Academic engagement, commercialization, and scholarship: Empirical evidence from agricultural and life scientists at US land grant universities

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Abstract

This article examines the involvement of agricultural and life science faculty at US land grant universities in two types of university-industry relations (academic engagement, academic commercialization) and conventional academic scholarship. It exploits large-scale, random 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 that academic commercialization does. Consistent with previous work, UIR activities are higher among faculty with higher academic scholarship activity, so UIR and academic scholarship appear synergistic. While individual, institutional, and university-level factors all help explain faculty UIR activity, econometric analysis highlights differences across basic and applied 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, a topic of future inquiry.

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1 Introduction

Research on the factors shaping engagement with and impacts of University-Industry Relations (UIR) has exploded in recent decades, as reflected by the hundreds of articles published on this topic.[1] At the heart of this take-off was the push by universities around the globe to pursue opportunities to commercialize intellectual property rights via patents, start-ups, and other forms of corporate-university alliances. Arguably, the 1981 passage of the Bayh-Dole Act put US public research universities at the forefront of this global expansion. This legislation expanded the intellectual property rights of universities and their researchers to pursue commercialization of 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 spread into new domains beyond the classic 'academic engagement' associated with sponsored research, university and industry scientist collaborations, consulting, and the like.

Recent research raises a fundamental question regarding the importance of academic commercialization relative to that of academic engagement in the realm of UIR. Perkmann et al. (2013) review the evidence on hand regarding faculty activity in these two realms and compare the prevalence of faculty activity, the intensity, and the impacts of these types of university industry relations. Specifically, they identify substantive information gaps, two of which we address directly in this paper. One is the lack of comparative evidence from US universities regarding faculty engagement in distinct types of UIR activities. The other is 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. Our paper fills this gap by using rich and unique individual-level faculty survey data from 2005 and 2015. We explore the prevalence, intensity, and importance of US land-grant faculty engagement with two major types of university-industry relations (UIR). We also examine how faculty attitudes toward research choices shape their participation in UIR activities, and how they combine UIR with traditional scholarship activities (such as article publications and training of graduate students and post-docs).

As in Perkmann et al (2013), we focus on two basic types of UIR. 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. This definition is used in other recent articles that examine UIR among university faculty in the UK (D'Este and Perkmann, 2011; Perkmann et al., 2011; Tartari et al., 2014; Tartari and Salter, 2015; Sengupta and Ray, 2017). Academic commercialization (AC) is the other, defined as faculty participation in

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

private intellectual property creation (via invention disclosures, patents, and licensing) and entrepreneurship (e.g., start-ups). It is important to note that at US land grant universities (LGUs), involvement with AE dates back to the turn of the 20th century, stemming from an emphasis on agricultural and engineering sciences, formal extension appointments for faculty, and ongoing outreach with farms and firms to improve performance. Conversely, involvement with AC is much more recent in the US and the UK. It took 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).

The salience of these UIR activities to US LGUs is large given the considerable financial stress they 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). This study sheds light on the ground-level of UIR at leading US LGUs by examining detailed and representative survey data on the activities, attitudes, and research choices of agricultural and life science faculty at these institutions.

Perkmann et al (2013) reviews the state-of-knowledge about these somewhat contrasting but not mutually exclusive types of UIR. They probe the prevalence of AE and AC activities, mostly building on recent research that explores how faculty activity in UIR affects the productivity of traditional academic scholarship (AS). One of their main findings is that the vast majority of recent research on UIR examines only the less common activity of AC and mostly overlooks AE, the more pervasive and potentially important UIR in terms of faculty participation and actual resource flows, especially at public universities. The aforementioned studies in the UK confirm those conclusions, finding for example that faculty research funding from AE sources is upwards of 15 times greater than that from AC (Perkmann et al. 2011). Perkamann et al (2013) find surprisingly little examination of the two UIR activities side-by-side and the factors shaping faculty engagement with them. They directly call for more empirical work on these issues in the US context. As mentioned above, our article fills this knowledge gap by exploiting random, representative, 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 address five 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 AE, AC, both or neither type of UIR compare? Are there synergies across AE, AC, and AS activities? And, last but certainly not least, how do the UIR activities and attitudes of land grant agricultural and life science faculty align with respect to issues related to research problem choice? As in other recent studies, these questions are examined from the starting point that UIR activities "tend to be individually driven and pursued on a discretionary basis," (Perkmann et al. 2015, p. 424). 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 empirical analysis provides a nuanced portrayal of the prevalence, coincidence, intensity, and productivity of faculty engagement in AE, AC, and AS. Factor analysis highlights how attitudinal data align with AE, AC, and AS activities as well as with the types of research funding secured. Regressions involving these attitudinal factors provide further insight into faculty UIR participation and intensity of activity. And, similar to Perkmann et al. (2013), we explore how three broad sets of factors shape faculty engagement in UIR: individual: including training, age, gender, rank, and values or attitudes toward scientific research and UIR; institutional (e.g., field of study, extension appointment), and organizational (university-wide factors). Following a selective literature review and description of the US LGU context, we develop hypotheses about how these factors relate to AE, AC, and AS activities of agricultural and life science faculty.

Our results largely confirm the broad UK findings for US LGUs; they show that AE is much more pervasive and important than is AC among faculty in colleges of agriculture and life sciences in US LGUs. Also, attitudes and activity choice align in ways that are consistent with faculty participating in UIR largely for reasons related to advancing scientific research rather than in pursuit of commercialization outcomes. This finding is buttressed by the fact that almost 35 years after the passage of the Bayh-Dohl Act only around 1% of the funding for faculty research labs flows from AC UIR activities as compared to 15% or so from AE UIR activities. The proportion of AC funds actually declined somewhat between 2005 and 2015, and so did faculty involvement with AC activities. The fuller portrayal of the pattern of UIR activities presented in section 5 provides further nuances about factors shaping the intensity of faculty UIR participation.

The next section selectively reviews the literature on UIR activities, especially what UK research uncovers about factors shaping AE and AC activities. Section 3 develops some hypotheses based on the UK literature and the US LGU context. Section 4 introduces the data and explains our methods, especially the use of factor and principal component analysis to construct, respectively, faculty 'attitude scores' and UIR intensity measures for faculty across AC and AE activities. Section 5 presents the results, while section 6 discusses the implications of our findings for UIR in the US and compares them with results from the UK. Section 7 concludes.

2 Select Literature Review

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 research performance, and related UIR activities, to current research performance, in search of positive feedback loops or virtuous cycles between these two pillars of university research activity. Consistent with other recent studies, they distinguish between AE and AC in order to explore not only which might be more prevalent and important in terms of Knowledge Transfer activities associated with university research but also for their respective roles in promoting future university research advances. 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 much 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 agricultural and life science faculty in the major US Land Grant universities.

Similar to D'Este and Perkmann (2011), our study highlights the role of faculty attitudes toward UIR. We use survey questions on values shaping research choices to estimate factor scores that are used to examine participation decisions in different forms of UIR. In their study, 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 goals. 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 goals. D'Este and Perkmann's particular focus is on 'collaboration' drivers and associated UIR outcomes, and they attempt to identify which of the two sets of values, commercial or science, are stronger drivers of faculty UIR activities. Their main regressions are ordered logits that exploit the count information they have on UIR participation in collaborative efforts of different types, which they use as a dependent variable along with attitudinal measures and a series of other individual and organizational control variables. We run similar analyses using intensity measures of AE and AC activity rather than the ordinal models they use.

Consistent with the findings of Perkmann et al. (2011), our study also explores the specific role of 'fields' and 'appointment type' as measures of institutional factors that can shape UIR participation. Their study 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.

More applied or technologically oriented fields, such as engineering or food science in a college of agricultural and life sciences, would be ones where higher quality faculty would be more likely to participate in UIR, and star scientists perhaps even more so. In a more basic field, the same general positive correlation between faculty quality and UIR might be present, but 'star scientists' could be less likely to be involved in UIR because the expected gains might be smaller and the constraints might not make it worthwhile. Put differently, the star scientists in basic sciences might put more emphasis on competitive federal grants and academic collaborations. Below, we build on a similar conceptual platform for the development of our LGU hypotheses about how fields of study within US agricultural and life science colleges may have distinctive patterns of UIR participation based on both their basic versus applied characteristics and what specific fields tend to value in terms of 'scientific' innovation. However, we do not feature 'star scientists' in our analysis, though they may be embedded in the category of faculty engaged in AE and AC activities.

