What Explains Science's Expanded Reliance On Postdoctoral Researchers?

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1. Introduction

In 2019, according to the NSF's survey of Graduate Students and Postdoctorates, there were 66,247 postdoctoral appointees employed at U.S. universities. Forty years earlier, in 1979, when the NSF first began to collect data on postdoctoral researchers (or postdocs) there were 18,101. In other words, over the last four decades the number of postdocs has grown at an average annual rate of 3.24%, resulting in a nearly 4-fold increase in their numbers. Over the same period, the number of graduate students at U.S. Universities approximately doubled.[1] Comparable data on faculty numbers are more difficult to obtain, but it seems likely that growth in the number of postdocs greatly outpaced increases in faculty numbers as well.[2]

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[1] Counts of postdoctoral appointees and graduate students are from National Center for Science and Engineering Statistics (20210, Table 1-1 [downloaded 28 Dec. 2021]. Data collection on postdocs has improved over time so some of the growth is likely an artifact of better measurement in recent years. Postdocs are also employed outside universities, in national labs and in private industry. Reliable statistics on their numbers are more difficult to obtain, but those that exist suggest they are a relatively small part of the total postdoc population. The graduate student figure includes both M.S. and Ph.D. students, Unfortunately, the survey only began collecting data separately for Ph.D. and Master's students in 2017, so it is not possible to disentangle these two groups in earlier years. In 2019 Ph.D. students accounted for about 40% of graduate student enrollment.

[2] The Integrated Postsecondary Education Data System (IPEDS) aggregates data on faculty at all degree-granting postsecondary institutions. According to these data full time faculty in higher education increased 87% (from 450,000 to 832,119) between 1979 and 2018. IPEDS Digest 2019 Table 315.10 < https://nces.ed.gov/programs/digest/d19/tables/dt19_315.10.asp> accessed

The consequences of the increased share of postdocs within the scientific workforce have been well documented and much complained about. The length of time spent in postdoc positions has increased over time, while the prospects of transitioning to independent research faculty positions have declined. Since the mid-1990s there have been a growing number of reports calling on universities to improve the working conditions of postdocs and on funding agencies to increase minimum salaries for these position (National Research Council 1981; Institute of Medicine 2020; National Institutes of Health 2012; Institute of Medicine 2014; National Academies of Sciences, Engineering and Medicine 2018). Other scholars have suggested that better information about career prospects for science and engineering doctorates might reduce the inflow of new postdocs and thus help to redress the imbalances in the system (Ganguli, Gaulé and Cugalj 2021).

The steps taken in the last few decades in response to these studies have had some impact on postdoc employment conditions, but they seem designed primarily to ameliorate the most acute symptoms of imbalance rather than to address the root causes of the growing reliance on postdocs in the nation's scientific enterprise. In the remainder of this paper I argue that the growing reliance on postdocs reflects the uncoordinated nature of funding for the nation's scientific enterprise. Federal R&D funding provides resources that support graduate student and postdoc populations, while numbers of faculty positions are driven largely by the staffing

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9/5/2021. The IPEDS universe is much broader than that covered by the Survey of Graduate students and Postdoctorates. An alternative is provided by data from the Survey of Doctorate Recipients, which is based on longitudinal samples of individuals who earned doctorates from U.S. universities in science and engineering fields. According to this source full time science and engineering faculty numbers grew by 88 percent (from 125,600 to 223,5000) between 1977 and 2017.

decisions of the nation’s research universities, which are increasingly dependent on undergraduate enrollments. As a result, growth in resources to support postdocs have grown disproportionately to opportunities to enter faculty ranks, with the result that these positions have become a kind of holding tank for scholars hoping to enter the faculty ranks. I also document that increased reliance on postdocs appears to have strong positive effects on research productivity (measured in articles published). But it is more difficult to assess effects on the quality of research output or the overall direction of scientific discovery.

Conclusively establishing the causes of the growth in postdoc employment is difficult if not impossible given the nature of the available evidence. Rather I will offer two different strands of evidence that are consistent with this argument. I begin by tracing the historical evolution of the use of postdocs since the early 1960s. Then I turn to a newly assembled panel data set that combines annual data on faculty, graduate student and postdoc numbers with data on federally financed R&D expenditures across a selection of seven different disciplines spanning the sciences, engineering and social science. Analyzing variation across universities, over time and between disciplines, I document both the strong positive association between faculty productivity and the presence of postdocs, and the correlation between funding levels and postdoc numbers. Because the analysis relies on observational variation there is no way to conclusively determine that these associations are causal. However, the panel nature of the data does allow me to control for many of the potential confounding factors, and the historical evidence adds support to a causal interpretation of the associations documented in the data.

