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Patenting, Commercialization, and US Academic Research in the 21st Century: The Resilience of Basic, Federally-Funded Open Science

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Abstract

The life sciences have been the most dynamic area of US university research and commercialization efforts over the past twenty-five years. Using unique data from a large representative sample of life scientists this work examines whether academic patenting and commercialization complement, substitute for, or "hold-up" other research activities. The results highlight the resilience of the basic, federally-funded open scientific research model. Our findings, in turn, underscore the fundamental importance of maintaining the public funding and commitment to the academic, scientific enterprise.

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Patenting, commercialization, and US academic research in the 21st century: The resilience of basic, federally-funded open science

1. Introduction

The life sciences have been the most dynamic area of US university research and commercialization efforts over the past twenty-five years. This dynamism is evident in the major role that life sciences have played in the explosion in academic patenting. While the annual number of academic patents rose from 340 to 3,274 between 1980 and 2000, the annual number of academic life science patents rose from around 40 to nearly 800, from a relatively small share of the total (10%) to nearly 25%.[1] Life science patenting has become in this period the leading edge of academic patenting.

The surge in academic life science patenting is part of a broader commercialization effort being undertaken by US universities and their counterparts around the world, as dozens (if not hundreds) of universities attempt to be core contributors to the 21st century bio-economy. In addition to the construction of major new laboratory facilities; university technology transfer offices, centers and institutes, labs, and individual scientists are active in developing licensing arrangements, pursuing sponsored research, spinning off new companies, working closely with existing companies, and developing public-private ventures to bring university life science research to the marketplace. How this commercialization push affects and reshapes the longstanding model of basic, federally funded open science research (Merton, 1973) is an issue that has generated considerable attention and a multi-faceted debate (Just and Huffman, 2007; Nelson, 2004)

Five decisive empirical questions in this debate are listed and labeled below:

- *Commercialization Impacts:* Does industry funding and collaboration have a significant impact on the research activities and direction of life science researchers?
- *Funding Impacts:* How do research funding sources shape academic publication and patenting activities?

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[1] Based on authors' calculations from US Patent data (USPTO, 2002).

- *Synergies*: Is academic patenting a complement or substitute for other research activities, especially the production of academic articles?
- *Hold-ups:* Are patents, material transfer restrictions, and other intellectual property right limits causing significant hold-up problems for life scientists?
- *Royalties:* How important and common are patent royalties and license revenue in the research portfolios of life scientists? Are they likely to change the way scientists fund their work?

These questions have been at the core of recent special issues of *Research Policy* in July of 2006 and *The Journal of Technology Transfer* in June of 2007 where science and technology researchers have examined the impacts of the increased emphasis on exploiting intellectual property rights to bring “Science to Life” (Sampat, 2006; Geuna and Nesta, 2006; Cook-Deegan, 2007; Lowe and Gonzalez-Brambila, 2007; see also Meyer, 2006; Van Looy, Callaert, and Debackere, 2006). These questions have been investigated both in terms of the productivity and direction of scientific research within the university and the transfer of those ideas into technologies beyond the university into a competitive and dynamic marketplace. As explored in the next section, the recent literature suggests that basic, federally-funded open science may be quite resilient to the recent growth of academic patenting activity and increased commercialization efforts. Yet, as Sampat’s lead survey article in the July 2006 issue of *Research Policy* also concludes, the available evidence in the current literature is for the most part not sufficiently robust or representative enough to buttress general answers to the issues raised above.

One limitation to the extant research is that it has not been built on data that provides direct answers to these key questions at the level of the individual research scientist. Typically, recent articles use either one or a combination of three types of data: university-level data gathered by government agencies (e.g. National Science Foundation) or associations (Association of University Technology Managers); individual patent data gathered by government patenting agencies (e.g., United States Patenting Office); or case study evidence gathered by researchers at leading US and European research universities. None of those data sources individually or when combined provide the type of evidence that can be used to address conclusively the types of issues at stake, because they do not have sufficient information on the choices, actions, or factors shaping the behavior of the fundamental unit of analysis – the individual academic life scientist.

The unique contribution of this study is to exploit a large, random-sample, survey of 1,822 US life scientists at the 125 top universities undertaken in 2005. This survey is the largest general survey of biological scientists (by number of respondents) in more than ten years (Blumenthal et al. 1996; Blumenthal et al. 1997) and includes all biological science disciplines, not just those disciplines presumed to be at the leading edge of university-industry relations (Campbell et al. 2002). Such a study provides a needed compliment to analyses that seek broad theorization of the origins and effects of commercialization on university research, and to findings derived from investigations of narrower scope conducted with individuals or at universities which may be exceptional, rather than representative, cases.

This survey aimed to examine how the increased participation in academic patenting and research commercialization efforts might affect the pace and direction of individual scientific research. The survey included questions about the full range of research outputs, research funding sources, collaborative relationships covering a broad span of potential research partners, academic patenting experience, licensing arrangements, material transfer issues, “hold-up” problems, as well as a battery of demographic, attitudinal, and disciplinary indicators. These data allow a direct appraisal of how research commercialization experiences affect the ways in which U.S. university life scientists pursue their research and the extent to which commercialization reshapes their approach with respect to “basic, open federally funded science”.

