
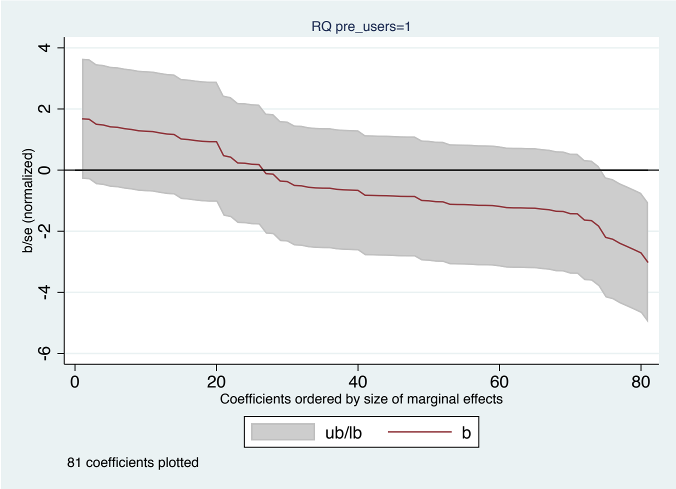


Figure 3. Specification Maps for impact of university research on commercialization (R&D Contribution)

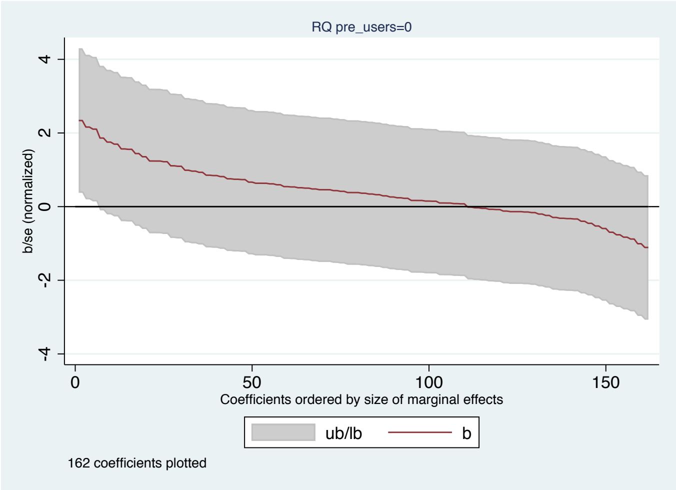
Panel 1. Citations to Publications, Control Group (pre-BDA=1)



Panel 2. Citations to Patents, Control Group (pre-BDA=1)



Panel 3.. Citations to Publications, Treatment Group (pre-BDA=0)



Panel 4. Citations to Patents, Treatment Group (pre-BDA=0)

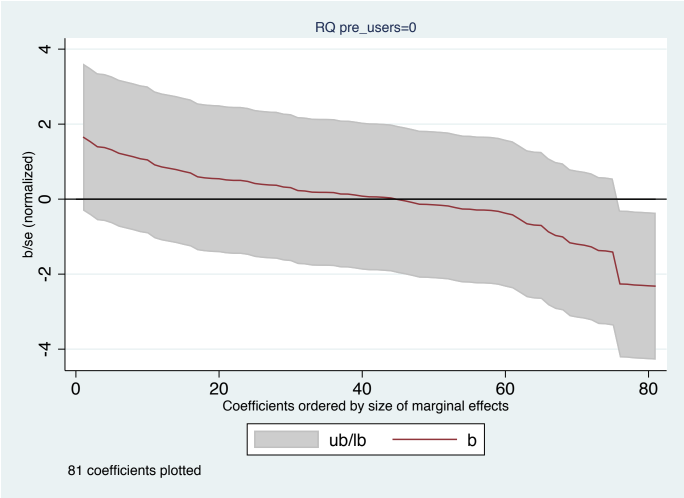
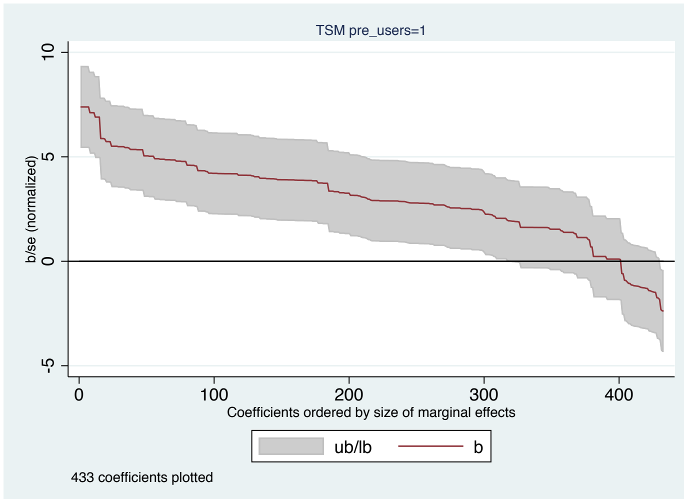
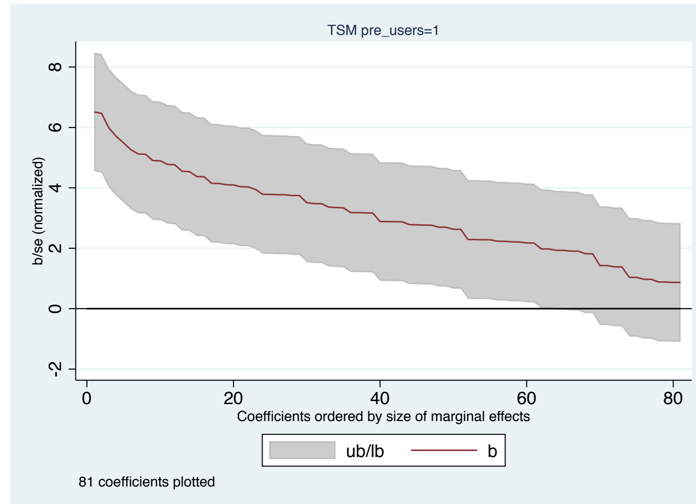


Figure 4. Specification Maps for impact of university research on commercialization (tsm)

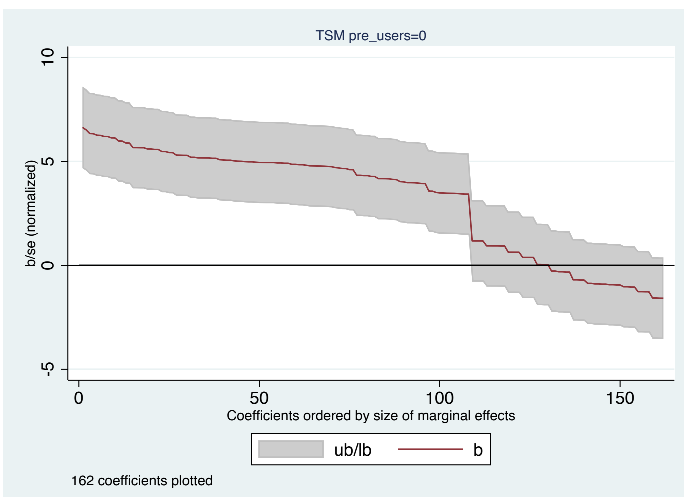
Panel 1. Citations to Publications, Control Group (pre-BDA=1)



Panel 2. Citations to Patents, Control Group (pre-BDA=1)



Panel 3.. Citations to Publications, Treatment Group (pre-BDA=0)



Panel 4. Citations to Patents, Treatment Group (pre-BDA=0)