Academic engagement, commercialization, and scholarship: Empirical evidence from agricultural and life scientists at U.S. land-grant universities

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Abstract

This article examines the involvement of agricultural and life science faculty at U.S. land grant universities in two types of university-industry relations (academic engagement, academic commercialization) and traditional academic scholarship. It exploits large-scale, random sample cross-section surveys in 2005 and 2015 to fill a knowledge gap regarding the prevalence, coincidence, intensity, importance and factors shaping faculty involvement in university-industry relations (UIR). Academic engagement, which includes sponsored research, industry collaborations, and presentations, is far more prevalent and important than is academic commercialization, which includes patenting, licensing, and start-ups. Academic engagement generates 15-20 times the research funds than academic commercialization does. UIR activities are higher among faculty with higher academic scholarship activity, so UIR and academic scholarship appears to be synergistic. While individual, institutional, and university-level factors all help explain faculty UIR activity, econometric analysis highlights differences across fields as well as faculty attitudes toward science and commercial activity in shaping the involvement with the two types of UIR. Significant differences also stem from university fixed effects and may be contingent on history, location, and quality of science.

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1 Introduction

Research on the factors shaping University-Industry Relations (UIR) has exploded in recent decades, as reflected by the hundreds of recent articles published on this topic.[1] At the heart of this take-off was the push by universities worldwide to pursue opportunities to commercialize intellectual property rights. Arguably, the 1981 passage of the Bayh-Dole Act put U.S. public research universities at the forefront of this global expansion. It expanded the intellectual property rights of American universities and their researchers to commercialize innovations and discoveries associated with federally sponsored research (Grimaldi et al., 2011; Sampat, 2006; Thursby and Thursby 2011). European and universities elsewhere followed suit to varying degrees. In the process, UIR around the globe expanded traditional scholarship models of publishing and training students into directly engaging with industry and entering commercial domains via patents, start-ups, and other forms of corporate-university alliances.

Recent research raises some fundamental questions on the importance of academic commercialization and engagement with industry relative to traditional scholarship. For example, using data from the UK, Perkmann et al. (2013) review the evidence on faculty activity in these two realms of university industry relations and identify three substantive information gaps, which we address directly in this paper. One is the lack of comparative evidence from U.S. universities regarding faculty engagement in distinct types of UIR activities, since the literature is mostly based on European university data. They also document surprisingly little examination of the two UIR activities (engagement and commercialization) side-by-side and the factors shaping faculty engagement with them. The other is the lack of temporal - including longitudinal - evidence that allows attention to trends over time of innovation in UIR. This is now a relatively mature episode, with the academic commercialization take-off in the US having occurred by the 1990s and in Europe not long afterwards, which warrants study.

Our study sheds light on the ground-level of UIR at leading US Land-Grant Universities (LGUs) by examining the activities, attitudes, and research choices of individual agricultural and

[1] See for example: Agrawal, 2001; Djokovic and Souitarius, 2008; Geuna and Muscio, 2009; Perkmann et al. 2013; Sengupta and Ray, 2017.

life science faculty. We fill the temporal and engagement mix gap by using rich and unique representative individual-level cross-sectional and panel survey data gathered in 2005 and 2015 from agricultural and life science faculty from all 52 of the original 1863 US LGUs. We explore the prevalence, intensity, and importance of US land-grant faculty engagement with industry as compared to traditional scholarship models. We also examine how faculty attitudes toward research choices shape their participation in UIR activities, and how they combine UIR with traditional scholarship.

We divide university industry relations into two types.[2] One is academic engagement (AE), defined as faculty participation in sponsored and collaborative research, contract research, consulting, and informal relationships with private firms and institutions. Academic commercialization (AC) is the other, defined as faculty participation in private intellectual property creation (via invention disclosures, patents, and licensing) and entrepreneurship (e.g., start-ups). These definitions are used in other recent articles that examine UIR among university faculty in Europe (D'Este and Perkmann, 2011; Perkmann et al., 2011; Tartari et al., 2014; Tartari and Salter, 2015; Sengupta and Ray, 2017).

These apparently contrasting categories are not mutually exclusive types of UIR, with many faculty doing both AE and AC, a category we call AE/AC. In our analysis we contrast faculty who engage in these three categories, AE, AC, and AE/AC with faculty who are not engaged in any of the three, which we categorize as "Traditional Scholars" (TS).[3] Together these four categories (AE, AC, AE/AC, and TS) characterize how university faculty engage with industry.

The agriculture and life science colleges of US land-grant universities (LGUs) are an important location to study UIR because their engagement with industry dates back to the end of the 19th century. This engagement stems from an emphasis on practical agricultural and engineering sciences, formal extension appointments for faculty, and ongoing outreach with farms and firms to improve their performance. Conversely, involvement with commercialization is much more recent

[2]We follow the classification adopted in Perkmann et al (2013).

[3]We are cognizant of the long-standing tradition of faculty, especially at Land-Grant Universities, engaging with industry. Our nomenclature is meant to distinguish between the traditional activities of teaching and research with UIR.

in the US and at most LGUs, having taken off at US universities following the passage of the Bayh-Dole Act in 1981 (Henderson and Jaffee, 1998; Thursby and Thursby, 2011). There is a vast body of research on academic commercialization and its impacts on faculty scholarship (Agarwal and Henderson, 2002; Azoulay et al. 2007) but relatively little that compares and contrasts it with the full UIR process.

The salience of UIR activities to US LGUs is also very important given the considerable financial stress they have faced over the past three decades due to significant declines in state and federal support (Just and Huffman, 2009; Ehrenberg, 2012). Both in public and private spheres, LGUs sought to increase the perceived and commercial value of their activities through UIR. In turn, most US LGUs intensively pursued academic commercialization as a potential mechanism to generate royalties and start-up revenue streams (Thursby and Thursby, 2011). At the same time, many LGUs faced tightening budget constraints in terms of extension budgets that put pressure on certain aspects of academic engagement (Hoag, 2005).

We address four major questions: What is the prevalence and intensity of AE and AC activities among agricultural and life science faculty at flagship public research universities across the United States? What role does UIR play in funding faculty research? How do the research and teaching outputs of faculty active in UIR activities compare to those of Traditional Scholars (TS)? And, last but certainly not least, how do the UIR activities and attitudes of land grant agricultural and life science faculty align with researcher problem choice? Because UIR activities "tend to be individually driven and pursued on a discretionary basis," (Perkmann et al. 2015, p. 424), we examine them at the individual faculty level where we can probe how they meet the values and motivations of faculty. Participation largely depends on the 'independent initiative of autonomous, highly skilled' faculty pursuing research and knowledge transfer activities that they value for scientific and/or commercial reasons.

Our descriptive empirical analysis provides a nuanced portrayal of the prevalence, coincidence, intensity, and productivity of faculty engagement in AE, AC, and TS. Factor analysis then highlights how faculty attitudes toward scientific discovery and commercialization align with AE, AC, and TS activities as well as with the types of research funding secured. Finally, regressions involving these attitudinal factors provide further insight into the correlations between faculty UIR participation and academic outcomes. Across all methods we explore how incentives, motivations, and values shape faculty engagement in UIR at three broad levels: individual, institutional and organizational characteristics.

Our results show that at US LGUs, AE, which includes sponsored research, industry collaborations, and presentations, is far more prevalent among faculty and financially important to them than is AC, which includes patenting, licensing, and start-ups. We find that UIR activities are higher among faculty with higher academic scholarship activity, so UIR and academic scholarship appear to be synergistic. While individual, institutional, and university-level factors all help explain faculty UIR activity, econometric analysis highlights differences across fields as well as faculty attitudes toward science and commercial activity in shaping the intensity of involvement with the two types of UIR. Significant differences also stem from university fixed effects and may be contingent on history, location, and quality of science.

The next section selectively reviews the literature on UIR activities, especially what research uncovers about factors shaping AE and AC activities. Section 3 introduces the data and explains our methods, including the use of factor analysis to construct faculty 'attitude scores'. Section 4 presents the results, while section 5 discusses the implications of our findings for UIR in the US. Section 6 concludes.

2 Select Literature Review

There is a large literature on university industry relations, but we focus here on a few recent studies primarily in the sociological literature that point toward the key issues to be investigated on university industry relations. Of note, most all of the recent studies of individual faculty behavior with respect to UIR focus on European universities, especially in England and Italy.