This article directly examines the five questions raised above, and confirms research that finds academic patenting generally complements other research activities. On a broader scale, the results highlight the resilience of the basic, federally-funded open scientific research model, which, in turn, underscore the fundamental importance of maintaining public funding and commitment to the academic, scientific enterprise. The next section summarizes briefly recent research regarding the paper’s main questions, the methods used in this paper, and our individual scientist dataset. Sections 3-5 provide the empirical evidence, and section 6 concludes.

2. Issues, Methods, and Data

A. Issues

We examine five intertwined issues in this article using individual data from US university life science researchers. Each issue provides an important angle on how the recent push to commercialize research and pursue patents affects the basic, open science model of US academic research. The first two issues identify the extent of current participation among life science researchers in commercial activities, their reliance on industry versus other sources of funding, and the impacts of commercialization activities and funding sources on the productivity and direction of their research. The third and fourth issues examine whether patents and academic articles are substitutes or complements at the individual scientist level, and the degree to which scientists find the intellectual commons to be diminished by intellectual property right limitations associated with patenting and commercialization efforts. The final major issue concerns the payoffs associated with patents and how their “lottery” like nature may limit their impact on the way in which scientific research is financed and pursued. Combined, these five empirical issues provide a rich portrayal of the way in which life science researchers at US universities pursue their craft.

Public policy concern about the impacts of commercialization on the productivity and direction of academic research has deep, historical roots in the science and dates back to the 1970s (see Sampat, 2006 for a description of the Congressional debate in that era). The passage of the Bayh-Dole Act in 1980 provided a fundamental shift in the institutional environment for U.S. universities by granting them the right to hold exclusive patent rights on patents resulting from federally funded research. Since that time, the literature on commercialization impacts on academic research has exploded (Slaughter and Rhoades, 1996; Slaughter and Leslie, 1997; Geuna, 2001; Nelson, 2001), mirroring the dramatic growth in academic patenting that occurred in the 1980s and 90s in the United States. Among the more critical observers have been Blumenthal et al. (1996) and Campbell et al. (2002) suggesting that faculty especially in the medical and biotechnology areas may be substituting commercial activity for open academic research efforts.

Several recent studies reveal a salutary relationship between industry connection and/or faculty entrepreneurial activities and research productivity. The star scientist literature stemming from Zucker, Darby, and Brewer (1998) suggests that the scholars most active in commercialization activities are frequently also among the most productive in the classical sense of producing highly cited academic publications. A recent investigation by Lowe and Gonzalez-Brambila (2007) of the productivity of 150 faculty entrepreneurs at 15 research institutes (9 University of California campuses, plus several others) compares them with a control group of scholars in comparable fields and finds that faculty entrepreneurs publish more, have more heavily cited work, and that these outcomes are present both before and after they help to start a firm. A study of faculty involved in contract research with industry at the Catholic University of Leuven in Belgium (Van Looy et al. 2004) finds that those faculty members publish more than colleagues in similar fields with no industry contacts. Overall, the message appears to be that commercialization activities have not hampered academic research productivity. This recent literature, however, merely counts outputs without controlling for funding levels or considering whether commercialization affects the direction of research. It also is based on case studies about a select group of universities or types of scientists rather than on a representative sample of university and scientist types.

A recent exception is a study of industry funding and university professor research performance in Norway (Gulbrandsen and Smeby, 2005) based on a nationally representative sample of tenured professors. As in the U.S. data used in this article, the respondents were asked about their research funding sources, their full range of research outputs, their collaborations, and their characterization of their research direction. Their main finding is consistent with the salutary view that academic publication levels of faculty with higher proportions of industry funding are higher than their counterparts without industry funding. Unlike our study, they do not report in the article on the potential impacts on supervision of doctoral students or the factors university professors viewed as critical in shaping their research directions.

The relationship between academic patenting and published articles has been much more thoroughly examined in recent years. The key initial study was undertaken by Agarwal and Henderson (2002) who examined the patenting and publishing activities of 236 scientists in the Mechanical and Electrical Engineering departments at MIT over a fifteen year period. They found that only a small proportion of the faculty patented, that publishing academic papers was a far more common activity, and that patenting was not serving as a substitute for research article production. Two similar studies from Europe explore the patenting and publication propensities of nano-science and technology scholars (Meyer, 2006) and academic inventors at Catholic University of Leuven (Van Looy, Callaert, and Debackere, 2006). Though not random or representative samples, both of these studies find even stronger evidence that patents and publications appear to go together, with those scientists that patent both more likely to publish and have more highly cited articles. Two broader samples of university researchers have been studied by Thursby and Thursby (2003) and Stephan et al. (2004) to examine the patenting-publication relationship. The former followed 3,342 researchers from six universities over seventeen years, while the latter analyzed the patent activity of almost 11,000 faculty members selected from the 1995 Survey of Doctoral Recipients. Both find evidence suggesting a complementary relationship between patents and publications.

While asserting the existence of complementarities, none of these studies on patents and publications formally test for the presence of scope economies which takes into consideration variation in research expenditures, or the costs of production. By ignoring variation in overall research costs involved in the research production of the university scientists these studies are unable to test whether the higher level of production of both outputs comes from higher levels of research funding or from cost complementarities of the two research products. Using the methodology developed in Foltz, Barham, and Kim (2007), and summarized below, we estimate a cost function for life science research output that addresses this short-coming in the literature on complementarities versus substitutes.