2. The Evolution of Postdoctoral Research Positions in the U.S.

One of the challenges in assessing the evolving role of postdocs in the scientific workforce is the heterogeneity of experiences of postdoctoral researchers. The term postdoctoral researcher, taken literally, refers to a career stage, not to a particular activity or job requirements. Even restricting one's focus to what has become the canonical definition of the postdoctoral experience as "…a temporary appointment the primary purpose of which is to provide for continued education or experience in research… " (National Research Council 1981, p. 11), there is still considerable variation. While some postdocs are supported on fellowships awarded to the individuals they support, most postdocs are funded through research or training grants and have become relatively low paid laboratory staff, more senior than pre-doctoral students, but dependent on the Principal Investigator for support. Postdocs first emerged primarily as a mechanism to enable further training in advanced skills, but over time, as funding sources have shifted they have increasingly become a relatively inexpensive part of the scientific labor force.

Early History

The history of postdoctoral appointments, at least in the United States, coincides with that of the modern research university. In 1876, the year of its founding, Johns Hopkins University offered 20 fellowships with the purpose of "…attract[ing] and support[ing] young men starting research careers." While the majority of the fellowships supported pre-doctoral students, 4 were awarded to men already holding Ph.D.'s (NAS 1969, p. 8). In the wake of the First World War, which prompted an awareness of the growing importance of science for national security, the National

Research Council, with funding from the Rockefeller Foundation, established fellowships in physics and chemistry. In 1922 the Rockefeller Foundation committed additional funding to support fellowships in medical science (NAS 1969, p. 16). These fellowships contributed to the growth of scientific expertise, but numbers remained relatively small, and their presence attracted relatively little attention.

The number of postdocs began to increase more dramatically after WW II, reflecting the growing federal support for science and engineering in the postwar era. The National Institutes of Health, in particular, established funding specifically to support postdoctoral fellows in medical sciences that greatly increased funds directed to this group. While the first systematic efforts to count postdocs were not undertaken until the early 1960s, the Google N-Gram reproduced in Figure 1 suggests that discussion of this group of scientists began in the early 1940s and followed a rising path until the early mid-1960s. After the mid-1960s, references to postdocs slowed for about a decade and then began to accelerate again until the mid-1990s.

Measurement Issues

Efforts to count the number of postdoctoral researchers have been hampered both by the heterogeneity of their responsibilities and employment relationships, and the limits of data collection by federal agencies (NIH, Biomedical Workforce Group 2012, p. 19). The National Science Foundation's National Center for Science and Engineering Statistics (NCSES) Survey of Graduate Students and Postdoctorates in Science and Engineering (often referred to as the GSS), first reported counts of the number of postdocs at U.S. universities in 1979.

These data exclude postdocs employed outside of academia at government labs or in industry. Moreover, because some postdocs with their own fellowships were not university employees, and because others were hired by departments or individual faculty with grant funds, previous researchers have accepted that, especially in its early years, the survey undercounted the academic postdoc population (Einaudi, Heuer, and Green 2013). In recent years, however, most universities have been encouraged to identify a postdoc coordinator to respond to the survey, and a number of other steps have been taken to improve the accuracy and reliability of data collection (Arbeit, Einaudi, Green, and Kang 2016).

Other researchers have made use of the Survey of Doctorate Recipients (SDR), which is also managed by the NCSES, to estimate the number of postdocs (see, e.g., Kahn and Ginther 2017). The SDR is a panel survey which follows individuals who earned doctorates from U.S. universities over several years and contains relatively rich data on individual characteristics as well as capturing employment transitions. The sampling frame of the SDR ensures that it captures postdocs outside the university sector, but because it is limited to graduates of U.S. universities, it excludes the large number of individuals who earned doctorates outside the country. The effects of this restriction to graduates of U.S. universities are evident in a comparison of aggregate numbers with the GSS. In 2017, for example, the SDR enumerated 18,400 postdocs across all scientific disciplines in academic institutions (SDR, Table S3-7), while the GSS reported a total of 66,733 in Science, Engineering and Health (GSS Table 1-1).