Sengupta and Ray (2017) offer a broad and dynamic framing of the relationship between UIR (what they call Knowledge Transfer) and research outputs at UK research universities. They explore the potential for dynamic feedbacks between past and current research performance, covering related UIR activities. Using a longitudinal, university-level dataset spanning 2008-14, they find that both AE and AC are positively associated with past research performance. However, consistent with the higher prevalence and intensity of AE relative to AC in UK universities, they also show that only AE has strong positive feedback effects on subsequent research performance, both via funding and research scholarship (using both quantity and quality measures). This sector-level finding in the UK sets the broad stage for our more ground-level consideration of UIR and research activities among individual agricultural and life science faculty in the major US Land-Grant universities.

In D'Este and Perkmann's (2011) study on a UK sample, they distinguish between two ways in which faculty attitudes toward UIR may shape participation. In the first, faculty are viewed as academic entrepreneurs who seek to engage in UIR for commercialization reasons, what we refer to as commercial motivation. In the second, faculty are viewed as scientists operating in a 'strongly institutionalized environment' who mainly seek UIR collaborations to advance their research efforts, what we later call scientific motivation. D'Este and Perkmann's particular focus is on 'collaboration' drivers and associated UIR outcomes. They attempt to identify which of the two sets of values, commercial or science, are stronger drivers of faculty UIR activities.

Perkmann et al. (2011) distinguishes between the likely UIR participation of faculty based on the type of science they do, basic or applied, as well as whether the faculty are 'star' scientists (Zucker and Darby, 1997). And, because UIR collaboration involves 'matching' between faculty and industry stakeholders and scientists, higher 'quality' faculty are likely to find it easier to forge collaborative initiatives. Combining these factors, their hypotheses are then organized around the distinction between more basic and applied scientific fields and the matching probabilities to suggest why there might be substantial heterogeneity in UIR participation across fields.

Perkmann et al. (2013), as well as Sengupta and Ray (2017), highlight the potential importance of university level infrastructure, research quality, and incentives for promotion and salary increases in shaping faculty engagement with UIR activities. Specifically, the historical experience and current resource base associated with university technology transfers offices can positively shape UIR outcomes. Likewise, universities with higher quality research performance may be more attractive to industry partners and thus attract UIR. Cutting the other way is the possibility that faculty at the very top universities, especially in some fields, may be less inclined toward applied research and UIR relative to pursuing large public or foundation grants and peer-based collaborations. In terms of incentives, linking tenure promotion or salary increases explicitly to external grants or commercialization could potentially shift behavior as well, though this administrative strategy may or may not align with values at the department level. Thus, attention to peer-based values and connections with UIR may be just as important as explored in Tartari et al. (2014).

3 US Land-Grant Universities

Three major legislative acts frame the longstanding tradition of academic engagement at US LGUs (Fitzgerald et al. 2016). The first is the Morrill Act of 1862 which granted states land to help finance the establishment of public universities. They emphasized agricultural and mechanical arts in support of those two major economic sectors, while broadening access to education and training. The second is the Hatch Act of 1887 which provided funding to land-grant universities to invest in agricultural experimental stations. It recognized the value of increasing public commitment to research that advanced knowledge for both farmers and consumers with respect to production and nutrition/health outcomes. Finally, the Smith-Lever Act of 1914 created the infrastructure for delivering knowledge to society via an extension system. It aimed at both sharing research discoveries with farmers, firms, and consumers and identifying future research issues based on feedback from those and other 'stakeholders'. Combined, these three acts shaped a long and rich history of 'academic engagement' at US LGUs that featured colleges of agriculture (and later 'life sciences') as the cutting-edge of UIR activities. Some faculty appointments included explicit attention to 'extension' in combination with traditional scholarship: research and instruction duties.

Faculty in US colleges of agricultural and life sciences generally span the breadth of basic and applied sciences reflected across the rest of public research universities.[4] Some departments are filled primarily with mostly basic scientists. This holds especially in "biology" departments, such as genetics, molecular biology, and biochemistry, as well as in "ecology" departments (of various names). There are mostly applied (but some basic) scientists in animal science departments (including specialties in dairy or poultry science), food and nutrition science departments, plant science departments (including agronomy, entomology, horticulture, plant pathology, and soil science), and agricultural or biosystems engineering. Finally, colleges of agriculture and life sciences have social scientist departments of various names that include economists, sociologists, journalism and communications, and regional planning and community development faculty. While most of these social scientists tend to work on more 'applied' questions, there are also some who could be viewed as closer to 'basic' in their orientation to pursuing advances on 'theory' and 'measurement' issues rather than emphasizing applied questions. Thus, the fields in US LGUs tend to provide distinctive 'institutional' contexts in which to frame the likely connections between faculty and UIR activities.

In the 1990s, as with other universities, academic commercialization efforts took off in US LGU colleges of agriculture and life sciences (Barham et al. 2002; Foltz et al. 2003; Sampat, 2006). Biotechnology patents especially were viewed as a potential source of growth and expansion in both UIR and revenue streams for universities and faculty inventors. A plethora of literature explores this period (Phan and Siegel, 2006; Grimaldi et al., 2011), with a primary focus on whether academic activities and the pursuit of open science would be advanced or reduced by the attention to commercialization efforts (Thursby and Thursby, 2011). At the 'field level', this AC push arguably expanded the potential for higher levels of faculty participation in UIR among more basic scientists who might be able to pursue patents on discoveries more readily than they might seek out sponsored research or active collaboration with industry scientists. Thus, it is arguable that AC engagement may be higher among biologists, but the longstanding engagement with AE activities by the more applied scientists could also readily give rise to patenting and commercialization efforts depending on the research topics and discoveries being pursued. These

[4] This is well described in both Perkmann et al. (2011) and Sengupta and Ray (2017).

cross-cutting trends make it difficult to envision a clear distinction in terms of AC participation across the natural science fields. On the other hand, social scientists are far less likely to be engaged with patenting and licensing efforts. Most of their 'idea' discoveries are likely to be algorithms and statistical or system modeling innovations rather than material ones. As a result, AC participation among social scientists is unlikely as compared to other types of science faculty in colleges of agriculture and life sciences.

The rise in US LGU efforts to promote AC coincided with a secular decline in federal and state support for higher education (Ehrenberg, 2012). While LGUs were initially able to largely compensate for that decline by raising tuition fees, significant pressures on the research and salary expenditures were experienced especially between 2005 and 2015. During that time period, most LGUs experienced an overall decline in state revenues. Faculty increasingly experienced real declines in salary levels as well as increased pressure to pursue extramural funding of various types - including UIR - to support their labs and their salaries (American Academy of Arts & Sciences, 2016). Indeed, many colleges of agricultural and life sciences pursued conversions of faculty salary contracts from 12-month to 9-month appointments. Faculty were 'incentivized' to pursue the additional 3 months of salary through external sources or 'administrative' postings. All of these changes could potentially be viewed as commercial or financial motivations to increase both AE and AC efforts, if in fact they held potential for filling holes in research budgets and faculty summer salary needs.

Two other contextual trends in US LGUs warrant attention here. One is the pressure on research time associated with 'changes' in university budgets. As documented in Barham et al. (2014), US LGU agricultural and life science faculty reported declines in 'research time' and concomitant increases in time spent on administrative activities. Reducing support staff and increasing faculty reporting efforts is one way in which LGUs dealt with budget cuts and compliance demands. This could have put pressure on faculty to limit UIR as part of the overall pressure on their time, especially research time. The other one, which is 'more speculative', is the potential for morale issues associated with this long period of budget pressures and time constraints. It seems likely that these could either have dampened enthusiasm for UIR activities (exhaustion) or increased incentives for faculty to pursue especially commercial links for more personal gain.

4 Data, Methods and Descriptive Statistics

This paper is based on data collected in surveys of agricultural and life science faculty conducted in 2005 and 2015. In each data collection effort we administered a survey to nearly 3,000 agricultural and life science faculty at all of the US 1863 LGUs.[5] Both surveys had a sample frame that included all tenure-track faculty scientists in agricultural and life science departments at these land-grant universities. We culled faculty names from university web directories to create the cross-sectional sample frame and then randomly selected a sample of scientists who were sent a web-based survey with follow-up paper-mail reminders as in Dillman (2011). In addition to the random samples in both years, we also re-sampled respondents from the 2005 survey in 2015 in order to have longitudinal data on 244 faculty. The response rate in 2015 was 32.9% based on respondents who answered at least one survey question, with a higher response rate in 2005 of 51%.