In contrast to work on commercialization and patent production, recent research on “hold-ups” provides a more negative view on the effects of the growth of intellectual property production in university life sciences. Particularly the works of Blumenthal et al. (1996) and Campbell et al. 2002) raise concerns about the potential for researchers to either keep scientific discoveries secret to allow time for pursuing commercialization steps (such as patenting) and for other researchers to experience limitations in getting access to materials or the rights to work with intellectual property of university and private company research. The former study surveyed life scientists from 50 US universities with NIH funded research, but is stratified to include 50% clinical medicine respondents and 50% non-clinical life scientists that also included medical researchers. In their preponderantly medical-school based sample, industry funding was reported by a little over a quarter of their sample, and of those about 11% reported withholding materials or ideas requested by other researchers, compared to 5% of those without industry funding. Overall, “hold-ups” would be about 7-8% of that sample. In the latter study, geneticists were the primary focus of a large sample survey, along with a comparison group of other life scientists. “Hold-ups” were found to be relatively common in this sample with higher percentages (closer to a third) reporting both having information and materials withheld from them and doing the same to others. It is important to highlight that both of those previous samples are heavily weighted toward the medical end of the life sciences, while our sample focuses on life scientists mostly outside of the clinical side of medical schools.

Perhaps the least well understood of the issues examined in this study is the role of patent license revenues in the research funding of university researchers. Inferences could be drawn from the relatively low proportion of faculty with patents in many fields, but it is critical to know whether academic patents regularly become significant sources of funding for university researchers, and if so whether they then have substantive impacts on that research. This study helps to complete the circle on the academic patenting issue by providing compelling evidence that academic patents in the life sciences are lottery tickets that mostly do not pay at all, occasionally pay a small amount, and very rarely produce a significant payoff.[2] This fundamental feature is crucial to explaining why the material conditions for major changes in academic research are basically unaltered by the dramatic expansion of patenting activity.

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[2] This idea of patents as lottery tickets mirrors the thinking of Michael Polanyi from 50 years ago on the generally stochastic nature of the scientific process. See for example Polanyi (1962).

B. Statistical Methods

We pursue two types of statistical analysis with the university life scientist survey data: i) descriptive statistics that portray the activities of individual life science researchers comparing those with various degrees of participation in commercialization activities; and, ii) econometric analyses of the productivity outcomes of life science researchers. Only the econometric exercises require substantive discussion.

The methodologically sophisticated econometrics is the analysis of the properties of the joint production process of research publications, doctoral students, and academic patents. We build on the methodology of a recent article (Foltz, Barham, and Kim, 2007) which measures both scale and scope economies in the production of these outputs at the university level using a multiproduct cost function (Baumol, Panzar, and Willig,1988). We adapt their university level approach to assess economies of scale and scope at the individual scientist level. Both scale and scope economy estimates are important properties of the cost function, because the presence of either or both suggests the potential for increasing returns in the activity. Scope estimates in particular provide evidence on whether the joint activity is preferable to a specialized approach of doing just one or the other. Without a formal investigation of the basic properties of the cost (or production) function, evidence of high quantities of patent and article production by individual scientists cannot test their fundamental nature as substitutes or complements because they lack a means of controlling for the research expenditures used in producing the outputs.

Typical multi-product cost function estimations are based on a version of the following equation,

$$(1) \qquad C(\boldsymbol{Y},\boldsymbol{w}) = a_o + \sum_j b_j Y_j + 1/2 \sum_j \sum_k c_{jk} Y_j Y_k + \sum_l d_l w_l + 1/2 \sum_l \sum_m d_{lm} w_l w_m \,,$$

where $C(\boldsymbol{Y},\boldsymbol{w})$ is the total cost of producing a vector of outputs $\boldsymbol{Y}$ with a vector of input prices $\boldsymbol{w}$, and a_o , b_j , c_{jk} , d_l, d_{lm} are scalars.[3] The coefficient estimates, b_j and c_{jk}, are

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[3] The different common functional forms can be seen in this formulation as follows: if Y=*ln(*y) and w=*ln(*w) then one gets the translog, while if Y=$\sqrt{y}$ and w=$\sqrt{w}$ then one gets the generalized leontief functional form. We use a generalized quadratic form because one of the key independent variables (patents) takes on a zero value for more than half of the scientists.

then used as evidence for synergies and tradeoffs and as arguments in the construction of estimates for ray economies of scale and economies of scope.[4] The scope comparison we construct compares the joint production of article, patents, and doctorates with a separate production process of producing patents separately from articles and doctorates. This allows us to analyze whether or not the production of patents is synergistic with the production of traditional university outputs.

Because this is a single cross-section dataset, all of our variation in input prices (primarily labor costs) will be observed as variation across universities. This implies that input price variation will be captured in a university fixed effect. We thus use a fixed effect approach to control for university specific input prices and other unobservables. This choice, forced by the nature of the data, implies that we do not estimate coefficients for input prices as is standard in most cost function estimations.