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). Our empirical analysis mostly sets aside the university level factors for future study by controlling for them using a university fixed-effects approach. However, as shown below, we are able to identify some initial trends of interest from the fixed-effect estimates.

3 US Land Grant University Context and Hypotheses

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 dedicated to broadening access to education and training as well as advancing agricultural and mechanical arts in support of advancing the performance of those two major economic sectors. The second is the Hatch Act of 1887 which 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 that was 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, with some faculty appointments including explicit attention to 'extension' in combination with traditional 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 as well described in both Perkmann et al. (2011) and Sengupta and Ray (2017). US LGU colleges of agricultural and life sciences generally consist of departments with mostly basic scientists, 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, they have social scientist departments of various names that include economists, sociologists, journalism and communications faculty, 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, similar to Perkmann et al. (2011), the fields in US LGUs tend to provide distinctive 'institutional' contexts in which to frame the likely connections between faculty and UIR activities.

Department homes are not 'clean' identifiers for the basic versus applied research orientation of faculty at LGUs. For example, the rapid expansion of genomic research over the past two decades has promoted a blending of biological science with more applied agricultural units. Path-breaking genomic and genetics research could readily be coming out of animal and plant science units as well as biological ones in a college of agriculture and life sciences. Likewise, efforts to improve eco-system outcomes of managed and natural systems could be emanating from both basic and applied units. One clean distinction between these types of fields is the likelihood of faculty carrying extension appointments, which make 'academic engagement' with farmers, industry, or other non-university stakeholders a core (and basically required) activity area for some LGU faculty. Specifically, extension appointments are far more likely to occur in the applied agricultural/food sciences and social science departments than they are in the biology units. Ecology units can fall on either side of that divide depending on what else they are linked with (e.g., forestry). Overall, though, when we combine the likely divide that favors basic over applied research, with the lack of faculty with extension appointments, biological departments (and similarly ecology departments) are less likely to provide the institutional platform for 'academic engagement' than are the other two major types of applied and social science units in US colleges of agriculture and life sciences.

In the 1990s, 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 AS 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 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 given that 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 highly 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 revenues, and 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, moving from what had conventionally been 12-month to 9-month appointments in which 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, as one way in which LGUs dealt with budget cuts and compliance demands was to reduce support staff and increase faculty reporting efforts. Likewise, faculty appeared to have taken on more 'administrative' responsibilities in terms of running programs and managing budgets and personnel. 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 also put downward pressure on the likelihood of US LGU faculty making the extra effort to pursue UIR activities.

3.1 Hypotheses

The above literature review leads to eight hypotheses about the levels, extent of, and evolution over time of UIR activities in US Land Grant University Colleges of Agriculture and Life Sciences. Below we develop the general hypotheses for UIR activities, although in our analysis we will often break UIR into its constituent parts of AE and AC activities. In most cases, we provide evidence that allows evaluation of the consistency of the hypotheses rather than testing them in a formal statistical sense.

Hypothesis 1: Participation: US-LGU's have a high participation rate in UIR activities. As outlined in the literature review, Land Grant universities have a long-standing tradition of working directly with industries, especially in the fields of agricultural and life sciences. We therefore expect this to lead to UIR participation by the vast majority of LGU faculty. Given that the tradition has been primarily about faculty engaging with farm and industry issues and problems, we expect this effect to be significantly stronger for AE than AC. What is not clear is whether AC is in ascendance given the push by LGU administrations and technology transfer offices to encourage higher levels of university commercialization of academic research.

Hypothesis 2: Rate of Change: UIR activities are increasing at US-LGU's based on the recent expansion of university AC promotion efforts. Because AC activities are potentially complementary to AE ones, and because they might appeal to faculty with more 'basic' science emphasis (Perkmann et al. 2011), UIR efforts could be expanding with AC. Two potential counterpoints might be the overall decline in 'time for science' as reported in Barham et al. (2014), as well as morale issues of extended downward pressures on LGU budgets and faculty salaries.

Hypothesis 3: Funding: UIR activities provide significant funding for US-LGU research activities.

Based on historical trends in AE and the recent push for expansion of AC activities, along with declines in state funding levels, UIR is expected to play a significant and perhaps growing role in funding faculty research activities. However, based on the UK experience, AC funding levels may be much less important than AE.

Hypothesis 4: Synergies: UIR activities are broadly synergistic with other US-LGU outputs such as producing articles and training graduate students. A wide set of studies in the US and UK document the apparent synergies between UIR activities, especially patenting, and traditional academic scholarship in public and private research universities. We expect similar outcomes in this context, though the mechanisms are not a focal point here.

Hypothesis 5: Scientific Motivations: The pursuit of scientific discoveries are the primary motivation shaping US-LGU faculty participation in UIR activities. Consistent with Sengupta and Ray (2017) and many other researchers, we distinguish between scientific and commercial motivations in shaping research choices and engagement in UIR activities. We argue that researchers are most likely to participate in UIR when the potential for scientific advance aligns well with UIR. One reflection in this alignment is the match between stated preferences or values and UIR activity. This hypothesis is one of the main 'behavioral' correlates explored below.

Hypothesis 6: Monetary Incentives: Monetary or commercial incentives are a positive, significant but less common motivation for US-LGU faculty research problem choice and participation in UIR activities than are scientific motivations. As discussed above, faculty research activities are shaped by multiple factors. The potential for financial payoffs, at the individual or research lab level, are likely to be positively related to those choices, especially in fields where scientific interests and private sector interests closely align. Nonetheless, for many faculty, commercial incentives will play a much smaller role based on values, field orientation, success in securing public research funds, and so forth.

Hypothesis 7: Fields of Study: US-LGU faculty in different fields of study have distinct participation rates in and patterns of UIR. As discussed above and detailed in Perkmann et al. (2011), the match between 'institutional factors' and UIR activities is likely to be shaped by how well different fields of study and their research emphases align with the needs of private economic agents, such as farmers and firms. In the US LGU case, we would expect applied science types, such as animal and plant scientists, to be more engaged in UIR activities, especially AE activities, than are more basic-research oriented biological, ecological and social scientists. On the other hand, we would expect more AC activity from basic scientists as compared to applied and especially social scientists.

Hypothesis 8: Extension orientations: Faculty with extension appointments have a higher propensity to engage in AE activities. The job description of faculty with extension appointments 'bakes in' academic engagement with the emphasis placed on linking research to outreach efforts in an integrated fashion. This would be especially true for faculty in the applied sciences, where they might also be expected by those with only research and instruction appointments to provide a bridge to 'industry' stakeholders.

4 Data and Methods

In the spring of 2016 we administered a survey to nearly 3000 agricultural and life science faculty at all of the US 1863 LGUs (The Institutional Review Board at UW-Madison approved this survey, #2015-0924). Similar to the 2005 survey, the 2015 sample frame 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 2,315 scientists who were sent a web-based survey with follow-up paper-mail reminders as in Dillman (2011). The response rate was 32.9% based on respondents who answered at least one survey question.

Response rates 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.

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

University-industry Relations			Survey item description
University-industry Relations	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

As shown in Table 1, the survey includes a rich set of questions with respect to faculty UIR activities. AE activities span a similar range described in the aforementioned studies in the UK including collaborations, sponsored research by industry (and commodity organizations), presentations to industry or farmers, and research problem identification. Likewise, AC activities span invention disclosures, patenting, licensing, product development, and start-ups. 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 neither UIR or both (we call that AE/AC). 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 as the main way describe trends in UIR participation on the 'extensive' margin.

We also use the same questions from Table 2 to construct intensive measures of AE and AC participation using principal component analysis (PCA). Construction of those measures are described more fully in the appendix, but these intensity measures are used mostly in the regression analysis when we explore correlations of different individual, institutional, and organizational factors with the intensity of UIR activity. The measures themselves also provide a richer portrayal of the 'depth' of AE and AC activities.