Response rates in 2015 did vary somewhat by discipline, from a high of 42% among plant scientists (the largest discipline represented) to only 28% among agricultural engineering scientists (the smallest discipline). We accept the null hypothesis of no response rate bias (see Barham et al. 2017) with respect to the following observed characteristics field, gender, faculty size of the agricultural college, total university research funding, or total full-time university student enrollment. In Appendix A we report further sample restrictions. Our final sample for analysis, from the random sample data collection, covers 982 scientists in 2005 and 628 in 2015 across all 52 LGUs. We also report some results from the longitudinal sample of scientists surveyed in both years.

Table 1 details the rich set of questions with respect to faculty UIR activities in our data. AE activities span a similar range described in the aforementioned studies in the UK. They cover collaborations, sponsored research by industry (and commodity organizations), presentations to

[5] The Institutional Review Board at UW-Madison approved both of these surveys, with the latest approval being #2015-0924

industry or farmers, and research problem identification. Likewise, AC activities span invention disclosures, patenting, licensing, product development, and start-ups.

Table 1: Types of university-industry relations and survey items included

University-industry Relations		**Survey item description**
Academic Engagement	Faculty participation in sponsored and collaborative research, contract research, and information relationships with private firms and institutions.	Had research support from private industry Had research support from commodity organizations Collaborated with scientists in private industry Co-authored with scientists in private industry Presented to farmers or farm organizations Presented to commodity groups Presented to the private industry Farmers or farm org. helped to you identify a research problem Collaborated on a research project with farmers or farm org. Co-authorship on paper or patent with farmers or farm org.
Academic Commercialization	Faculty participation in private intellectual property creation - via invention disclosure, patents, and licensing - and entrepreneurship (e.g. start-ups).	Had licensing or patenting revenue returned to your research lab Number of disclosures generated Number of patent applications generated Number of patents issued Number of patents licensed out Number of products under regulatory review generated Number of products on the market generated Number of start-up companies founded

Table 2 provides a comparison for 2005 and 2015 of the prevalence of each of the UIR activities. We use these data to construct categorical variables of AE and AC participation measures, as well as ones that identify when individuals do both (AE/AC). We identify individuals not fitting in any UIR category as Traditional Scholars (TS). The participation measure is 'liberal' in the sense that participating in any of the AE or AC activities identifies an individual with that category. We use these categorical variables to describe trends in UIR participation on the 'extensive' margin.

In addition to these key outcome variables, the subsequent analysis also focuses on other faculty research activities. We mostly focus on published articles, training of graduate students and post-docs, and receipt of research funding. Those research activities are incorporated into the comparisons of faculty across UIR categories in order to help identify the potential for synergies or tradeoffs between UIR and traditional scholarship outcomes. Similarly, we use data on total research grant revenues and different sources of revenue, such as federal, state, industry, commodity groups, foundations, and licensing revenues, to examine how UIR activities might change the relative importance of funding streams.

Table 2: AE and AC Activity Participation Rates and Counts, 2005 and 2015

Academic Engagement	**2005**		**2015**		Δ p.p.
	Rate	Count	Rate	Count	
Had research support from private idustry	0.46	455	0.45	281	-0.01589
Had research support from commodity organizations	0.32	311	0.29	179	-0.03167
Collaborated with scientists in private industry	0.29	288	0.36	224	0.06341***
Co-authored with scientists in private industry	0.12	120	0.15	94	0.02748
Presentated to farmers or farm organizations	0.41	398	0.38	238	-0.02631
Presentated to commodity groups	0.32	319	0.30	191	-0.02071
Presentated to the private industry	0.32	311	0.29	184	-0.02371
Had help from farmers or farm organizations to you identify a reseach problem	0.37	363	0.38	237	0.00773
Collaborated on a research project with farmers or farm organizations	0.27	268	0.31	196	0.03919
Co-authorship on paper or patent with farmers or farm organizations	0.03	31	0.03	19	-0.00131

Commercial Engagement	**2005**		**2015**		Δ p.p.
	Rate	Count	Rate	Count	
Received any royalties income from patent (past 5 years)	0.04	38	0.04	28	0.00589
Had licensing or patenting revenue returned to your research lab (last year)	0.02	24	0.04	23	0.01218
Number of disclosures generated	0.14	137	0.13	82	-0.00894
Number of patent applications generated	0.15	147	0.11	69	-0.03982*
Number of patents issued	0.09	92	0.06	39	-0.03158*
Number of patents licensed out	0.04	40	0.04	23	-0.00411
Number of products under regulatory review generated	0.02	21	0.02	10	-0.00546
Number of products on the market generated	0.07	72	0.05	29	-0.02714*
Number of start-up companies founded	0.03	33	0.03	17	-0.00653

Two other important sets of measures from the survey warrant description here. First, in both 2005 and 2015 surveys, respondents were asked about the reasons motivating them to pursue a certain research topic in the last five years. They are generally oriented toward 'scientific' motivations, such as 'scientific curiosity' or 'potential contribution to scientific theory', or commercial ones, such as 'potential marketability' or 'potential to patent and license the discovery'. The full set of 14 questions are shared below. They are all asked using a 1-5 Likert-type scale with a score of 1 being "not at all" and a score of 5 being "Extremely". Responses to these questions are examined using factor analysis in order to uncover latent factors that might shape faculty research choice. That approach is also more fully described in the Appendix, reporting on the actual factor loadings and estimated factors. Second, with respect to organizational - or university wide factors, we engage the issue by using a university fixed effect measure to control for differences across universities. We analyze the estimated parameters on those fixed effect results for patterns of university level incentives across LGUs.

4.1 Descriptive Statistics

We start with three broad observations that start to frame US-LGU participation in UIR activities. They can be gleaned from Tables 3 and 4, which provide, respectively, a comparison over time of faculty participation in the four UIR categories and a description of participation rates in AE and AC UIR activities by gender, rank, appointment type, and field. We find that US-LGU faculty participation rates in UIR activities are high. Between 60-90% of faculty in most fields participate in UIR, with minimal variation across rank, gender, or appointment type. The lowest UIR participation rates are in the 60-70% range for the biological, ecological and social sciences. This outcome is also consistent with findings from the UK mentioned above, where more basic research is associated with somewhat lower UIR activity.

Consistent with other evidence in the literature, AE participation is far more prevalent than AC, with about 75% of LGU faculty pursuing AE as compared to about 20% in AC. Moreover, if we isolate on the AC only category in Table 3, we find that around 2-3% of faculty are just doing AC in the two time periods. In other words, the vast majority of faculty engaged in AC activities are also active in AE. The proportion of faculty that are not engaged in UIR, the TS category, is greater than the total proportion active in AC. Thus, AC participation is the least prevalent in the mix of faculty engagement types examined here.

UIR participation changed somewhat between 2005 and 2015; declines in AC activities led the way, with a 6 percentage point decline from 25% of respondents in 2005 to 19% in 2015. When we look at the four exclusive measures, this change concentrates in faculty moving from AE/AC to AE only. AE participation was essentially unchanged. This decline in AC participation between 2005 and 2015 contradicts the expected increase based on university-level commercialization promotion in previous decades. We conclude that the popular perception following university rhetoric on expansion of UIR activities is not borne out by the behavior of LGU faculty in terms of engaging with industry in AC activities.