The other econometric model estimated in this paper relates the number of articles to different types of funding sources and to total funding levels. That regression is used to identify how industry funding shapes the production of academic articles. Because the key dependent variables of interest in this model is a count measure, we use count data techniques to estimate them (Blundell, Griffiths, and Van Reenen, 1995, 1999). Count models assume either a Poisson or Negative Binomial distribution on the dispersion term (Cameron and Trivedi). The first moment condition for these models is: $E(Y_{it}) = e^{X_t'\beta}$, where Y_i represents the number of articles produced and X is a vector of funding, individual, disciplinary, and university characteristics that affect the dependent variable. The estimation procedure uses a fixed effects formulation to control for the unobserved university specific effect, η_i, thereby assuming that the unobserved heterogeneity is randomly distributed across universities. In terms of the distribution on the disturbance

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[4] The ray economies of scale for the joint production process are defined by: $S_n(Y) = \dfrac{C(Y)}{\sum_j Y_j \dfrac{\partial C(Y)}{\partial Y_j}}$,

where ray economies of scale exist if $S_n(Y)$ is greater than one. The economies of scope for a product set t relative to the product set of all other n products not including t: (n-t), can be computed from following function: (3) $SC_t(Y) = {[C(Y_t) + C(Y_{n-t}) - C(Y)]}/{C(Y)}$,

where $C(Y_t)$ is the cost of producing only the product set t and $C(Y_{n-t})$ is the cost of producing the other n products except those in set t. Economies of scope exist when $SC_t(Y) > 0$.

terms, a Negative Binomial approach is chosen here over a Poisson model, because it allows more flexibility by not requiring that the mean and the variance of the estimated disturbance term be equal. The Negative Binomial approach instead allows the dispersion parameters to vary across individuals.[5]

C. Data

A team of researchers collected the data used in this study in 2005 from a random sample of 1822 university life scientists. The breadth of the surveyed population and the depth of respondent size place this study in a unique position to evaluate general features of university commercialization. The sampling population for this study is comprised of professorial faculty in the biological sciences at the top 125 U.S. universities in terms of biological sciences research. We selected universities based on a ranking of research and development expenditures in the biological sciences in 2000-2002 (NSF, 2002). For the purposes of this study, the biological sciences are those defined by the National Center for Education Statistics and the National Science Foundation (NSF, 2004). NCES and NSF categorize biological science as a subset of a more general category, life science, which also contains agricultural science and medical science.

Respondents were asked a wide range of questions. The ones most pertinent to this article concerned: their research outputs over the past three years, their average research funding levels over the past three years and the previous year, the sources of that funding, their time allocation, their experience with commercialization and industry collaborations, their research priorities, factors that influence their research choices, and their views on commercialization. In terms of academic patenting, respondents were asked about invention disclosures, patent applications, patents granted in the past three years and in their entire academic career, patent or licensing revenues, and related matters. For the purposes of this work we primarily use patents issued in their entire career as our measure of whether someone is a “patenter.”

3. Commercialization, Research Funding, and the Role of Federal Funds

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[5] Tests of the null hypothesis of equal mean and variance for the dispersion parameter were strongly rejected in all versions of this model.

Commercial links in general and academic patenting in particular are relatively uncommon among US university life scientists. For example, in our sample 53% of the respondents reported no patents, invention disclosures, industry funding, membership on company boards, or research collaborations with the private sector. Only 33% of respondents had ever applied for a patent, while only 25% had ever received a patent, and only 13% had more than one patent. Only 23% of respondents had applied for a patent in the past three years, and only 12% had received one. In this sample, 80% of respondents reported no industry funding supporting their research in the past three years. The evidence these data provide is that commercialization activities, especially patenting, are by no means pervasive among US university life scientists, and play a relatively minor role for the vast majority of university life scientists.

In table 1 we show the substantive variation in these numbers by fields. At one extreme, only 1% of ecologists and evolutionary biologists have ever been issued a patent. At the other, 44% of immunologists hold at least one patent. Likewise, while only 4% of genetics researchers report industry funding, 50% of food scientists do. Nonetheless, among most of the groups, industry funding is relatively uncommon, with only the fields of botany and food science having more than 30% of their respondents receiving industry funding to support their research. And, similarly, only biochemistry and immunology have more than 20% of their respondents with 2 or more patents in their lifetime. Thus, in no life science field is academic patenting a frequent activity, and only in two is industry funding a common source of research money.

A closer investigation of industry funding, other sources of funding, and their connection to research production in table 2 provides further insight. In the full sample, federal funding accounts for 67% of research funds, compared to only 5% from industry sources. Own university funds are the second largest source at 15%, foundations are third at 9.5%, and state government is only about 2%. Almost all research funds are secured through extramural or intramural grants rather than through commercial connections. Of the 20% of respondents with private industry funding, that source accounts for 25% of their research budgets, while federal funding still accounts for more than half of their research support. Thus, as a proportion of research support, federal funding remains dominant even among life scientists with industry funding.

The connection between research outputs and industry funding sources is explored first using descriptive cross tabulations in table 3, which compares patents, publications, and students between life scientists with and without industry funding. Researchers with industry funding average 1.5 patents in their research careers, compared to 0.7 patents for those without industry funding. While the patent numbers are higher for those life scientists with industry funding, patenting remains a relatively rare event even for them. Life scientists with industry research funding also had significantly higher numbers of articles (13.2 vs 9.7), doctorates produced (1.34 vs 0.95), and post-docs supervised (1.51 vs 1.16) over the past three years. Thus, industry funding is correlated with more research production on all fronts rather than merely commercial activities. This finding does not, however, imply a directional causality since it could be that the best researchers attract commercial interest or that the most commercial researchers are able to maintain their pre-existing research productivity differences. It does, however, suggest that industry funding does not detract from the production of articles, the training of doctorates, or supervision of post-doctoral scientists.