In addition to these key outcome variables, the subsequent analysis also focuses on other faculty research activities, which we label as AS (academic scholarship). We mostly focus on published articles and training of graduate students and post-docs, though the survey data include some other measures like books and conference abstracts. 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 AS outcomes. Similarly, we use data on total research grant revenues and different sources, such as federal, state, industry, commodity groups, foundations, and licensing revenues, to examine the relative importance of funding streams and levels to relate them to UIR categories.

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	434	0.43	271	-2.59
Had research support from commodity organizations	0.31	296	0.28	176	-3.17
Collaborated with scientists in private industry	0.30	288	0.36	223	5.18
Co-authored with scientists in private industry	0.13	119	0.15	93	2.28
Presentated to farmers or farm organizations	0.38	364	0.38	238	-0.46
Presentated to commodity groups	0.29	272	0.31	196	2.56
Presentated to the private industry	0.03	28	0.03	19	0.08
Had help from farmers or farm organizations to you identify a reseach problem	0.44	414	0.38	237	-5.90
Collaborated on a research project with farmers or farm organizations	0.35	329	0.30	189	-4.59
Co-authorship on paper or patent with farmers or farm organizations	0.34	317	0.29	180	-4.76

Commercial Engagement	**2005**		**2015**		Δ p.p.
	Rate	Count	Rate	Count	
Received any royalties income from patent (past 5 years)	0.05	43	0.04	28	-0.07
Had licensing or patenting revenue returned to your research lab (last year)	0.02	23	0.03	18	0.44
Number of disclosures generated	0.16	147	0.13	82	-2.44
Number of patent applications generated	0.16	152	0.11	70	-4.89
Number of patents issued	0.10	91	0.06	39	-3.39
Number of patents licensed out	0.04	40	0.04	23	-0.55
Number of products under regulatory review generated	0.02	21	0.02	10	-0.62
Number of products on the market generated	0.08	71	0.05	29	-2.87
Number of start-up companies founded	0.04	37	0.03	17	-1.20

Two other important set 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, with the actual factor loadings and estimated factors being shared in the next section.

Finally, with respect to organizational - or university wide factors, we engage the issue in two specific ways. First, we use a university fixed effect measure to control for differences across universities, and we look at those fixed effect results for patterns relative to a top tier LGU in both arenas. Second, we construct for each university three relative measures of incentives for AE and AC as compared to AS by using survey questions on faculty perceptions of how different activities contribute to promotion and tenure incentives. These AE/AS and AC/AS responses for each university are grouped by basic, applied, and social scientists to construct a university average for these three types of fields, with each measure reflecting how those types of scientist view the relative incentives for AE to AS or AC to AS. These measures are used as a control variable to explore whether perceptions of university incentives shape AE or AC engagement across our three broad fields of science in LGUs.

5 Results

We start with three broad observations that help to frame US-LGU participation in UIR activities. They can be gleaned from Tables 3 and 4, which provide, respectively, a description of participation rates in AE and AC UIR activities by gender, rank, appointment type, and field and a comparison over time of faculty participation in the four UIR categories.

- Consistent with hypothesis 1, US-LGU faculty participation rates in UIR activities are very high. Between 80-90% 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.
- Also consistent with the explanation of hypothesis 1, AE participation is far more prevalent than AC, with about 75% of faculty pursuing AE as compared to less than 20% in AC.

Moreover, if we isolate on the AC only category in Table 4, 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. And, the proportion of faculty that are engaged in neither AE nor AC is greater than the total proportion active in AC. Thus, AC participation is the least prevalent of the three broad types of UIR in our data.

- UIR participation, overall, fell somewhat between 2005 and 2015; declines in AC activities led the way, with a 7 percentage point decline from 26% of respondents in 2005 to 19% in 2015. AE participation was essentially unchanged, 77% in 2005, 76% in 2015. This decline in AC participation between 2005 and 2015 contradicts hypothesis 2 that envisioned an 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 behaviour of faculty in terms of engaging with industry in AC activities.

Table 3: Individual characteristics of UIR categories, 2005 and 2015

	2005				**2015**			
	AE	AE/AC	AC	Neither	AE	AE/AC	AC	Neither
Gender								
Female	0.53	0.18	0.04	0.24	0.62	0.10	0.02	0.25
Male	0.55	0.24	0.03	0.18	0.58	0.19	0.02	0.21
Rank								
Professor	0.52	0.25	0.03	0.19	0.57	0.21	0.02	0.20
Associate Professor	0.58	0.22	0.03	0.17	0.63	0.09	0.01	0.26
Assistant Professor	0.55	0.18	0.04	0.23	0.60	0.14	0.04	0.22
Fields								
Ag Engineering	0.56	0.34	0.03	0.07	0.59	0.22	0.04	0.15
Animal Science	0.57	0.32	0.04	0.06	0.61	0.23	0.03	0.13
Biology	0.24	0.26	0.11	0.39	0.35	0.20	0.09	0.35
Plant Science	0.62	0.26	0.03	0.09	0.68	0.25	0.02	0.06
Ecology	0.56	0.17	0.01	0.26	0.63	0.08	0.01	0.28
Food/Nutrition	0.51	0.34	0.02	0.12	0.46	0.34	0.00	0.20
Social Sciences	0.63	0.03	0.01	0.32	0.59	0.04	0.01	0.37

Table 4: Faculty participation rates in UIR, 2005 and 2015

	2005	**2015**	Δ p.p.
AE	0.77	0.76	-1.82
AC	0.26	0.19	-7.21
AE only	0.55	0.59	4.40
AC only	0.03	0.02	-0.99
AE/AC	0.23	0.17	-6.22
Neither	0.19	0.22	2.81

Since the rejection of hypothesis 2 presented above might be based on changes in the demographic composition of or types of faculty rather than on changes in individual faculty behavior over time, we also examine the persistence of UIR activities among the same faculty. Specifically, we use a smaller panel dataset 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

Percentage

		2015				
		AE	AE/AC	AC	Neither	**Total**
2005	AE	41%	11%	1%	7%	60%
	AE/AC	6%	13%	1%	2%	22%
	AC	0%	1%	0%	1%	2%
	Neither	4%	0%	1%	11%	16%
	Total	52%	25%	3%	20%	100%

Count

		2015				
		AE	AE/AC	AC	Neither	**Total**
2005	AE	97	26	2	16	141
	AE/AC	15	30	2	4	51
	AC	1	2	0	2	5
	Neither	9	1	2	25	37
	Total	122	59	6	47	234

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 80% 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. The panel data evidence bolsters the contradictory evidence on hypothesis 2 with respect to AC activities, and we return to this issue below after considering more evidence on UIR activities.

In order to provide evidence on hypothesis 3, Table 6 shows research funding outcomes for different UIR participation categories, showing amounts of funding from different sources as well as the shares associated with each funding source. The main observations emerge from comparing industry and commodity funding outcomes with those from patent licensing in both 2005 and 2015. Notice first that in neither of the two time periods did any individuals in the AC-only category report receiving licensing revenues from their inventions, while in the AE/AC category the mean funding amounts from licensing were under $5,000 per year and just over 1% of the research budget for those faculty in both 2005 and 2015. By contrast, the mean funding amounts for both industry and commodity organizations for the AE/AC categories were 16-20 times the amounts of licensing revenues, and for AE/AC types those sources accounted for more than 25% of the faculty's total research budgets.

Across the board the evidence in Table 6 demonstrates that AE funding is far more important in its support for US-LGU faculty research than is AC. This is true more than 3 decades after the passage of Bayh-Dole and 25-30 years after most LGUs began pursuing commercialization opportunities in earnest. Across 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. Thus, hypothesis 3 on funding is confirmed for AE, but not for AC activities. Overall, we conclude that UIR activities do not appear to be expanding their role in financing research despite recurrent financial pressures and university promotional efforts to do so, at least in colleges of agricultural and life sciences.