Growing Awareness of the Postdoc Population

Among the earliest efforts to systematically study the roles and experiences of postdocs was a study by Bernard Berelson (1962) undertaken in the early 1960s at the behest of the American Association of Universities (AAU). Berelson personally visited 10 different campuses and sent a survey to all the members of the AAU. Based on this canvas as well as his examination of data on funding for postdoctoral fellows, Berelson estimated that there were close to 10,000 postdocs in 1960 (of which about 8,000 were employed in higher education), and that the number had clearly been increasing in the years leading up to his study. Summarizing the situation, he observed (p. 128-29): "…postdoctoral work….is substantial, it is established, and it is wanted. In constitutes an invaluable service to the national effort in scientific research. In the arts and sciences, it is an important means to obtaining advanced training in a research specialization. In medicine, it is the major rout for research training….In both fields, the universities receive the benefit of a young and well-trained faculty…"

The rapid growth in postdoc numbers noted by Berelson, continued throughout the 1960s. See Figure 2, which traces the growth in numbers of postdocs in the higher education sector from 1960 through 2020. Beginning in 1979 I have relied upon data collected by NCSES in its survey of Graduate Students and Postdoctorates. Before this, I have been able to find only two other efforts to count postdocs: Berelson's estimate, cited above, and the 1969 National Research Council Study discussed in the next paragraph. The National Research Council study implies that by 1967 the number of postdocs in higher education had doubled to 16,000, implying a growth rate of 9.9 percent per annum. Postdocs in the life sciences accounted for 55.5% of this total, and another 32.3% were found in the physical science, mathematics, and earth sciences. Engineering accounted for only 2.6% of the postdocs counted by the National Research Council, and the remaining 10% were scattered across the social and behavioral sciences and other fields (National Research Council 1969, p. 54).

The National Research Council study conducted between 1967 and 1969, like Berelson, viewed the rapid growth in the number of postdocs it reported as a positive reflection of the growth of the nation's scientific enterprise (National Research Council 1969). "If a graduate student is pointing toward a career as a faculty member," the preface of the report summarized, "…a postdoctoral appointment will be almost required to acquire new skills and experience in research and to join the pool from which new appointments are almost always made. The period spent in such an apprentice role is for the most part an enjoyable one…" during which predoctoral pressures and near poverty-level stipends are removed (National Research Council 1969, p. xi). The only significant issue that the report identified was that despite the rapid expansion of postdoc numbers this important segment of the scientific workforce the larger academic community remained largely unaware of this segment of the scientific labor force.

Growth in the number of postdocs slowed significantly across the 1970s. When the NCSES time series began in 1979, they recorded just 18,101 postdocs, implying an increase of just over 2,000 postdocs in the 12 years between the NCSES data and the National Research Council Study, or an average annual rate of growth of 1 percent. When the National Research Council returned to the topic of postdocs in 1981, not only had growth slowed but the perception of postdoctoral researchers had shifted considerably, a fact reflected in the title of the report they issued:

"Postdoctoral Appointments and Disappointments" (National Research Council 1981). As the National Research Council committee detailed, since 1969 obtaining faculty appointments had become more difficult. Although, most postdocs (84%) reported taking their appointment to gain additional research experience, to work with a particular group or to switch fields, close to 1 in 6 (16%) said they had taken a postdoc because there was no other employment available (National Research Council 1981, p. 84). Whereas, the postdoc had been an important route to faculty positions in the 1960s, by the early 1980s an increasing number of postdocs were obliged to wait longer before finding more permanent appointments, or to abandon the search for research faculty positions entirely. Almost 40 percent of chemistry and physics doctorate recipients in Fiscal Year 1972 reported extending their postdoc appointments because of a lack of employment opportunities, as did nearly 30 percent of bioscience doctorate recipients (National Research Council 1981, p. 101).

In addition to these career related concerns, the committee identified two additional problems, that perhaps loomed larger because of the growing number of postdocs and the longer time spent by many researchers in these appointments. The first of these was the low pay and lack of recognized status for postdocs within the academic community NAS 1981, pp. 226). The second was the absence of women and minority groups among the postdoc population (p. vii).

In the years after the 1981 National Research Council study, the number of postdocs once again began to grow rapidly. Between 1979 and 1989, the growth rate averaged 4.3 % per year; in the 1990s the growth rate averaged 3.8 % per year; and in the decade ending in 2009 the growth rate averaged 3.5% per year (see Figure 2). Strikingly after 2010, growth leveled off, and the number of postdocs actually fell for several years, before beginning to increase again in 2018 and 2019.

As the number of postdocs grew, there were important changes in their distribution across scientific fields. Figure 3 traces the changing composition of the postdoc population beginning in 1979. As had been true in 1967, the biomedical and health sciences have continued to account for the largest share of postdocs. Their share of the total had increased to slightly over 60% by 1979, and continued to rise until the early 2000s, when postdocs in biomedical sciences and health related fields accounted for close to 70% of all postdocs. Collectively the physical and earth sciences have made up the second largest concentration of postdocs, but numbers in these fields have not kept up with the overall growth of the postdoc population, dropping from 24% of the total in 1979 to about 13% in 2019. In contrast, the number of engineering postdocs has grown relative to the total, rising from about 5% in 1979 to over 12% in 2019.