We examine this observation more closely in table 4 by estimating a negative binomial count model of academic publications in the past three years on funding sources. The specification includes two funding source variables, one for the percentage of federal funds and one for the percentage of industry funding. The other control variables are total research funds, years since PhD in a linear and quadratic term, and an indicator variable for whether the life scientist has tenure. Other regressions that include other funding sources were run without any significant changes in these results.

Notice first that the percent of federal funding is positive and strongly significant in predicting article production which demonstrates the importance of federal funding for the major life sciences research output. The coefficient on industry funding is also positive but is not statistically significant. All of the control variables have significant and expected signs. Higher levels of funding generate more research articles, as do professors with tenure (probably reflecting the selection process as well as experience).

We close this section with an investigation of the factors that life scientists report as critical to their choice of research direction. Table 5 shows the relative importance of different criteria for life scientists’ choice of research problem on a scale of 1 (not important) to 5 (very important). The table compares life scientists with and without patents, and finds very similar patterns of responses for the ranking of what they deem as most and least important to shaping their research direction. Note that while each element in the ranking is significantly different across patenters and non-patenters, the overall rankings of what is most important does not change across groups. Most important for both types of scientists are their scientific curiosity and intention to contribute to scientific theory, both with average scores over 4. At the bottom of the list of factors they were asked to consider are the contribution the research might make to a start-up company, a consultative relationship with a private firm, patent potential of the research direction, and private firm interest. None of those factors scores higher than 2.2 for either of the two groups of life scientists. The potential importance of the research to society also scores relatively high at 3.85. While these data are subjective reflections of the life scientists' research choices, they are quite consistent with the rest of the results in this section which suggest that commercialization incentives and motives play a minor role in the research life of most US life scientists.

4. Synergies, Hold-Ups, and Academic Patenting

In this section, we examine how patent production affects the productivity of academic research by looking first for synergies in the research output of the individual scientist and then at whether they find hold-ups and material transfer to be serious constraints on the input side. We begin with a brief review of the results presented in a related paper which examined university-level data to see whether there were synergies or tradeoffs among patents, articles, and doctorates among US life scientists using data from 1981-1998. Then, we turn to the individual level estimation done with the survey data gathered in 2005.

One motivation for this comparison is that scale and scope economies could be present at one level of activity and not another in university life science research. For example, it could be that scope economies between patents and articles could be present at the university level because of the interactions across labs, disciplines, or between the technology transfer office and the scientists. One reason for thinking that there might be scope economies at the lab level would be that if the fundamental basis for the production of both published articles and patents was a really novel idea. In terms of the impact of patenting and intellectual property rights limits on research direction and access to key materials, we take only a descriptive look at the data, mostly because it turns out that research limits associated with “hold-ups” appear to be very uncommon among our respondents.

At the university level, Foltz, Barham, and Kim (2007) estimates a life science multi-output cost function using panel data on research outputs, expenditures, and input costs from 96 US Research 1 universities. They find that the cost function estimates provide strong evidence of scale economies in life science research production (suggesting that more article or patent production come at lower unit cost) as well as evidence that scope economies are important when output quantity is adjusted for quality (citations) but weak scope economy evidence for strict quantity measures of outputs. The scale and scope estimates are particularly strong at small and large land grant universities as compared to non-land grant universities.

Before investigating the parallel regression estimates at the individual scientist level, we present descriptive comparisons between researchers who patent versus those who do not. Table 6 provides those results, comparing the average number of articles, doctorates, and post-docs generated over the past three years across the two groups. On all research production outputs, those with patents have significantly higher outputs than those without. Life scientists with patents average 12.3 articles over the past three years, compared to 9.7 for those without patents, almost a 30% differential. The PhD and post-doc comparisons are, respectively, 1.25 vs 0.92 and 1.86 vs 1.05. These comparisons are suggestive of the potential for scope economies and of the possibility that certain researchers do more of everything, patenting, working with industry, and producing more articles and students.

We report results from an individual scientist multi-output cost function estimation using university fixed effects in table 7. We present a specification with the outputs as well as years since PhD to control for academic age effects and disciplinary dummy variables. The coefficient estimates on patents and doctoral students suggest the presence of scale economies (concavity), while the coefficient estimates on articles suggest decreasing returns to scale (convexity). Combined, these estimates produce an estimate of decreasing returns to scale with a scale parameter of 0.55. In terms of complementarities, the coefficient estimates on the interaction terms are not significant for the interaction of patents and PhD or publications and PhDs, yet the coefficient estimate for the interaction of patents and publications is negative and statistically significant (suggesting the potential for cost reduction or scope economies between these research outputs). We generate a measure of economies of scope by comparing production of patents as a stand alone operation compared with producing an integrated set of outputs. At the mean of the variables this produces an estimate of economies of scope of 0.42, which is significantly different from zero (F test(1,979) = 8.86), demonstrating positive economies of scope.

Overall, the evidence from the descriptive and econometric analysis bolsters the findings in Foltz et al. (2007) that patents are synergistic with articles and that they do not pose significant tradeoffs with other research activities in the life sciences. The individual level analysis provides more than confirmation of the synergies involved in the addition of academic patenting to the outputs of US university life science research. It does so in a context that firmly demonstrates that patenting is not yet a major research activity for most life scientists despite the fact that it is one of the leading edges of academic patenting and university commercialization efforts. In that sense, these results bolster our broader conclusion that the basic open model of research largely funded by public sources continues to be the dominant story among life scientists in U.S. universities.