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

		2005				2015			
		AE	AE/AC	AC	Neither	AE	AE/AC	AC	Neither
Research Lab Revs (Mean)	$	159,757	219,218	148,129	105,662	291,887	402,126	275,495	271,912
Research Lab Revs (Median)	$	75,000	150,000	120,000	65,000	100,000	200,000	167,000	60,000
Federal Grants	$	76,731	102,449	102,116	68,158	157,608	222,213	194,592	212,927
	%	36.07	39.44	60.63	47.42	37.92	43.17	62.33	50.43
State Grants	$	16,375	19,395	11,260	5,663	21,034	18,256	17,133	19,825
	%	9.32	6.82	9.17	7.48	8.17	4.85	5.20	5.53
Private Industry	$	16,741	39,380	-	-	38,966	70,745	-	-
	%	11.63	17.60	-	-	13.05	17.46	-	-
Commodity Orgs	$	8,768	11,233	-	-	20,767	25,307	-	-
	%	8.91	9.02	-	-	9.23	8.03	-	-
Foundations	$	6,113	9,565	2,825	5,915	13,335	17,509	34,266	17,115
	%	4.06	4.11	1.77	5.95	6.29	5.24	12.93	6.59
University Funds	$	11,146	14,706	23,030	10,532	17,025	29,163	16,037	12,930
	%	10.91	7.57	15.65	15.84	11.31	9.46	13.74	16.12
Patent Royalties	$	-	3,975	-	-	-	4,116	-	-
	%	-	1.24	-	-	-	1.41	-	-
Others	$	17,550	16,719	9,127	10,263	23,808	16,419	13,467	10,669
	%	17.17	12.21	10.48	17.48	12.34	9.86	5.80	15.61

For each category of UIR, Table 7 reports on articles published in the last 5 years, main advisor for PhD and Masters' students, as well as on industry collaborations and patents as a test of hypothesis 4. Consistent with many other previous studies in the literature, academic scholarship (AS) 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 23.5 articles in 2010-15) and a similar number of Ph.D. students trained (mean of 2.59 in 2010-15) to the AC group (2.57). These compare to about 14 articles over 2010-15 for AE and Neither categories and 1.73 and 1.61 Ph.D. students, respectively, for those two UIR categories. The high AS outputs of the AE/AC group are consistent with synergies between UIR and AS activities that is found in econometric studies elsewhere (e.g., Foltz, Kim, & Barham, 2003). Secondary comparisons of AE and AC faculty with the Neither category also show similar or higher productivity levels for

AS activities, so there is no prima facie evidence to contradict hypothesis 4 of synergies rather than tradeoffs between UIR and AS activities. 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).[2]

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

	AE		**AE/AC**		**AC**		**Neither**	
2005	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Scholarly articles (5 yrs)	11.44	9	16.71	14	13.34	14	10.55	9
Masters students (5 yrs)	3.15	2	2.88	2	1.83	1	3.10	2
PhD students (5 yrs)	1.42	1	1.81	2	1.67	2	1.65	1
Collaborations Industry (past year)	0.89	0	1.31	0	0	0	0	0
Invention disclosures (5 yrs)	0	0	1.54	1	1.09	1	0	0
Patents Applications (5 yrs)	0	0	1.53	1	1.06	1	0	0
Patent royalties*	.	.	32,067	1,150	0	0	.	.
2015								
	AE		**AE/AC**		**AC**		**Neither**	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Scholarly articles (5 yrs)	14.64	12	23.25	19	19.20	13	14.67	12
Masters students (5 yrs)	2.85	2	2.41	2	1.85	1	1.93	1
PhD students (5 yrs)	1.73	1	2.59	2	2.57	2	1.61	1
Collaborations Industry (past year)	1.18	0	1.89	1	0	0	0	0
Invention disclosures (5 yrs)	0	0	2.05	1	0.93	1	0	0
Patent Applications (5 yrs)	0	0	1.49	1	0.67	1	0	0
Patent royalties*	.	.	3,895	0	0	0	.	.

*Conditional on receiving any patent royalties: 2005 = 43 observations, 2015 = 28 observations.

We turn next to hypotheses 5 and 6 with 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 doing UIR activities and are significantly higher for AC and Neither than for the AE and AE/AC categories. 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

[2] 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.

with the AE/AC category having the highest scores and the neither and AE categories having the lowest. While we explore these values further in the regressions below, this descriptive evidence on stated preferences is consistent with hypotheses 5 and 6 that identify scientific motivation as more important than commercial ones to US-LGU faculty research problem choices.

The binary categories of AE and AC used so far may mask significant differences in the intensity of UIR activity. We therefore turn to a next set of results that integrate a principal component analysis (PCA) intensity measure of UIR activity with the factor analysis scores from the 'research choice' attitudes just discussed. This PCA method allows us to examine the intensity of UIR activities and provide a 'visual' heat map of the correlations across UIR activities and attitudes. Prior to presenting those figures, we briefly discuss each of the measures.

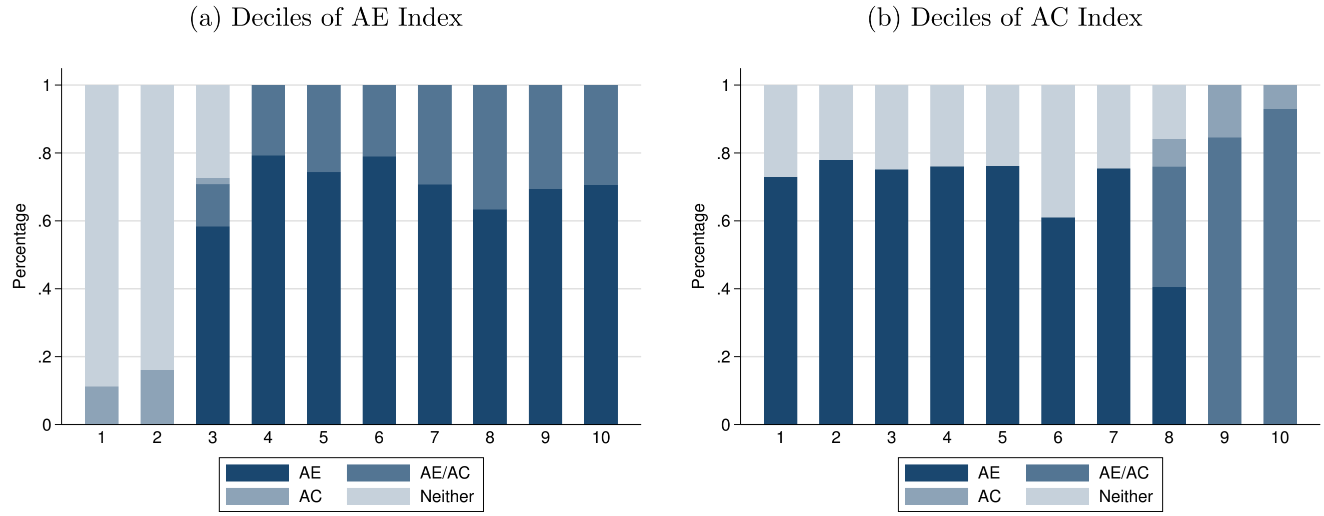
Table 8: Research choice criteria across UIR types, 2005 and 2015

	2005				**2015**			
Research Choice Criteria	AE	AE/AC	AC	Neither	AE	AE/AC	AC	Neither
Enjoy research	4.51	4.50	4.75	4.64	4.27	4.34	4.53	4.54
Scientific curiosity	4.16	4.26	4.66	4.38	4.02	4.17	4.47	4.40
Importance to society	4.33	4.24	4.38	4.15	4.06	4.30	4.27	3.99
Potential Marketability	2.47	3.36	2.75	1.70	1.76	3.12	2.40	1.36
Private Firms Commerc.	1.80	2.77	2.22	1.34	1.44	2.69	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".

The intensity measures, as described further in the appendix, were generated by pooling the UIR activity measures and using PCA to generate weights that map into the intensity of AE and AC activity. PCA is conducted for the pooled 2005 and 2015 data. For interpretation purposes, in Figure 1 we split the estimated measures into deciles of AE and AC intensity and report the distribution of the aforementioned binary UIR types across the deciles. Figure 1a shows the high level of concentration of AE and AE/AC types in the top 7 deciles of the academic engagement index, while Figure 1b shows similar high levels of concentration for the AC and AE/AC types in the upper three deciles of commercial engagement.

Figure 1: Distribution of UIR types (dummy) by deciles of UIR indexes (PCA), 2005 and 2015 pooled



For faculty stated preferences on scientific and commercial motives for research problem choice, we constructed factors scores from the factor loadings and items shown in Table 9 using a standard prediction. Each have some consistent 'high loadings', such as scientific curiosity or potential contribution to scientific theory for the scientific latent factor and likely interest by private firms in commercializing the discovery and potential marketability of the final product for the commercial latent factor.