Table 3: Faculty participation rates in UIR, 2005 and 2015

	2005	2015	Diff.
Academic Engagement (AE)	0.75	0.76	0.01
Academic Commercialization (AC)	0.25	0.19	-0.06**
Multually exclusive measures			
Academic Engagement (AE) - Exclusively	0.53	0.59	0.06*
AC and AE	0.21	0.17	-0.05*
Academic Commercialization (AC) - Exclusively	0.03	0.02	-0.01
Traditional Scholarship	0.22	0.22	0.00

Table 4: Individual characteristics of UIR categories, 2005 and 2015

	2005				2015			
	AE	AE/AC	AC	TS	AE	AE/AC	AC	TS
Gender								
Female	0.54	0.23	0.03	0.20	0.58	0.19	0.02	0.21
Male	0.50	0.16	0.04	0.30	0.62	0.11	0.02	0.25
Rank								
Professor	0.50	0.24	0.03	0.23	0.57	0.21	0.02	0.20
Associate Professor	0.59	0.20	0.03	0.18	0.64	0.09	0.01	0.26
Assistant Professor	0.55	0.17	0.04	0.25	0.60	0.14	0.04	0.22
Fields								
Ag Engineering	0.57	0.33	0.03	0.07	0.61	0.21	0.04	0.14
Animal Science	0.60	0.30	0.03	0.07	0.61	0.23	0.03	0.13
Biology	0.23	0.26	0.10	0.41	0.35	0.20	0.09	0.35
Plant Science	0.63	0.26	0.03	0.08	0.68	0.25	0.01	0.06
Ecology	0.56	0.16	0.02	0.27	0.64	0.07	0.01	0.28
Food/Nutrition	0.51	0.34	0.04	0.11	0.46	0.34	0.00	0.20
Social Sciences	0.53	0.04	0.01	0.42	0.58	0.05	0.01	0.37

AE = Academic Engagement; AC = Academic Commercialization. We define Traditional Scholarship (TS) as those that do not engage in either AC or AE.

The decline in AC captured in the cross-section analyses can be a result of changes in the demographic composition of types of faculty. We look at individuals for which we have panel data to check for changes in individual faculty behavior over time. This smaller panel dataset was gathered as part of the ongoing study to probe the persistence of individual participation in each of the categories. Table 5 provides a transition matrix between 2005 and 2015 of UIR participation counts across the UIR categories.

Table 5: Persistence in faculty participation in UIR

		2015				
		AE	AE/AC	AC	TS	Total
2005	Academic Engagement (AE)	99	27	2	18	146
	AE and AC	16	30	2	4	52
	Academic Commercialization (AC)	1	2	1	2	6
	Traditional Scholarship (TS)	11	1	2	26	40
	Total	127	60	7	50	244

We offer three observations based on the transition patterns in Table 5. First, there is a high exit rate out of AC reflected in the AE/AC and AC rows, where only a little over half of faculty that were doing AC in 2000-05 stay engaged in AC activities in the 2010-15 time-period. By contrast, about 85% of faculty who were engaged in AE or AE/AC activities in 2000-05 remain engaged with AE activities in 2010-15. Viewed differently, other UIR categories show a higher rate of persistence over time that does AC. Second, the AC-only category is by far the least likely to gain faculty across the two time periods, reflecting the low likelihood of faculty activity in just AC. Third, a transition to AE/AC from any of the other categories is far more likely, suggesting the potential joint nature of AC with AE rather than the move to AC as an independent activity. Thus, the decline in AC evident in the cross-sectional data also shows up as a lack of persistence and a lack of new faculty entrants into this activity. Fourth, 25% of traditional scholars transitioned to AE activities over time, but at the same time a larger number of scholars transitioned from the UIR categories into the TS category. Thus the traditional scholars category increases from 16% to 20% of the sample, showing its robustness to the purported increase in UIR emphasis at LGUs.

Table 6 shows research funding for different UIR participation categories. It compares amounts of funding from different sources as well as the shares associated with each funding source.[6] Across

[6]Note that "Private Industry" and "Commodity Organization" fundings are used to define AE and "Patent

all of the UIR categories federal funding remains the primary source of research funds, with industry and commodity organizations playing a substantial but subordinate role. At 1% overall, licensing revenues from AC activities are a trivial source and they are 10 - 15 times smaller than the funds earned by faculty doing AE from private industry and commodity organization sources. Interestingly, faculty who earned patent royalties are only found within the AC faculty who also engages in AE. It is also worth noting that for the median research lab, those associated with faculty engaged in AC and AE/AC have the highest research funding levels across both years of data, although this pattern is less evident in the mean values. Both AE only and TS labs have at the median lower levels of funding.

Royalties" to define AC. Therefore, by definition, these amounts are zero for some UIR categories.

Table 6: Research lab financial sources across UIR types, 2005 and 2015

		2005				2015			
		AE	AE/AC	AC	TS	AE	AE/AC	AC	TS
Mean Research Lab Revs	$	158,073	211,376	256,063	112,627	292,627	396,048	284,459	271,912
Median Research Lab Revs	$	75,000	150,000	126,500	70,000	100,000	200,000	183,500	60,000
Fed Grants	$	76,739	94,661	198,238	70,902	162,598	220,446	202,886	213,966
	%	36.14	39.24	58.64	45.52	38.17	44.37	62.64	50.82
State Grants	$	16,069	17,399	7,432	6,125	20,106	18,078	14,286	18,168
	%	9.24	6.42	7.10	7.41	8.03	5.08	2.86	5.03
Private Industry	$	16,435	38,203	-	-	36,613	68,311	-	-
	%	11.81	17.00	-	-	12.62	16.74	-	-
Commodity Orgs	$	7,857	10,956	-	-	19,474	24,203	-	-
	%	8.28	8.95	-	-	8.85	7.71	-	-
Foundations	$	6,264	9,949	16,086	7,685	12,324	16,900	36,304	15,828
	%	4.27	3.81	4.09	7.08	6.11	4.93	13.79	6.06
University Funds	$	10,595	14,404	22,684	10,209	16,522	28,355	16,769	11,284
	%	10.62	7.83	17.43	16.00	11.04	9.24	14.64	14.67
Patent Royalties	$	-	3,766	-	-	-	4,031	-	-
	%	-	1.08	-	-	-	1.38	-	-
Others	$	16,337	17,278	11,623	9,763	22,621	15,724	14,214	10,471
	%	16.33	12.28	12.74	15.92	11.96	9.60	6.07	15.45

For each category of UIR, Table 7 reports on articles published in the last 5 years and being the main advisor for Ph.D. and Masters' students. Consistent with many other previous studies in the literature, academic outcomes are robust to faculty participation in UIR activities. The most active faculty in UIR, the AE/AC group have the highest article productivity (mean of 23 articles in 2010-15) and a similar number of Ph.D. students trained (mean of 2.5 in 2010-15) to the AC group (2.7). These compare to about 14 articles over 2010-15 for AE and TS categories and 1.7 and 1.6 Ph.D. students, respectively, for those two categories. The high outputs of the AE/AC group are consistent with synergies between UIR and scholarly outputs that is found in econometric studies elsewhere (e.g., Foltz, Kim, & Barham, 2003). Table 7 is also noteworthy for providing continued evidence of rising productivity over time of US-LGU faculty based on article counts (Prager et al. 2014).[7]

Table 7: Scholarly outputs across UIR types, 2005 and 2015

	2005							
	AE		**AE/AC**		**AC**		**TS**	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Scholarly articles (5 yrs)	11.17	9	16.65	14	16.64	14	10.54	9
Master students (5 yrs)	3.16	2	2.81	2	1.80	1	3.19	2
Ph.D. students (5 yrs)	1.42	1	1.86	2	1.93	2	1.84	1
	2015							
	AE		**AE/AC**		**AC**		**TS**	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Scholarly articles (5 yrs)	14.41	12	23.15	19	18.93	12	14.46	11
Master students (5 yrs)	2.83	2	2.41	2	2.00	1	1.93	1
Ph.D. students (5 yrs)	1.71	1	2.55	2	2.77	2	1.61	1

We turn next to Table 8 showing the values or stated preferences of US-LGU faculty with respect to their motivations for ‘research problem choice’. We first report for both 2005 and 2015 the average scores (1 low to 5 high) for a select set of questions related to ‘scientific motivations’ versus ‘commercial motivations’ and compare them across UIR categories. Note first that in both years, ‘enjoy the research’ and ‘scientific curiosity’ scores average well above 4 for all categories of faculty. By contrast, the scores for ‘potential marketability’ or ‘private firms commercialization interest’ are lower for all of the UIR categories relative to scientific motivations, by at least a full point and often times two or three points. By the same token, there is considerable variation across the UIR categories with respect to the commercial motivation scores with the AE/AC category having the highest scores and the TS and AE categories having the lowest. While we explore these

[7] We make no effort to control for quality or increases in co-authorship either of which could lead to an adjustment in the raw measure provided here. The evidence from Foltz, Kim, & Barham (2003) suggests quantity and quality (as measured by citations) are highly correlated, which suggests the bias from unmeasured quality could be small. We have no evidence on which way the bias from co-authorship patterns might go.

values further in the regressions below, this descriptive evidence identify scientific motivation as more important than commercial ones to US-LGU faculty research problem choices.