We present two further pieces of evidence to augment our arguments about the incentives inherent in the commercialization of university activities. First is an assessment of whether scientists engaged in the commercial world engage in less basic research. Overall in the sample the average life scientist spends 70% of his/her time engaged in basic, 25% in applied, and 5% in developmental research. This varies over disciplines with at the low end applied disciplines such as epidemiology, pathology, and food sciences having basic research levels below 30%, while at the upper end one finds anatomy and cell biology, physiology, molecular and developmental biology, and biochemistry all averaging above 80% basic research. Scientists who have patents do (statistically) the same amount of basic research (71.2%) as those without a patent

(70.9%). Scientists with industry funding, however, spend only half their time on basic research (49.4%), which is significantly different than their counterparts with no industry funding who spend 76% of their time on basic research. We thus see no association between patenting and a movement away from basic research. It is likely that those who do applied research are best able to attract industry funding and the evidence does show that those with industry funding do more applied research.[6]

With regards to “hold-ups” table 8 shows the proportion of respondents who responded to questions regarding hold-up problems associated with material transfers from private industry, other universities, and the affordability of intellectual property licenses. An answer of NA means that the issue is not applicable to their research, while a 1 denotes no problem and a 2 denotes a minor problem. An answer of 4 or 5 denotes a serious or very serious problem with respect to “hold-up”. Overall, none of the three questions generated more than about a 5% combined response of 4 or 5, i.e., a serious hold-up problem. Close to 90% report at most a very minor hold-up associated with any of the three questions. When we look at the same question by different disciplinary fields, none of the results are ever higher than 16% (parasitology, immunology – 15%), and some such as ecology and evolutionary biology are essentially zero. In this data the evidence on “hold-ups” is consistent with a conclusion that basic academic research is only minimally affected by commercialization’s incentives.[7]

5. Economic Returns to Patents

The final empirical issue we address concerns the economic returns that life science researchers receive from their patents. As described in sections 3 and 4, patents remain relatively uncommon among US university life science researchers, with only 25% having a patent and less than 12% having 2 or more patents in their careers. Only 33% of those with a patent receive any licensing revenue, which implies that overall 8% of university life scientists receive licensing revenues. The median royalty payment among those receiving any money is $5,000, which represents about 2% of the annual

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[6] In a cross section data set we are unable to assign causality in this relationship, but suspect that it is an interest in applied research that attracts industry funding rather than industry funding diverting a researcher to do less basic research.

[7] The stronger hold-up results found in the work by Blumenthal et al. (1996) and Campbell et al. (2002) likely reflects the stronger commercial orientation of clinical medical research in their sample.

research budget of the typical respondent. For at least 95% of university life scientists then, patent licensing revenues are zero or trivial sources of funding.

Yet, for the 1200 patents reported by respondents, a total of $27 million in licensing revenues was generated, which is a mean of more than $15,000 per patent. However, one of the patents in the sample accounts for 90% of the total licensing revenues or $24 million per year, and two others account for about $ 1 million. Thus, about 96% of the patent license revenues are captured by 3 patents out of 1200, with one of those capturing 90% of the revenue.

The very low probability and extreme concentration of patent royalties makes patents more like a lottery for individual scientists, even while they can be a relatively stable source of income for their universities. For individual scientists, even those securing a ticket are very unlikely to get any payoff and if they do it is likely a minor benefit. On the other hand a few lucky winners, less than 1% of the entrants, receive very high benefits that can be seen as justifying participation. Universities in contrast, by having multiple patent lottery players on their faculty, can potentially reap the aggregate benefits of having many “tickets.” To what extent academic patenting pays, on average, for US universities seems a proposition worth exploring, and could be quite variable across different classes of patents.

Clearly, the pattern of patent revenue outcomes observed in our sample implies that university researchers do not and cannot rely on patents to be a substitute for grants. The probabilities of a “win” are very low and unpredictable both in terms of timing and outcome. No rational lender (university, bank, or company) would loan a university scientist funds to run their lab now based on the rights to a future patent. Thus, research grants (extra and intramural) remain the *sine qua non* for keeping a research lab or program going. That situation seems unlikely to change anytime soon given that universities are now twenty-five years into the Bayh-Dole era and that academic patenting output has leveled off in recent years.

6. Conclusion

Life science research is often viewed as a leading edge of university commercialization efforts, where one might expect to see the impacts of significant changes in the direction of academic research. The evidence presented in this paper suggests otherwise. Using a nationally representative sample of life scientist researchers from the 125 top tier U.S. universities, we explored five issues: Commercialization Impacts, Funding Impacts, Synergies, Hold-Ups, and Patent Royalties. Across the board, the results demonstrate the continuing importance of the basic, open science model of research among US university life scientists. Commercialization and industry funding continue to play a small role in their research activities, and seem to be associated with higher research productivity rather than lower research productivity. Academic patenting is, on average, synergistic with other academic research rather than a significant source of trade-offs. Hold-ups are rare, and patent royalties resemble a lottery with literally a handful of winners among the nearly 2000 patents reported by respondents.