Table 9: Factor Loadings Estimation, after rotation

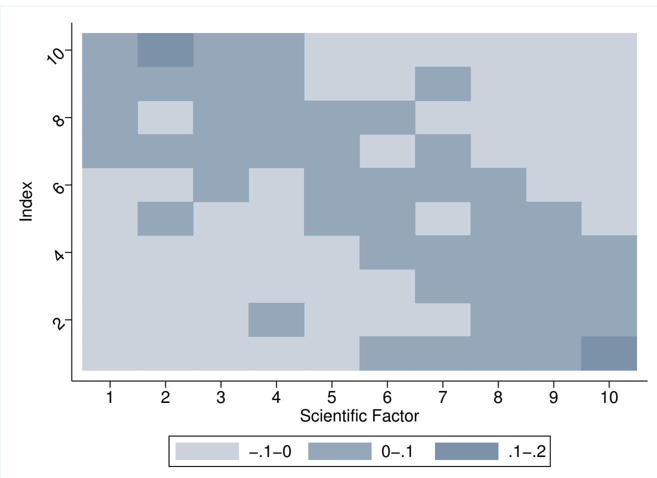
Item	**Commercial**	**Scientific**
Potential contribution to scientific theory		0.61
Enjoy doing this kind of research		0.50
Probability of publication in professional journal		0.50
Scientific curiosity		0.62
Availability of research facilities	0.38	0.31
Request made by clientele	0.53	-0.32
Feedback from extension personnel	0.49	
Potential to patent and license the research findings	0.66	
Likely interest by private firms to commercialization	0.73	
Potential marketability	0.67	
Availability of public, state and federal funds	0.33	
Availability of private and corporate funds	0.54	
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 92% of the variance. We used Principal Factor with orthogonal quartimax rotation to estimate the factor loadings.

Correlations between the PCA measures on intensity of UIR activities and stated preferences on the factor scores are explored in Figures 2 and 3. The first explores the intensity of AE engagement with respect to the two factors and shows a strong negative correlation between AE and the scientific latent factor and a strong positive correlation between AE and the commercial factor. They appear to be almost mirror images of each other. By contrast, in Figure 3, there is a weakly positive correlation between AC index and the scientific factor. At the upper end of Figure 3 there is a somewhat stronger positive correlation between AC and the commercial factor. This is likely due to the low prevalence of AC. Note that, not surprisingly, we detect a stronger correlation precisely within the deciles of Commercial Engagement with a higher concentration of exclusive AC types as shown in Figure 1. Broadly speaking these figures support hypotheses 5 and 6 related to the factors shaping faculty engagement with UIR but more so for AE than AC.

Figure 2: Correlation between attitudes and AE Index for pooled cross-section data

(a) Academic Engagement vs. Scientific Factor



(b) Academic Engagement vs. Commercial Factor

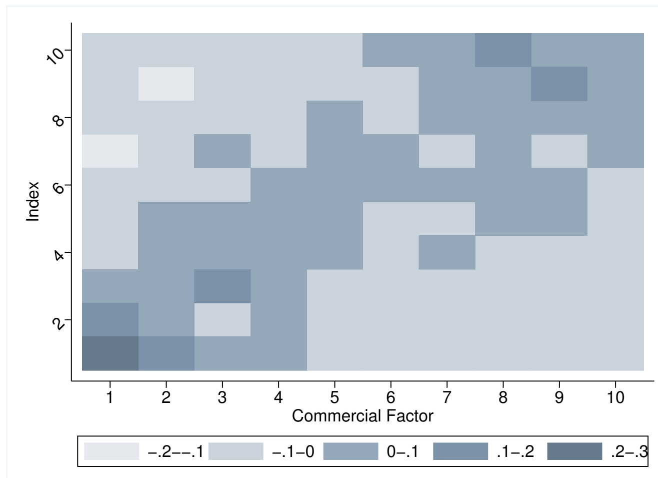
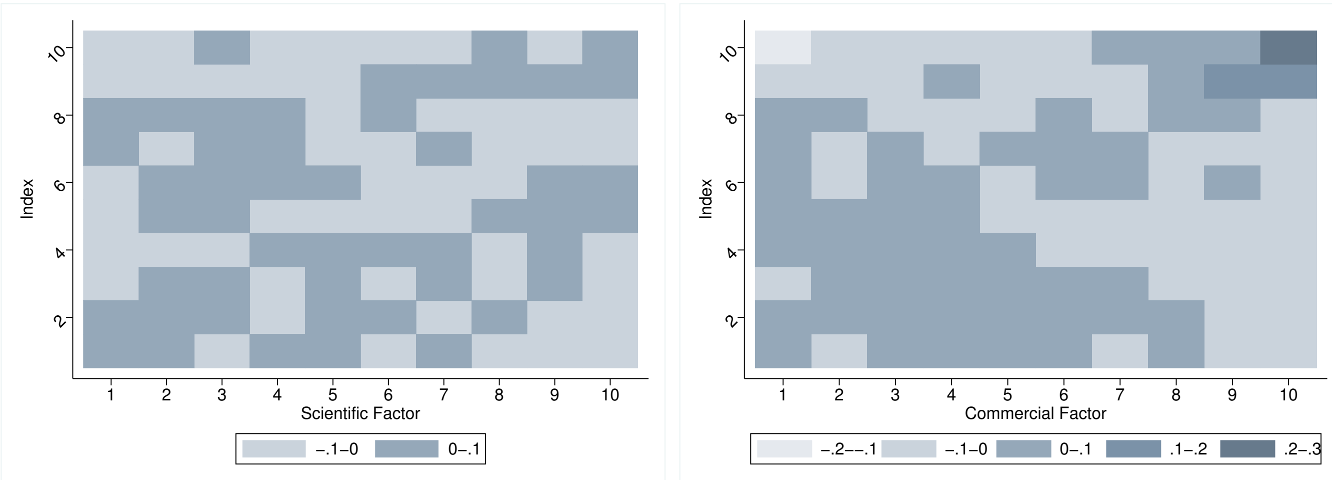


Figure 3: Correlation between attitudes and AC Index for pooled cross-section data

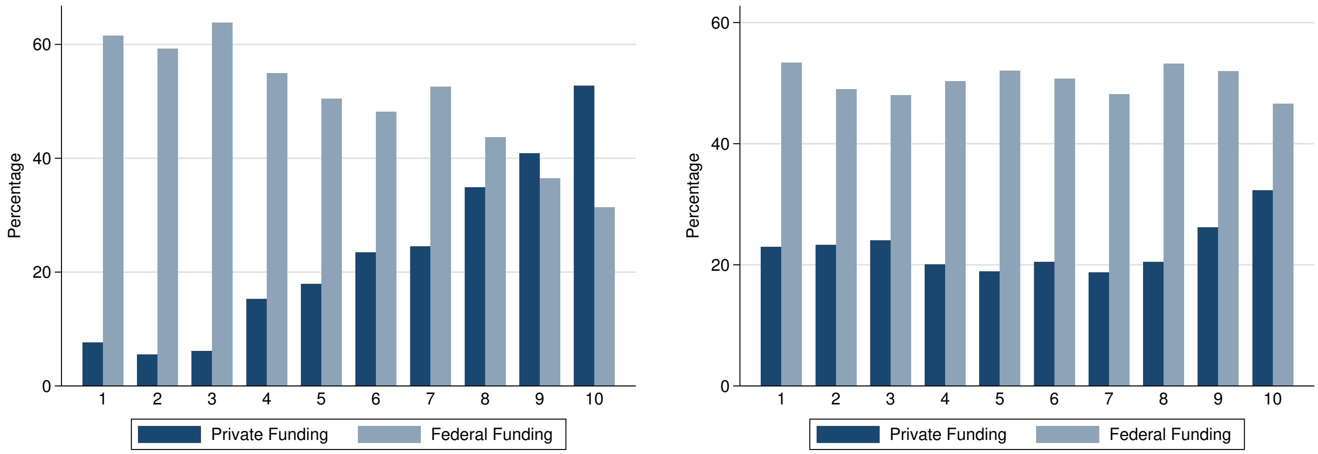
(a) Academic Commercialization vs. Scientific Factor (b) Academic Commercialization vs. Commercial Factor



We explore one more set of 'correlations' with our 'intensity' of UIR measures before we turn to the multivariate regressions that examine intensity of UIR activity. In Figure 4, we examine the changing share of funding from federal and private sources for both AE and AC intensity measures (again expressed in terms of 'deciles'). In the case of AE intensity, the share of private funding rises steadily from a negligible share in the first decile of AE intensity to around 20% in the middle deciles to more than 50% in the top decile with a big jump occurring in the top 3 deciles of the AE index. Meanwhile, federal funding falls from just over 60% in the bottom deciles of AE intensity to under 40% in the top deciles. With respect to AC intensity, there is basically no shift in funding sources, with federal funding continuing at around 50% across the deciles until the 9th and 10th deciles. This contrast, in combination with the evidence from the Table 5, is suggestive of there being more positive payoffs in private funding associated with AE intensity relative to the low payoffs associated with AC intensity.