Table 8: Research choice criteria across UIR types, 2005 and 2015

	2005				**2015**			
Research Choice Criteria	AE	AE/AC	AC	TS	AE	AE/AC	AC	TS
Enjoy research	4.52	4.51	4.58	4.66	4.27	4.35	4.50	4.54
Scientific curiosity	4.16	4.25	4.33	4.37	4.02	4.18	4.43	4.40
Importance to society	4.32	4.24	4.27	4.21	4.06	4.30	4.29	3.99
Potential Marketability	2.43	3.34	2.70	1.68	1.76	3.08	2.50	1.36
Private Firms Commerc.	1.77	2.75	2.15	1.27	1.45	2.68	2.00	1.14

Note: These questions are reported using a 1-5 Likert-type scale, with a score of 1 being "not at all" and a score of 5 being "extremely".

We next use factor analysis to recover potential underlying factors explaining the variance in the motivations for research choices data. Two factors explains most of the variance in the data, which we identify as Scientific and Commercial Motivation factors. We constructed scores from estimated factor loadings and items shown in Table 9 using standard prediction methods. Some have consistent 'high loadings', such as scientific curiosity or potential contribution to scientific theory, for the scientific latent factor. Meanwhile, likely interest by private firms in commercializing the discovery and potential marketability of the final product "loads high" in the commercial latent factor. We use these factors in the econometric models of UIR participation we estimate in the next section.

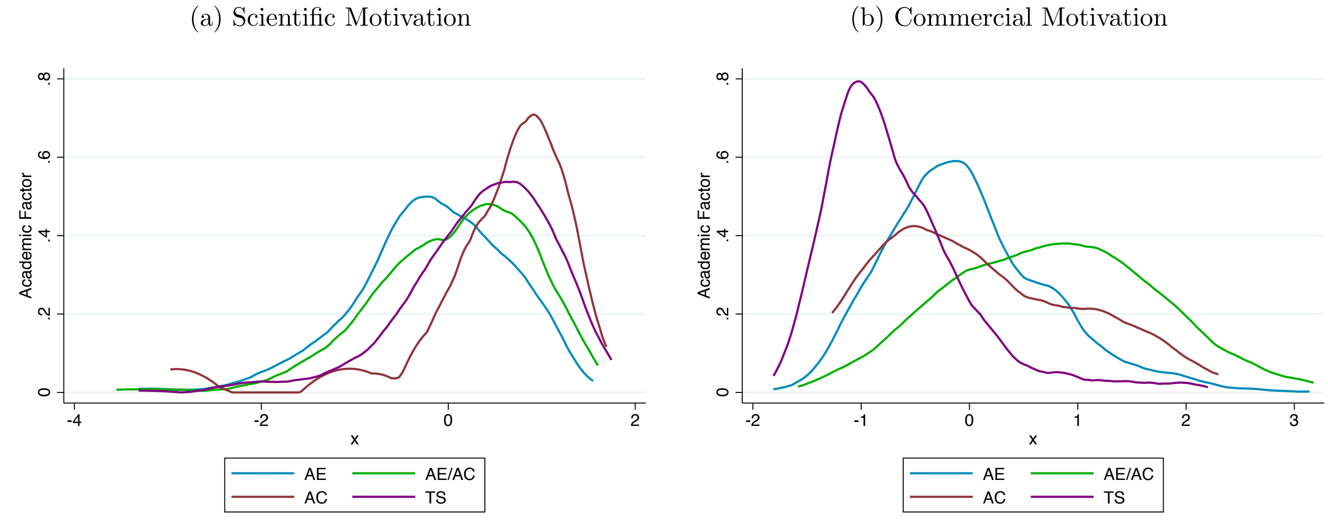
Table 9: Factor Loadings Estimation, after rotation

Item	**Commercial**	**Scientific**
Potential contribution to scientific theory		0.62
Scientific curiosity		0.62
Enjoy doing this kind of research		0.51
Probability of publication in professional journals		0.49
Availability of research facilities	0.38	0.31
Potential marketability	0.68	
Availability of public, state and federal funds	0.33	
Availability of private and corporate funds	0.52	
Request made by clientele	0.51	
Feedback from extension personnel	0.47	
Potential to patent and license the research findings	0.69	
Likely interest by private firms in commercialization	0.76	
Approval of colleagues		
Importance to society		

Note: Factors are calculated jointly for both waves. Comparing eigenvalues and its variances we confirm the existence of two factors. Together, they explain 93% of the variance. We used Principal Factor with orthogonal quartimax rotation to estimate the factor loadings. Factors scores are calculated using linear prediction.

We show the distribution of the factors by UIR category in Figure 1. As would be expected, traditional scholars are skewed far to the right on scientific motivations and far to the left on commercial ones. Yet we see that both categories of academic commercialization (AC and AE/AC) also have high levels of scientific motivation, with only AE as distinctly below the others. Meanwhile there is a fair amount of diversity in the commercial motivations beyond the low levels for the TS category. AE/AC appears to show both the highest average levels of commercial motivation and the greatest diversity of motivations within the category, as exemplified by a flatter distribution.

Figure 1: Distribution of Scientific and Commercial motivation by UIR category, 2005 and 2015 pooled



5 Empirical Strategy and Results

Descriptive statistics show remarkable differences in academic outputs across UIR as well as in factors shaping research topic choice. In order to isolate these relationships, we apply an econometric empirical strategy in which we estimate correlations between UIR categories and various university outputs. The models, which are correlational rather than causal, use Traditional Scholars (TS) as our comparison category.

In the first set of estimates, we set aside the determinants of UIR and we isolate how each UIR activity correlates with academic productivity. The uniqueness of our dataset allows us to control for an often unobserved dimension of individual heterogeneity: faculty motivations, both scientific and commercial. We also control for individual, field and institutional characteristics.

We estimate different versions of Equation 1, in which Y_{ifu} varies in each regression covering: number of journal articles, Ph.D. Graduates and Funding for scientist i in field f at university u. AC, AE/AC and AE are our mutually exclusive measures of UIR and traditional scholars is the omitted baseline category. The values F_i^S and F_i^C are the factor scores for scientific and commercial motivation, respectively. The vector X measures individual characteristics and includes: gender, university appointment (professor, assistant professor or full professor), and an indicator for whether the scientist was awarded a Ph.D. from a land-grant institution. The variables μ_f and ν_u are field and university fixed effects, respectively. Equation 1 is as follows:

$$Y_{ifu} = \alpha + \beta_1 AC + \beta_2 AE/AC + \beta_3 AE + \psi_S F_i^S + \psi_C F_i^C + \gamma X_i + \mu_f + \nu_u + \epsilon_{ifu} \qquad (1)$$

The standard errors are clustered at the university level to control for university level heteroskedasticity.

Table 10 shows the results of estimating equation (1) with journal articles and PhD students produced over the last five years as the dependent variable. The columns provide increasing levels of control variables, with a first column the baseline, the second adds in our motivational measures, the third individual controls, and the fourth field and university fixed effects. Across all models one sees two dominant statistically significant and large effects, which are (i) that compared to traditional scholars, AE/AC and AC only faculty produce more journal articles and more Ph.D. students and (ii) that "scientific motivations" are also significantly correlated with both journal articles and PhD students. We also see that once we control for individual effects that commercial motivations are also correlated with journal article production, though not at the level of scientific motivations. Overall the picture that emerges from Table 10 is that UIR faculty, especially those with commercial ties are more productive than traditional scholars. In addition, those in the AE only category appear to produce scholarship and students at about the level of traditional scholars.

Table 10: OLS estimates - Journal articles publications and PhD graduates under supervision, 2005 and 2015 pooled.