At the most basic level, funding for life science research remains almost entirely in the public or non-market domain. Including foundation funding, more than 90% of the research funding for university life science researchers in 2005 came from non-market sources. Only 5% came from industry sources and an additional 1% from licensing revenues associated with patents. For the 8% of university life scientists with licensing revenues from patents, the median payment in support of their research labs was 2% of their 2005 budget. In contrast, on average, federal funding supported 2/3 of the research budgets of life science researchers. The bottom line is that the federal government remains the primary source of research funding, and there is good reason for this. Most of the research that university life scientists pursue is basic in its orientation and made available in the public domain.

The public nature of this research is underscored in several manners. First, academic publications and doctoral students remain the primary research production activities of university life scientists. While only 12% of the respondents had more than one patent in their academic lifetime, the typical respondent averaged more than 10 academic publications in the past three years and about one Ph.D. student per year. Moreover, the life scientists with patents were also higher producers of publications. Our analysis of scope economies buttresses this finding by demonstrating synergies between patents and articles and doctorates at both the individual scientist and university levels. Good ideas can be turned into both products at lower cost than if the activities were separated. That is particularly good news from a social perspective in the sense that patenting does not diminish other research efforts, at least on average, at either level. Of course, in specific instances, or if patenting activities were to accelerate dramatically, that relationship could shift, although the economies of scale in academic patenting suggests that there might actually be increasing returns to more patent activity.

Despite a literature that has suggested an impending “anti-commons” in university research, life scientists do not seem particularly troubled by hold-up problems in their research. Very few reported having their research efforts restricted even in a minor fashion by intellectual property rights limits on their access to materials or choice of issue. Perhaps this is related to the predominance of basic research. It could also stem from their relatively low level of attention to commercialization efforts, another striking feature of the data, both in terms of attitudes and actions.

The resilience of the basic, open science research approach in university life sciences raises a more fundamental question that may be overlooked with all of the debate over the implications of university commercialization initiatives. Is the public will to support university research being replenished by discussions of the importance of basic knowledge generation for society and humankind? It would seem that a clearer picture of the way in which university life science research actually gets done could be critical to that support and the continued pursuit and acquisition of knowledge.

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Table 1
Patenting Experience and Industry Funding

Percent of Faculty who had	**Applied for Patent Lifetime**	**Received Patent Lifetime**	**Applied for Patent Last 3 Years**	**Received Patent Last 3 Years**	**More than One Patent Lifetime**	**Industry Funding Last 3 Years**
Total (N=1822)	**34%**	**25%**	**22%**	**12%**	**13%**	**20%**
By Field						
Anatomy& Cell Biology	40	30	25	10	14	18
Biochemistry/Chemistry	48	33	33	16	23	17
Biology*	41	33	25	15	19	16
Biophysics& Struct Biology	24	17	17	9	7	13
Botany, Entomology, Zoology	23	21	12	12	10	37
Ecology and Evol Biology	1	1	0	0	1	6
Epidemiology and Biostats	10	7	6	3	1	27
Food Science	24	22	20	18	14	50
Genetics	39	31	23	11	15	4
Immunology	61	44	39	23	23	19
Microbiology**	46	36	27	14	20	24
Molecular and Dev Biology	43	31	30	17	13	13
Pathology	28	20	16	9	9	28
Pharmacology & Toxicology	35	25	23	15	14	28
Physiology	23	15	22	8	8	12

* includes Biomedical and Veterinary, ** includes Bacteriology, Virology, and Parasitology

Table 2
Funding Sources for Life Sciences Research

Source	Percent of Funding from Different Sources
Federal	66.8
Own University	14.5
Foundations	9.5
Industry	5.3
State Government	2.4

Table 3
Research Output of Life Scientists & Industry Funding

Research Output (Last 3 Years)	Life Scientists w/ Industry Funding	Life Scientists w/o Industry Funding	
Patents (lifetime)	1.5	0.7	***
Journal Articles	13.2	9.7	***
Completed PhD Students	1.34	0.95	***
Postdoctoral Trainees	1.51	1.16	*

*, **, *** Significantly different at a 90, 95, and 99% confidence level

Table 4
Determinants of Journal Article Production
Negative Binomial Regression

	Coefficient	z-statistic
Federal %	0.00357	5.64
Industry %	0.00110	0.78
yrssincephd	-0.03322	-3.54
yrssince_2	0.00053	2.87
Total funding	7.22E-07	11.53
asstprof	-0.41033	-6.08
Molecular Bio	-0.21194	-3.18
Micro Bio	-0.26607	-3.60
Macro Bio	-0.16700	-2.11
Constant	2.53705	19.95
/lnalpha	-1.09733	Std Err =0.053238
alpha	0.33376	Std Err = 0.017769

Number of obs = 1205
LR chi2(9) = 321.12
Prob > chi2 = 0.0000
Log likelihood = -3795.2088 Pseudo R2 = 0.0406
Likelihood-ratio test of alpha=0: chibar2(01) = 2575.55
Prob>=chibar2 = 0.000

Table 5
University Life Scientist Factors Influencing Research Choices
(1 – 5 ranking: 1 = not important…..5 = very important)

Influencing Factors	Researchers with Patents	Researchers without Patents	
Scientific Curiosity	4.69	4.6	*
Scientific Theory	4.34	4.11	***
Importance to Society	4.01	3.80	***
Private Firm Interest	2.19	1.68	***
Patent Potential	2.07	1.54	***
Start-up Prospect	1.65	1.39	***
Potential Consulting Relationship	1.59	1.45	***