During the 1990s the National Academies' Committee on Science, Engineering, and Public Policy (COSEPUP) returned to the topic of postdoctoral training as part of a larger agenda investigating the education and training of scientists and engineers in the U.S. (Institute of Medicine 2000, p. vii). In contrast to the 1969 and 1981 studies, which had devoted considerable effort to simply documenting the growth in the number of postdocs and trying to better understand the causes and consequences of this growth, the COSEPUP study shifted attention to the training that postdocs received and the conditions under which they worked.

Their investigation highlighted many areas in which reality fell short of the ideal, noting that: (1) training opportunities varied substantially, (2) mentoring and career development resources were often limited, (3) postdoc employment status remained poorly defined, and (4) postdoc pay was often quite low. The report concluded with a list of actions that advisors, institutions, funding organizations and disciplinary societies should undertake to remedy the situation (Institute of Medicine 2000, p. 99). Chief among these were to regularize the institutional status of postdocs, develop clear policies for this group of employees, increase their compensation and provide access to health insurance and other employee benefits, provide substantive career guidance, facilitate postdoc transitions to regular career positions, and improving the collection of data on the numbers and working conditions of the postdoc population.

The NIH "Doubling" and its Aftermath

Beginning in Fiscal Year 1998, at about the same time the COSEPUP study was being completed, the National Institutes of Health embarked on an approximate doubling of R&D funding for biomedical sciences. By 2004, NIH funding had increased to $19.6 billion from $9.8 billion at the start of the doubling (both figures in current dollars). The rapid acceleration in funding is apparent in Figure 4, which plots both current and inflation adjusted NIH research grant figures from 1975 through 2017. Increased funding resulted in a growing demand for biomedical research labor. Because of the time lags involved in producing new Ph.D.'s the initial effect of this demand was to cause an influx of foreign temporary residents to fill new postdoc positions (Blume-Kohout 2013, p. 2).

Increased funding also resulted in an increase in support for graduate students, and enrollment in Ph.D. programs in the biomedical sciences expanded. With normal time to degree in these programs of 5-6 years, the bulk of these students completed their studies just as the NIH doubling was coming to an end or in the next few years (Blume-Kohout 2013). The number of doctorate recipients in the life sciences at U.S. universities, which had been nearly stable at around 8,500 from 1998 through 2004, began to increase in 2005, rising to about 12,000 by 2012, (nearly 40% above its 1998 level). The rapid increase in doctorate recipients, which was not accompanied by a comparable increase in permanent faculty positions, resulted in increases in both the number of doctorate recipients without definite employment at the time of graduation, which rose from 27.6 % in 1998 to 37% in 2012; and the share of those with definite commitments who had accepted positions as postdoctoral researchers, which increased from 60.9% in 1998 to a peak of 70% in 2010 (NCSES 2022, Survey of Earned Doctorates, special tabulations).

The manifest imbalances between the training and employment of biomedical scientists, whom we have seen make up the bulk of the postdoc population underlay a growing chorus of concerns about the biomedical workforce, and resulted in a series of studies documenting the challenging environment for aspiring biomedical researchers. In 2011 the National Institutes of Health established a working group to study the biomedical workforce and make recommendations about steps that the agency could take to support a future sustainable biomedical research infrastructure (NIH Biomedical Research Workforce Working Group, 2012, p. 15).

In 2014, the National Academies conducted another study of postdoctoral experience, noting that since its last study in 2000, "…the number of postdoctoral researchers in all disciplines has continued to grow sharply," but "the number of independent and especially academic research positions into which they might transition did not" (Institute of Medicine 2014, p. ix). Drawing on data from the Survey of Doctorate Recipients stretching back to the 1980s, Kahn and Ginther (2017) offered one of the most detailed analyses of the declining prospects for postdocs in the biomedical sciences. While the share of U.S. trained doctorate recipients entering postdocs had remained roughly stable between 1980 and 2010, they found that after 2000, a sharp drop in the share of these Ph.D. recipients transitioning to faculty positions within 10 years of graduation (Kahn and Ginther 2017, p. 92). These concerns were echoed and further amplified in a 2018 report of the National Academies on the biomedical workforce (National Academies of Sciences, Engineering and Medicin 2018). Not only were Ph.D.s in the biomedical sciences less likely to secure faculty positions, but the average age at which they obtained these positions and secured their first independent grant funding was creeping ever higher. As the report observed, the obstacles to success "…have created a career path that is increasingly unattractive, in terms of pay, duration, culture, risk-taking, and future job prospects…" (NAS 2018, p. 2).