	Journal Articles				PhD Graduates			
AE only	0.335	1.425*	1.438*	0.745	-0.210	0.026	0.040	0.190
	(0.732)	(0.774)	(0.779)	(0.724)	(0.150)	(0.143)	(0.131)	(0.124)
AE/AC	6.970***	6.889***	6.121***	4.670***	0.365**	0.562***	0.393**	0.489***
	(1.135)	(1.085)	(1.067)	(1.068)	(0.176)	(0.185)	(0.184)	(0.158)
AC only	5.618**	4.679*	4.706**	4.313**	0.466	0.452	0.434	0.660*
	(2.186)	(2.351)	(2.309)	(2.132)	(0.347)	(0.377)	(0.354)	(0.349)
Scientific Motivation		2.937***	3.068***	2.704***		0.377***	0.404***	0.438***
		(0.449)	(0.481)	(0.517)		(0.067)	(0.064)	(0.076)
Commercial Motivation		0.654	0.876**	0.820*		-0.064	-0.003	0.067
		(0.428)	(0.422)	(0.457)		(0.070)	(0.065)	(0.060)
Survey year	x	x	x	x	x	x	x	x
Individual Controls			x	x			x	x
Field/University FE				x				x
Observations	1,568	1,568	1,568	1,568	1,465	1,465	1,465	1,465
R-squared	0.068	0.107	0.138	0.198	0.016	0.039	0.166	0.267

Note: coefficients on UIR categories are relative to traditional scholars (omitted). Dependent variables are total of articles published in the last 5 years and number of PhD graduates under supervision in the last 5 years. Individual controls include: gender, position as professor, and a dummy for whether PhD was in a land grant institution. Field includes: plant science, Ag/Engineering, animal science, biology, ecology, food/nutrition, and sociology. University fixed effects correspond to the 52 land-grant universities. Standard errors are clustered at the university level. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table 11 shows the results of estimating equation (1) with total funding and public funding as the dependent variable. It is worth noting that our categories of UIR are partially created with funding data, so we should expect a positive relationship with total funding, though not with public funding. Here we see very strong and statistically significant correlations of any UIR activity with both total funding and federal funding. While the former is somewhat expected, the latter suggests that rather than be a distraction from traditional scholarship directions, faculty engagement in UIR activities is synergistic with traditional scholarship. We also see strong correlations of scientific motivations with both total and federal funding, while commercial motivations are only correlated to total funding and not to federal funding.

Table 11: OLS estimates - Total and Public Funding, 2005 and 2015 pooled.

	Total Funding (IHS)				Public Funding (IHS)			
AE only	1.129***	1.373***	1.394***	1.343***	0.762**	1.358***	1.387***	1.489***
	(0.245)	(0.267)	(0.268)	(0.259)	(0.316)	(0.345)	(0.343)	(0.331)
AE/AC	2.004***	1.963***	1.975***	1.866***	1.480***	1.862***	1.777***	1.773***
	(0.264)	(0.303)	(0.309)	(0.308)	(0.393)	(0.460)	(0.470)	(0.471)
AC only	1.672***	1.442***	1.429***	1.336***	1.608**	1.489**	1.500**	1.667**
	(0.394)	(0.383)	(0.387)	(0.389)	(0.676)	(0.654)	(0.643)	(0.689)
Scientific Motivation		0.690***	0.672***	0.561***		1.077***	1.052***	0.910***
		(0.093)	(0.097)	(0.094)		(0.150)	(0.159)	(0.167)
Commercial Motivation		0.171**	0.158*	0.253***		-0.040	0.012	0.177
		(0.081)	(0.081)	(0.089)		(0.157)	(0.158)	(0.166)
Survey year	x	x	x	x	x	x	x	x
Individual Controls			x	x			x	x
Field/University FE				x				x
Observations	1,571	1,571	1,571	1,571	1,562	1,562	1,562	1,562
R-squared	0.056	0.098	0.101	0.156	0.014	0.051	0.056	0.115

Note: coefficients on UIR categories are relative to traditional scholars (omitted). Dependent variables current annual budget and its subcategory of total public funding. Total public funding categories are USDA, NSF, NIH, other federal agencies, and state agencies. Individual controls include: gender, position as professor, and a dummy for whether PhD was in a land grant institution. Field includes: plant science, Ag/Engineering, animal science, biology, ecology, food/nutrition, and sociology. University fixed effects correspond to the 52 land-grant universities. Standard errors are clustered at the university level. *** p<0.01, ** p<0.05, * p<0.10.

In the second set of econometric results, we flip around the correlations and explore individual and institutional factors shaping UIR engagement. Here, we explore the relative role of faculty motivations, and field and university specific effects. We estimate Equation 2 using a linear probability model with standard errors clustered at the university level. Our dependent variable UIR_{ifu} is an indicator variable for any UIR engagement, relative to traditional scholarship (TS). We adopt a flexible functional form to capture the potential correlation between motivation and UIR participation, $\sum_{k=1}^{k=4} Q_{k}{}_{i}^{m}$, with $m \in \{Sci, Com\}$. $Q_k F^m$ is an indicator for each quartile k of each motivation m distribution. $Q_1 F^m$ is the omitted category.

$$UIR_{ifu} = \alpha + \sum_{k=1}^{k=4} \beta_k^S Q_k F_i^{Sci} + \sum_{k=1}^{k=4} \beta_k^C Q_k F_i^{Com} + \gamma X_i + \mu_f + \nu_u + \epsilon_{ifu} \quad (2)$$

To demonstrate the correlations between UIR participation and our variables of interest which are all categorical we plot the effects in a series of figures. Figures 2 and 3 plot the set of estimated parameters for categorical variables, β_k^m, μ_f and ν_u, which are respectively motivation categories, university effects, and field effects.

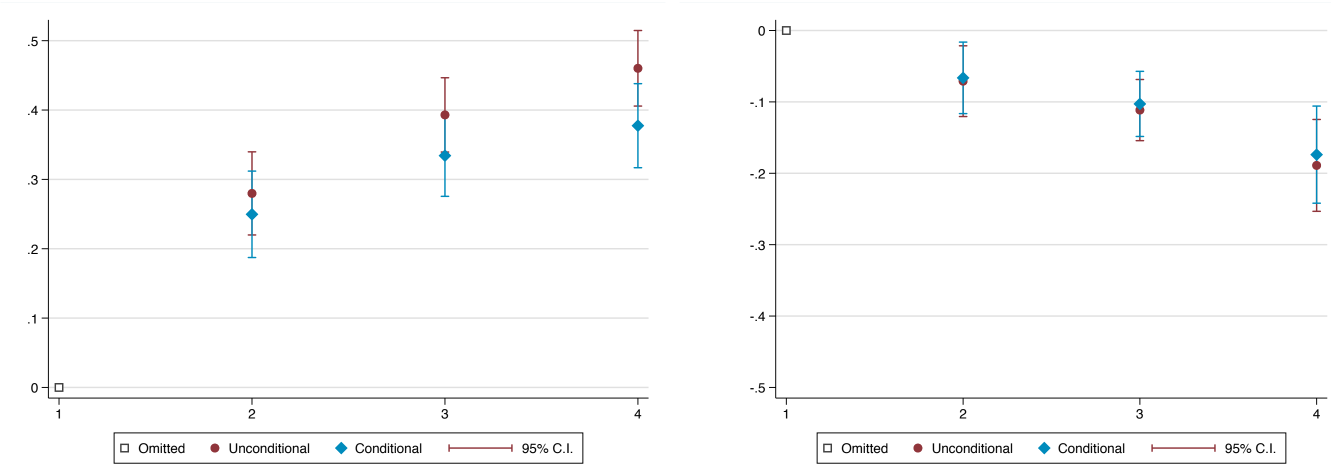
Figure 2 shows the parameter estimates for quartiles of the scientific and commercial motivation factors on the probability that a faculty member engages in UIR activities. The figure shows both unconditional (no other controls) and conditional (all controls in equation (2)) along with 95% confidence bands. The figure shows that as scientific factors increases there is a reduction in the probability of doing UIR activities and that when the commercial factor increases there is increase in UIR. These correlations corroborate the descriptive statistics above and the fact that there is little change between the conditional and unconditional versions is suggestive of robust effects.

In figure 3 we show how the estimated parameters on university fixed effects, estimated from equation (2) vary across university, with University of Wisconsin-Madison, which has the oldest technology transfer office among US universities as the baseline. Here we see a great deal of variation in coefficients. There are high university specific effects, which indicate more UIR activity at that university, at some of the major LGU's such as Illinois, UC-Davis, Purdue, Iowa State. But we also see some smaller LGU's Alaska, Rutgers in the top tier. There are some surprising effects with UC-Berkeley and Cornell in the bottom tier along with a number of smaller LGU's that have fewer resources and newer traditions of UIR.