Figure 4: Percentage of funding source by deciles of UIR indexes (PCA), 2005 and 2015 pooled

(a) Deciles of AE Index (b) Deciles of AC Index



The last set of empirical results focus on a multivariate regression analysis of UIR activities. We ran both a participation regression, a binomial analysis of AE and AC participation, and an intensity regression for each category separately. We report only on the latter one here to show the intensity measures of AE and AC involvement, because they provide more variation and reveal more about explanatory factors than does the regression based on binary measures. In Table 10 we report on how individual and institutional factors shape UIR participation with regressions that use university-fixed effects and a university-based measure of incentives for AE and AC activities relative to AS for basic, applied, and social sciences. This latter measure exploits Likert-type scale questions of individual faculty responses to their perception of the importance of specific AE, AC, and AS outcomes in promotion and tenure evaluations. The scores are the averages for each individual of the AE/AS and AC/AS outcomes, which are then used to construct university level averages across all respondents in 'basic', 'applied', or 'social science' departments.

Table 10: AE and AC intensity index regressions

	(1) **AE Index (log)**	(2) **AC Index (log)**
Scientific Factor Score (sd)	-0.53824***	0.00375
	(0.05644)	(0.01100)
Commercial Factor Score (sd)	0.80632***	0.14031***
	(0.05494)	(0.01829)
Field		
Plant Science (omitted)	-	-
Ag./Engineering	-0.77889***	-0.02071
	(0.16785)	(0.04856)
Animal Science	-0.07441	-0.04489
	(0.13206)	(0.03584)
Biology	-1.02736***	0.04728
	(0.18149)	(0.03737)
Ecology	-0.54833***	-0.06507***
	(0.16079)	(0.02113)
Food/Nutrition	-0.25875	-0.03151
	(0.16223)	(0.04387)
Sociology	-0.78472***	-0.08812***
	(0.18797)	(0.01948)
University Salary Incentives		
Field-incentives AE	0.45040	0.17735
	(0.92640)	(0.14025)
Field-incentives AC	1.64311	0.16960
	(1.06863)	(0.11846)
Male	0.12564	0.04066***
	(0.12505)	(0.01510)
Rank		
Professor	0.12841	0.09089***
	(0.12267)	(0.02123)
Associate Professor	0.15733	0.02067
	(0.13448)	(0.01940)
Assistant Professor (omitted)	-	-
Extension and Outreach; Formal conditions (pct)	0.01197***	-0.00198***
	(0.00183)	(0.00034)
PhD from a Land Grant Univ.	0.06759	-0.05644***
	(0.11220)	(0.01723)
Wave = 2015	0.10755	0.00175
	(0.15853)	(0.02449)
Control for missing inputs	x	x
University Fixed Effects	x	x
Constant	-2.31945***	0.24105**
	(0.74629)	(0.10815)
Observations	1,571	1,571
R-squared	0.41337	0.23315

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The main results from the multivariate regressions are as follows. First, faculty attitudes are a significant explanatory factor with respect to the intensity of UIR activity, consistent with the 'heat maps' offered in Figures 2 and 3 above. Specifically, higher scientific factor scores are negatively related to AE intensity and positively related to AC intensity, while higher commercialization factor scores are positively related to the intensity of both AE and AC. Thus, the alignment of attitudes and activities is somewhat distinct across UIR activities, with a more complementary view of AC for both factors. This finding is consistent with previous empirical evidence on the synergies between articles and patents. In terms of UIR activity mixes, it also seems consistent with faculty who do both AE and AC viewing them as complements rather than substitutes, while many of the faculty who do just AE see those activities potentially as substitutes for research. This is likely to be especially the case for faculty with high levels of extension appointments where tradeoffs between AE and AS activities have been previously documented (Foltz and Barham, 2009).

Second, significant differences are evident across fields in terms of UIR intensity. The reference field in our regressions is plant scientists, and relative to that field there are significantly lower levels of intensity for AE for all other fields but animal science and food and nutritional sciences. Consistent with Perkmann et al. (2011), biological sciences have the most negative difference in intensity of AE relative to plant sciences, with social sciences also strongly negative. The only significant differences on the AC intensity side relative to AE are the significant and negative coefficients on the ecology and social sciences field measures. As shown in Table 3, they have much lower participation rates in AC activities, which is again consistent with Hypothesis 7.

Third, and not surprisingly, the percentage share of a faculty member's extension appointment is positively and significantly related to the intensity of AE involvement and negatively and significantly related to the intensity of AC involvement, both of which seem consistent with the expected roles of those faculty. This result confirms hypothesis 8, and provides additional confidence in the regression results.

Fourth, as suggested by the descriptive statistics above, we see no significant differences across gender in AE intensity and only small significant effects of rank and gender in the AC intensity measure, with more senior, male professors being somewhat more likely to be more intensive in their AC activities but no more intensive in their AE activities. We also see no significant differences in AE intensity based on whether the faculty member got their Ph.D. originally at an LGU, but faculty are also less likely to be active in AC activities. Overall, fields and faculty attitudes seem to play a larger and significant role in shaping UIR activity levels than do individual demographics.

Fifth, all of the 'incentive' measures for AE or AC activities relative to AS are positive, as one might expect, but none of them is statistically different from zero. Thus, faculty perceptions of the promotion and tenure incentives for UIR activities appear to play at most a weak role in shaping

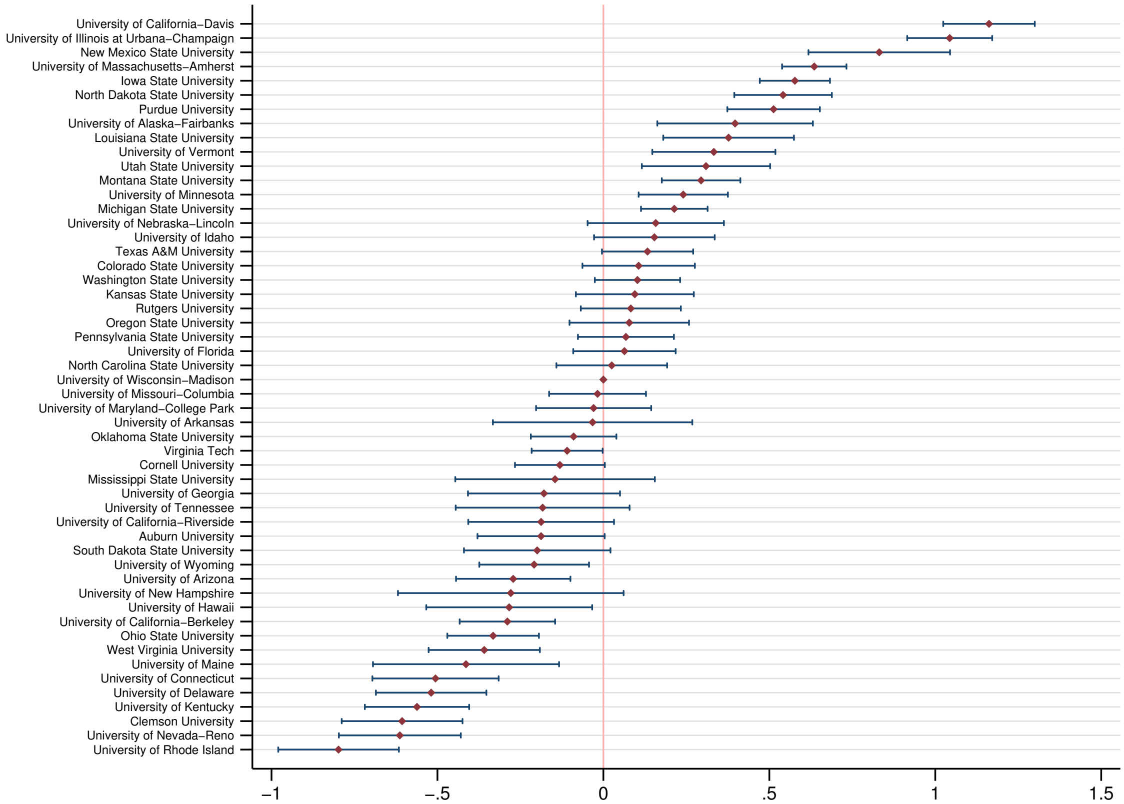
UIR activity. This is a first and somewhat cursory look at the issue of perceived incentives and their effects on UIR activity choices of faculty, but the result is not surprising given the primacy of AS activities to tenure promotion and the scientific motivation for research choices reported above.