*, **, *** Significantly different at a 90, 95, and 99% confidence level

Table 6
Research Output of Life Scientists:
Patenting & Industry Funding

Research Output (Last 3 Years)	Life Scientists w/ Patents	Life Scientists w/o Patents	
Journal Articles	12.3	9.7	***
Completed PhD Students	1.25	0.92	***
Postdoctoral Trainees	1.86	1.05	***

*, **, *** Significantly different at a 90, 95, and 99% confidence level

Table 7
Cost Function Estimates
Dependent variable total research costs

	Coefficient	t-statistic
Publications	18251.35	8.28
Patents	49686.61	2.66
PhDs	54062.94	2.60
Pat^2	-45.3329	-1.80
Pubs^2	4440.103	1.95
Phd^2	-9716.08	-2.30
Pat*pub	-2983.89	-2.95
Pat*phd	-3001.27	-0.41
Pub*phd	523.5036	0.57
Yrs since phd	2248.631	2.38
Molecular Bio	-45923.6	-1.28
Micro Bio	-8385.74	-0.21
Macro Bio	-111775	-2.65
_cons	48644.19	1.14
sigma_u	169974.5	
sigma_e	302117.1	
Rho: fraction of variance due to u_i	0.24042	
F test that all u_i=0:	F(120, 979) =	1.68
Prob > F = 0.0000		
Number of obs = 1113, No. groups 121		
R-sq: overall = 0.2442		

Table 8
Evidence on hold-up problems:
Percent of life scientists reporting constraints

	Not applicable	None or minor constraint	Some or major constraint
Affordability of licensing intellectual property	61.5	33.6	4.9
Materials transfer agreements from another university	49.1	39.1	11.8
Materials transfer agreements From private industry	56.2	33.4	10.4

Data Appendix

The data used in this study was obtained based on a 2005 survey developed by a team of researchers at the University of Wisconsin-Madison.[8] The breadth of the surveyed population and the depth of respondent size place this study in a unique position to evaluate general features of university commercialization. This survey is the largest general survey of biological scientists (by number of respondents) in more than ten years (Blumenthal et al. 1996; Blumenthal et al. 1997) and includes all biological science disciplines, not just those disciplines presumed to be at the leading edge of university-industry relations (Campbell et al. 2002). Such a study provides a needed compliment to analyses that seek broad theorization of the origins and effects of commercialization on university research (Gibbon et al. 1994; Bowie, 1994), and to findings derived from investigations of narrower scope conducted with individuals or at universities which may be exceptional, rather than representative, cases (Bird and Allen, 1989; Owen-Smith and Powell, 2001; Zucker et al. 2002).

The sampling population for this study is comprised of professorial faculty in the biological sciences at 125 U.S. universities. We selected universities based on a ranking of research and development expenditures in the biological sciences in 2000-2002 (NSF, 2002). For the purposes of this study, the biological sciences are those defined by the National Center for Education Statistics and the National Science Foundation (NSF, 2004). NCES and NSF categorize biological science as a subset of a more general category, life science, which also contains agricultural science and medical science.

In May-June 2005 we constructed the sampling frame based on faculty directories on university websites from which we drew a simple random sample. An invitation to participate in the survey was mailed on September 26, 2005. The following week an email containing a link to the survey website and further description of the survey was sent. After two weeks, a follow-up email was sent to non-respondents. Following this reminder email, attempts were made to contact non-respondents by telephone. A final email was sent November 7, 2005. The University of Wisconsin Survey Center administered the online survey, email, and telephone contacts. During the data collection process, we excluded 134 individuals from the sample due to retirement, death, and unknown addresses. The result was an adjusted sample of 3,866 biological scientists. Of these faculty, 1,822 completed a substantive portion of the survey, yielding a response rate of 47.1%. Table 1 contains selected descriptive statistics of respondents.

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[8] Jeremy Foltz, Bradford Barham, Timo Goeschl, Fred Buttel, Jessica Goldberger, and Mark Cooper.

Table 1. Descriptive Statistics for Selected Demographic Variables

Variable	Percentage
Gender	
Male	74.7%
Female	25.3%
Age	
Under 45	31.0%
45 to 54	36.1%
55 and over	32.9%
Academic Rank	
Professor	48.1%
Associate Professor	24.9%
Assistant Professor	27.0%

Descriptive statistics of the various disciplines in the survey data are presented below. Below are two lists, one that breaks the life scientists into 15 fields and one of 4 fields that are used in the statistical analysis in the article. Next to each field is the proportion of the sample that it accounts for.

1. Anatomy and Cell Biology – 8.8%
2. Biochemistry/Chemistry - 9.3%
3. Biology (general), Biomedical (general), and Veterinary - 5.3%
4. Biophysics and Structural Biology - 4.6%
5. Botany, Entomology, and Zoology – 5.7%
6. Ecology and Evolutionary Biology – 6.9%
7. Epidemiology and Biostatistics – 7.6%
8. Food Science – 4.0%
9. Genetics – 4.3%
10. Immunology – 5.1%
11. Microbiology, Bacteriology, Virology, and Parasitology – 9.7%
12. Molecular Biology and Developmental Biology – 11.1%
13. Pathology – 5.7%
14. Pharmacology and Toxicology – 4.9%
15. Physiology – 7.2%

Molecular: 1, 2, 4, 9, 12, 15	50%
Micro: 10, 11	20.4%
Macro: 3, 5, 6,	13.5%
Other: 7, 8, and Vet	11.6%