The second half of the figure shows the estimated parameters on the field of specialty level fixed effects, with plant sciences, which is the largest category, as the baseline. The other production agriculture sciences, namely animal sciences, agricultural engineering, and food and nutrition studies are not statistically distinguishable from plant sciences. This result, likely driven by academic engagement in production agriculture fields, is expected. However, ecology and basic biological sciences show lower levels of UIR engagement than do plant sciences, despite those fields potentially having higher potential in commercialization. And as one would expect the social sciences are at the lowest levels of all of the agriculture and life science college disciplines in terms of UIR activities.

Figure 2: Linear probability model: (any) UIR engagement by quartile of attitudes

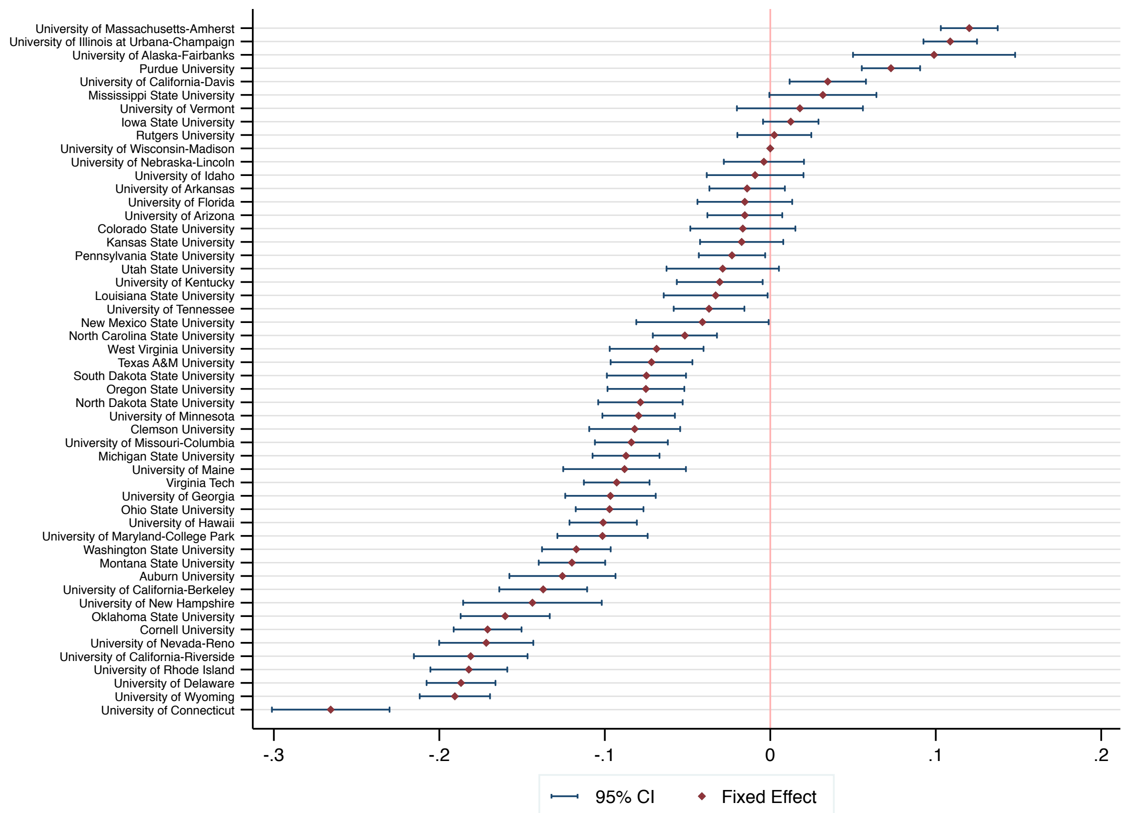
(a) Quartiles of Commercial Factor (b) Quartiles of Scientific Factor



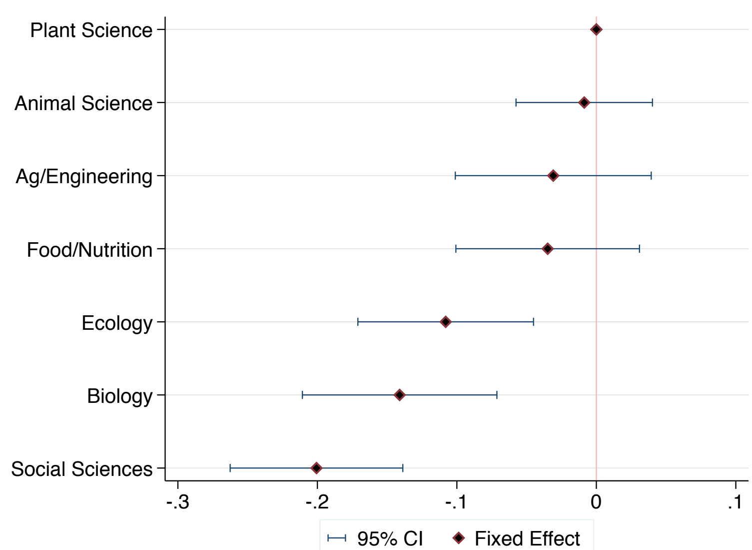
Note: coefficients are for quartiles of motivation, with the first quartile as omitted variable. Dependent variable is an indicator for whether individual engages in any UIR type (1) as opposed to being a traditional scholar (0). Unconditional estimates includes a survey year dummy. Controls for the conditional estimates include: gender, position as professor, a dummy for whether PhD was in a land grant institution, field (plant science, Ag/Engineering, animal science, biology, ecology, food/nutrition, and sociology), and university fixed effects, which correspond to the 52 land-grant universities. Standard errors are clustered at the university level.

Figure 3: Linear probability model of UIR engagement - Field and University Fixed Effects.

(a) University estimated FE



(b) Field estimated FE



Note: For both panels, dependent variable is an indicator for whether individual engages in any UIR type (1) as opposed to being a traditional scholar (0). (a) coefficients are for 52 university indicators, with UW-Madison as omitted variable. (b) coefficients are for field indicators, with plant science as the omitted variable. We choose plant science as the omitted variables for being the most popular field in our sample. The field of Social Sciences includes Ag. Economics and Economics departments. Coefficients from from both come from the same equation. Additional controls include: gender, position as professor, a dummy for whether PhD was in a land grant institution. Standard errors are clustered at the university level.

6 Discussion

Our empirical findings present a number of new findings for the study of UIR activities at US universities on a number of important fronts. First, faculty participation rates in UIR activity are quite high; generally, around 80-90% of US LGU agricultural and life scientists engage in AE, AC, or both. Second, faculty participation in UIR is predominantly in the area of AE, the more traditional type of research collaboration involving sponsored research, industry collaboration (including farmers and their commodity organizations), and other types of research exchanges (presentations and shared problem identification). In fact, only about 2-3% of faculty in either the 2005 or 2015 survey participated in just AC activities. Moreover, UIR activity trended a bit downward between 2005 and 2015, driven by a decline in faculty participation in AC activities. Third, as a source of research funding for agricultural and life science faculty at US LGUs, AE industry revenues completely dominate AC license revenues, but the largest individual faculty funding levels come from those who do both AE and AC. Overall, patent license revenues provide about 1% of lab revenues, as compared to close to a 20% share for industry and commodity group funds. This funding outcome appears to be in 'steady-state' now thirty-five years after the passage of the Bayh-Dole Act and more than twenty-five years after the takeoff of US public university patenting activity, as the ratio of AE to AC funding was the same in 2015 as it was in 2005.

This study also finds descriptive evidence that UIR activities are highly correlated and likely synergistic with traditional academic scholarship activities. This outcome is consistent with previous studies that find the more productive researchers are also often the ones most highly 'in demand' or active in UIR activities. While this study does not undertake the type of longitudinal dynamic statistical analysis of Sengupta and Ray (2017) who find positive feedbacks between AE and research outcomes at the university level, *prima facie* evidence here at the individual faculty level is consistent with that outcome. In particular our finding that the AE/AC faculty persist across time periods and that this group has more research revenues and higher publication and student counts, demonstrates this individual positive feedback loop.

This study examines factors shaping the participation of US-LGU faculty with UIR activities.