Finally, while the university-level fixed effects are included to provide a ‘control’ to help identify unbiased individual and institution-level effects, a careful look at the coefficients on specific universities is also informative about the potential importance of ‘university-level’ factors. In the Table 10 regressions, University of Wisconsin-Madison is the omitted university, from which the fixed effects of others are identified. That university has a long and successful history of commercialization based on Vitamin D fortification and other discoveries early in the 20th century. For that reason, the Wisconsin Alumni Research Foundation (UW’s ‘tech transfer’ patenting office) was established decades earlier than similar offices in most other US LGUs. In addition, the state of Wisconsin had one of the country’s most active and heavily staffed extension systems for several decades. As a result, one might expect the fixed effect measures relative to UW-Madison to be negative and significant for many other universities, especially on the AC side of Table 10 regressions.

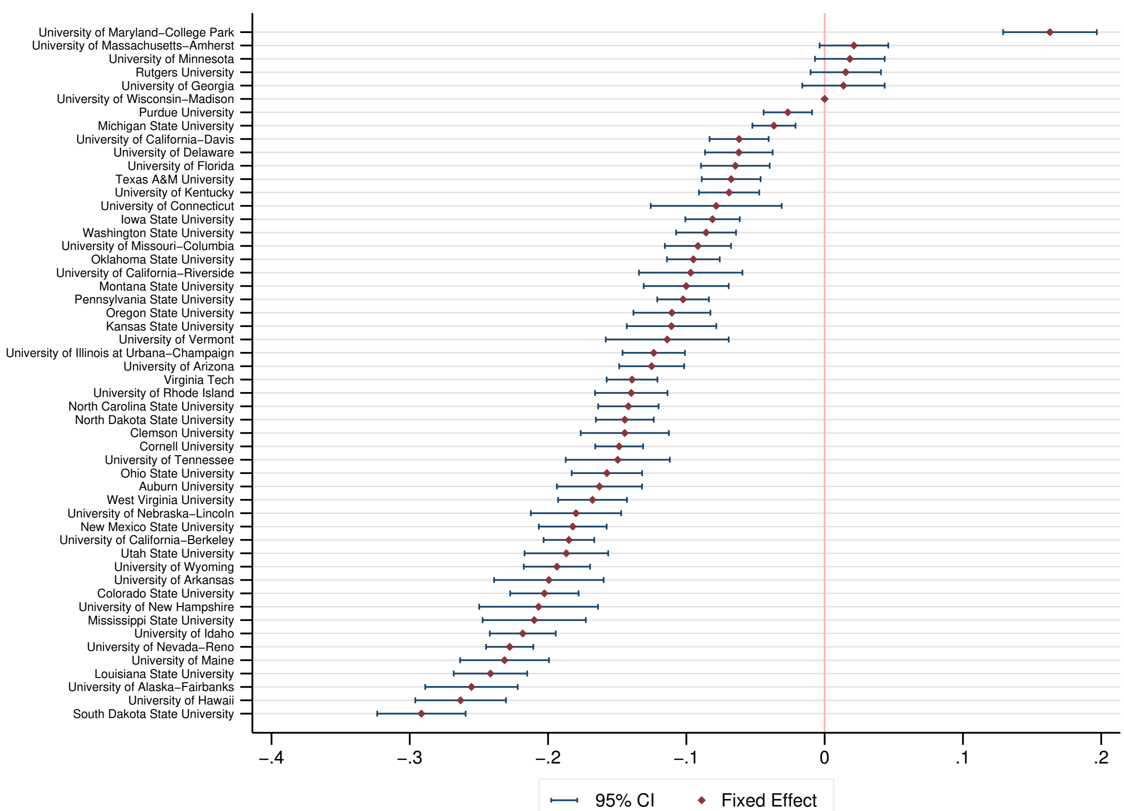
In Figure 5, we plot all of LGU fixed effects and show those with statistically significantly higher and lower AE and AC coefficients as well as those with university fixed-effects that are insignificantly different than those of UW-Madison. The confidence intervals that do not intersect zero are reflective of statistical significance. Note first that for the AE plots that the LGU fixed effect estimates are about evenly split in terms of estimates that are significantly above and significantly below UW-Madison, with about 13-14 on each side. By contrast, all but five universities have significant negative fixed-effect measures on AC relative to UW-Madison, and only one (University of Maryland) has a positive and significant fixed effect estimate relative to UW-Madison. These university-level outcomes recovered from the fixed-effect estimates are suggestive of a fruitful future research path wherein differences across LGUs are more thoroughly explored integrating other types of national and college level data sources, such as National Science Foundation, Association of University Technology Managers, and article and patent databases. More comprehensive and longitudinal university-level data would permit a deeper look at university differences that could be used to examine behavioral effects at the individual level.

Figure 5: Distribution of estimated university fixed effects from regressions on PCA indexes.

(a) Fixed Effects for AE PCA



(b) Fixed Effects for AC PCA



6 Discussion

This article examines the UIR activities of agricultural and life science faculty at the premier US LGUs, using survey data gathered from large, random samples in 2005 and 2015. It fills an empirical gap identified in Perkmann et al. (2013) 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.

Our findings are consistent with the UK studies 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% of faculty in either 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 completely dominates 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' 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 is not the first paper to support the notion that university patents appear to be like lottery tickets in terms of their potential to fund research in the scientific fields captured in this study. A big winner now and then may be great for the university and the lucky inventor, but consistent funding for faculty research continues to come from public funds and sponsored research arrangements with industry and commodity organizations, not so much from academic commercialization efforts.

This study also finds descriptive evidence for both 2005 and 2015 that UIR activities appear to be 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 is consistent with that outcome but at the individual faculty level. Note that the AE/AC faculty persist across time periods and this group tends to have more research revenues and higher publication and student counts.

This study examines factors shaping both the participation and intensity of engagement of US-LGU faculty with UIR activities. Institutional factors, specifically 'fields' or 'disciplines' are a significant conditioning factor as shown in Perkmann et al. (2011), 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 'intensity' of 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 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. We also find that higher factor scores for both science and commercial motives are positively associated with more intensive AC activity, while there is a negative correlation between the science motives and AE intensity and a positive one between commercial motives and AE activity. This distinction may in turn reflect an applied versus basic science divide that separate some lines of AE research from AC areas, especially in the applied fields of plant sciences, animal sciences, and food and nutritional sciences.

Finally, university fixed-effect measures in our AE AC intensity regressions reveal statistically significant differences that appear to relate to the timing of initial AC 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

Attention to UIR promotion at US universities took off in the 1990s and 2000s, with much of the emphasis placed on promoting academic commercialization of intellectual property rights in the form of patents and in some cases through support for faculty-assisted 'start-ups'. A huge amount of what one might call 'research on research' has examined that push, exploring the potential effects of this new type of UIR on the pursuit of science and innovation by faculty. Research on research has been pursued around the world, focusing on the balance between the three missions of learning, creation of knowledge, and technology transfer. Many articles in this journal and others, dedicated even more narrowly to the topic of technology transfer, have probed these issues, searching for synergies, trade-offs, and factors shaping UIR activity. Most studies find 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.