We find that institutional factors, specifically ‘fields’ or ‘disciplines’ are a significant conditioning factor, with more applied science fields like plant and animal sciences having higher UIR rates than more basic ones like biological and ecological ones. Most of the differences in UIR activity by fields are driven by variations in AE rather than AC as shown in the UIR activity regressions. This finding is consistent both with the lower overall participation in AC and the fact that most of the faculty active in AC are also active in AE. The reverse is not true. Most faculty engaged in AE are not active in AC. In this regard, it appears that AC may be somewhat opportunistic, and may depend on the types of inventions or discoveries being made by scientists. Put simply, ongoing collaboration with industry or sponsored research arrangements may, from time to time, give rise to the pursuit of invention disclosures and patents, and so entry and exit into AC activities appears to occur regularly as shown in the transition matrix in Table 5 above.

The most substantive individual factors shaping the intensity of participation in UIR appear to be faculty ‘attitudes’ with respect to research problem choice. While we do not attempt here to identify a causal relationship between attitudes and UIR activity involvement, agricultural and life science faculty at US-LGUs report that their research problem choices are strongly driven by scientific factors, such as curiosity or the potential to contribute to scientific theory relative to commercialization motives. This is true across all of the UIR categories used here, though what distinguishes the AE, AC, and AE/AC from TS is a somewhat stronger level of commercialization motive. This basic preference for science has been a consistent outcome across decades of surveys of US-LGU faculty and is consistent also with the continued importance of federal, competitive grants as a primary source of research funding.

Finally, university fixed-effect measures in our UIR regressions reveal statistically significant differences. These differences appear to relate to the timing of initial commercialization activity and potentially to other historical and locational factors that could be important for how they shape faculty behavior over time. This is an area of ongoing interest and potentially productive inquiry.

7 Conclusion

This article has examined the university-industry relations activities of agricultural and life science faculty at the premier US LGUs, using survey data gathered from large, random and longitudinal samples in 2005 and 2015. The analysis of this unique set of data fills an empirical gap identified in the literature by carefully exploring the relative importance of academic engagement and academic commercialization. Because US LGUs are 'ground-zero' of US public research university UIR activities, the empirical context is of broader significance to the US and beyond. We have found descriptive and correlational evidence that traditional academic scholarship has not systematically been distorted or constrained in the ways that some originally feared, and that UIR while important to faculty, universities, and society is not a fundamental threat to the advancement of science.

At US LGUs, the longstanding tradition of academic engagement, involving sponsored research and direct collaboration with scientists and managers in industry and agriculture, dominate the new academic commercialization relationships in prevalence, importance for faculty research funding, and intensity of involvement. Moreover, these two types of UIR appear to be complements, with AC being an occasional outgrowth of AE in some fields and for some faculty, which likely depends on the continuity of AE relationships to emerge. Seen in this way, the UIR activities of agricultural and life scientists at LGUs is more of a natural outgrowth of the Land-Grant system's traditional model of working with industry to foster improved outcomes in their own states and the nation. Fears of UIR subverting the mission appear to be misplaced, rather UIR appears to be helping the top scholars in agricultural and life science fields maintain or enhance their traditional scholarship levels while accessing more funding and connections with industries in their field.

Future research with these data will attempt to pursue a more causal identification of UIR participation and intensity outcomes using historical information as instruments as well as more of the panel data. Expanding the focus on university-level factors seems worth special attention in this effort. In addition, given the significant growth in the proportion of women and foreign faculty in the US LGUs over time, there are open questions as to whether this has changed the dynamics of UIR participation.

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Appendix A

A. Sample selection and imputation of missing values

	2005	**2015**
Random Sample	1,960	2,315
Sample completed survey	1,180	711
drop field=other	1,153	704
drop not professor	1,100	680
drop missing PCA	1,028	641
drop missing factor	1,028	641
drop cross-missing	982	628
Final Sample	**982**	**628**

Within the sample of individual who completed the survey, there was a large number of missing values. We assumed a set of hypothesis in order to impute values. (i) Research attitudes: Likert scale ranging from 0 to 5. We assigned a neutral value, ”3”, if the individual answered the block at least partially. When all items are missing, variables remain missing; (ii) UIR related measures: assigned zero to missing when the person answered part of the block. When all are missing, variables remain missing; (iii) Extension and Outreach: as long as the block is not all missing, missing values are replaces as zero; For each block, we calculated the total number of imputed values and results are robust to adding these variables in the regression as a control. Results upon request.

B. Research Incentives and Attitudes: factor analysis method

Factor analysis, as PCA, is another useful tool to reduce the dimensionality of a vector of variables and to control for measurement error. The method assumes each measure to be imperfect proxies for latent factors. In our context, we apply factor analysis to a set of 14 items related to attitudes towards research. It identifies blocks of correlation across the questions and to estimate the distribution of underlying factors that commonly explain the variance in the data.

Formally, these models estimate (unobserved) latent traits based on observed measures. Consider $F_i = (F_{i1}, ...F_{iK})$ as the set of K latent factors, $K = \{1, ..., K\}$. Each vector of factors F_i will be estimated from the set of N measures $M_{i,n}$, $n = \{1, ..., N\}$. Individuals are indexed by $i = \{1, ..., I\}$. Each measurement ($M_{i,n}$) for each individual i is such that:

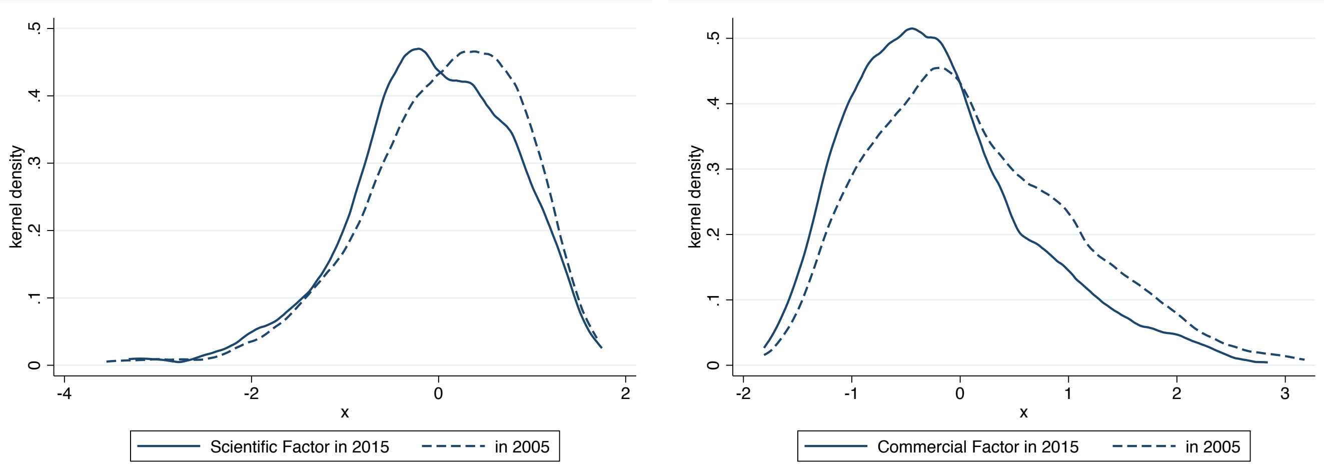
$$M_{i,n} = \beta_n' F_i + \epsilon_{i,n} \tag{3}$$

where $\beta_n = (\beta_{n1}, ..., \beta_{nK})$ are the factor loadings. The recovered factors are the ones that explain the maximum variance from the dataset. This procedure reduces the number of measures from N to K, while also controlling for measurement error, $\epsilon_{i,n}$.

For this exercise, we used the pre-programed Stata packages *factor, rotate* and *predict*. The factor estimation strategy employed here is a simple three step exercise of: (i) determining the number of factors; (ii) rotation and estimation of the factor loadings; (iii) prediction of the factors scores. For this analysis, we used all sample pooled for both years. The method is intuitively comparable to PCA, but the main and crucial difference can be seen by comparing Equations **??** and 3. PCA is a linear combination of the items, with the PCA as a result of this operation. On the other hand, by applying factor analysis, we are assuming the items are a proxy for one or more unknown underlying factors. In fact, each item is a linear combination of the latent factors.

Table 9 in the main text shows the results. We display the factor loadings that are higher than 0.3, which reveals a clear pattern. The first set of items composing the first factor block could be interpreted as scientific incentives for research while the second block is more related to commercial incentives. The resulting distributions for each factor, by year, is displayed in Figure 4.

Figure 4: Distribution of Commercial and Scientific Incentives Factors, pooled cross-section data.



Note: This figure displays the distribution of the estimated latent factors from the cross-section data for individuals surveys both in 2005 and 2015.