This study confirms those findings but using comprehensive UIR data from US Land Grant Universities, which are often viewed as the core of US public research universities. 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 may be complements, with AC being an occasional outgrowth of AE in some fields, which might depend on the continuity of AE relationships to emerge.

Future research with these data will attempt to pursue a more causal identification of some 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 faculty in the US LGUs over time, and the lack of strong, significant effects found so far with respect to gender and UIR, we intend to see whether the US-LGU context is distinct from some recent European studies that find a persistent gender gap in UIR activities (van den Besselaar and Sandstrom, 2017).

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Appendix A

A. Sample selection and imputation of missing values

	2005	**2015**
Random Sample	1,963	2315
Sample completed survey	1,005	711
drop field=other	21	deleted
drop not professor	27	deleted
drop missing PCA	37	deleted
drop missing factor	20	deleted
drop cross-missing	39	deleted
Final Sample	**946**	**626**

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; (iv) Salary Reward: Likert scale ranging from 0 to 5. We assigned a neutral value, "3", if the person answered the block at least partially. When all are missing, variables remain missing.

For each block, we calculated the total number of imputed values and we added these variables in the regression as a control. General results are robust to selecting the sample without imputations. Results upon request.

B. Measuring university-industry relations (UIR) and research incentives.

1. University-industry relation indexes: principal components analysis

Principal component analysis (PCA) is a widely used application of basic linear algebra. It reduces the dimensionality of a set of variables while preserving the larger set's main features. PCA reduces the dimension of the data by projecting its points onto lower dimensions (or principal components). It seeks to minimize the distance between the data and the components while maximizing their variance and keeping the components uncorrelated. From the resulting set of all components, we keep the ones explaining the larger share of the variance, dropping less important ones. The continuous scores C_j are linear combinations of the original variables X:

$$C_j = a_{11}X_1 + a_{12}X_2 + ... + a_{mn}X_n \tag{1}$$

Applying this to our context allows us to assign to each individual a continuous measure for the degree of engagement in each of our university-industry relations measures. Empirically, we use pre-programed packages in Stata[3] to estimate the weights and the scores (or indexes) for our sample. Our method consists of two main steps. First, we estimate the principal components using all set of variables as an exploratory exercise. The eigenvectors suggest us to keep two components. Each of them have factor loadings consistent with our priors on how to split the variables into commercial and academic engagement ones.[4] Second, we run the principal component analysis on each set of dedicated measures separately. We chose this way to not force them to be uncorrelated. We pooled both years of data for this exercise.

In Figure 6, we plot the density distribution of the scores - standardized to have mean zero and standard deviation 1 - for both years. The AE distribution is more dispersed than AC, which is expected given the larger number of people engaged in AE type of activities than in AC.

[3] *pca* and *predict*

[4] Detailed results upon request.

Table 11: Coefficients for the prediction of Principal Component Index for UIR types.

Academic Engagement

Item	**Weights**
Funding Sources: Private Industry	0.34
Funding Sources: Commodity Organization	0.37
Research: Collaborated with scientists in private	0.30
Research: Co-authored with scientists in private industry	0.17
Research Presentation: farmers or farm organizations	0.38
Research Presentation: commodity groups	0.37
Research Presentation: private industry	0.18
Help Identifying Research Question: Farmers or Farm Org	0.36
Research Collaboration: Farmers or Farm Org	0.35
Paper/Patent Coauthorship: Farmers or Farm Org	0.26

Commercial Engagement

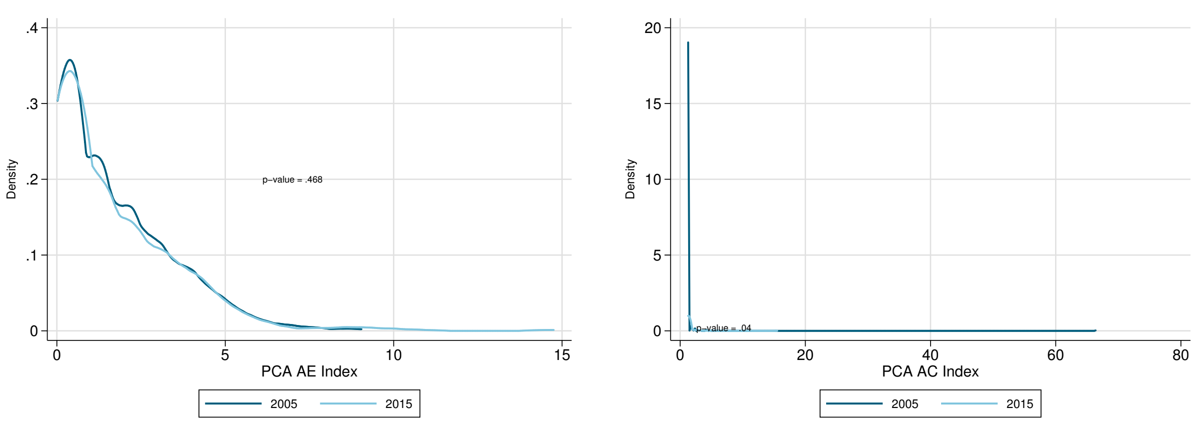
Item	**Weights**
Funding Sources: Licensing or patenting revenues returned	0.23
Outputs from research: Invention disclosures	0.22
Outputs from research: Patent Applications	0.48
Outputs from research: Issued Patents	0.49
Outputs from research: Patentes Licenced Out	0.45
Outputs from research: Products under regulatory review	0.04
Outputs from research: products on the market	0.41
Outputs from research: start-up companies founded	0.07
Laboratory receive any royaty income from patents	0.23

Note: this table displays the resulting weights used to predict the PCA scores for the Academic and Commercial Engagement indexes. The calculated eigenvalues suggest we should keep one component in both cases. The first component for the AE variables explains 31% of the variation in the data. For the AC variables, the first component explains 42% of the variation in the data.

Figure 6: Kdensity Distribution of PCA indexes by UIR types, the cross-section samples in 2005 and 2015

(a) AE Index

(b) AC Index



2. 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:

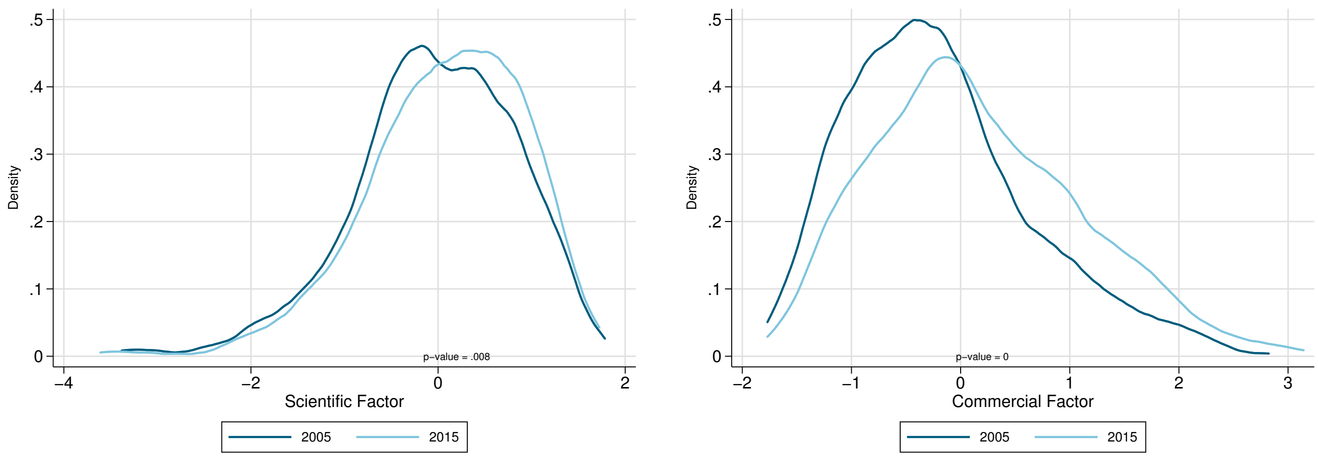
$$M_{i,n} = \beta_n' F_i + \epsilon_{i,n} \tag{2}$$

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 1 and 2. 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 7.

Figure 7: 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. P-values are for the test with equality fo the distributions as the null hypothesis.