The Evolving Role of Postdocs in Scientific Production

As the preceding account documents, postdoctoral positions first emerged primarily as a mechanism of advanced training, during which new skills could be acquired to augment training during the pre-doctoral period. At the same time, postdocs, because of their doctoral training, and full-time research focus, became important contributors to the production of scientific knowledge. So long as this additional preparation led predictably to faculty appointments for the majority of postdocs, the system appears to have worked effectively and to have raised little concern.

Beginning in the late 1960s, however, the growth of faculty positions in U.S. universities slowed, resulting in a mismatch between inflows into postdoc positions and outflows into faculty appointments. This created a growing perception of postdocs as a "holding" position in which aspirants to independent researcher status were obliged to wait until an appropriate opening occurred. With this shift in status, the balance between training and scientific production shifted. With many postdocs funded on research grants, PIs came to see them as a productive and relatively inexpensive source of labor, while de-emphasizing training and career development investments.

Although these shifts were coming into focus as early as the late 1970s, leading to a growing emphasis on reforms designed to improve working conditions for postdocs, the situation was greatly exacerbated by the NIH doubling of research funding between 1998 and 2004. While the purpose of this funding expansion was ostensibly to address the increasing competitiveness of the funding environment for faculty investigators, increased funding allocated across the relatively fixed faculty population provided the financial resources to support additional Ph.D. students and hire more postdoctoral researchers. Graduate programs expanded and produced a growing number of Ph.D's but this was not met with a comparable expansion of faculty numbers. The resulting imbalances in the system contributed to a sense of crisis within the biomedical research community and among scholars studying the community.

At heart the problem was the fact that determinants of the number of faculty positions were being made by universities based largely on factors such as anticipated undergraduate enrollments and the availability of suitable laboratory space, while decisions about the amount of research funding available were made by NIH administrators. Recognizing the unpredictability of research funding, universities and academic medical centers expanded largely by increasing graduate student enrollment and hiring additional postdoctoral researchers supported on soft money and able to contribute to new grant applications to sustain their funding.

3. Correlates of Postdoc Employment

The argument of the preceding section is that in the absence of mechanisms linking the inflow of aspiring researchers into postdoc position to the likely opportunities to enter independent faculty research positions increases in the availability of federal R&D funding have encouraged growth in the number of postdocs in at least some areas of science well beyond the number needed to fill faculty vacancies. Postdocs have become an important part of the scientific workforce and play a key role in the organization of labs and the production of new scientific knowledge, but this transition has, in turn, reduced the value of the advanced training these positions provide. As postdocs' role has shifted toward production of new knowledge, opportunities for training have diminished and the value of the training they do receive has declined, since many will ultimately exit the academic sector for industry or government jobs that place less value on these skills.

While the conjectures of the preceding paragraph are largely untestable given the available evidence, further insight into the contributions of postdocs to scientific production as well as the role of federal funding in supporting the growth of postdoc populations can be gained by considering more disaggregated data that exploit variation across disciplines and universities in the number of postdocs and their relationship to scientific outputs, funding and other variables. To do this I use newly assembled data on inputs to the research process—faculty, graduate students, postdocs, and R&D expenditures—as well as outputs—publications and citations. Data on the numbers of postdocs and graduate students are drawn from the NCSES Survey of Graduate Students and Postdoctorates in Science and Engineering. R&D expenditures are based on data reported in the Higher Education Research and Development Survey. Data on faculty, publications and citations are from Academic Analytics, which is a private company that collects data on university faculty and their research output.[3] Data from all of these sources are available from 2009 through 2018, and additional details about the data can be found in the appendix.

I limit analysis to the U.S. universities that accounted for 90 percent of cumulative R&D expenditures in this period.[4] In addition, because of the work involved in merging the different data sets, I restrict attention to seven broad fields of scholarship: (1) biomedical science, (2) chemistry, (3) chemical engineering, (4) electrical engineering, (5) computer science, (6)

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[3] This data set is the result of a collaborative project being conducted with Donna Ginther.

[4] Using the NSF HERD, 90 percent of R&D expenditures were concentrated in the top 173 universities or academic medical centers in this period. Because these 173 entities include multiple entries for some universities for which postdoc and graduate student numbers are reported in aggregate form, merging the HERD data with data on graduate students and postdocs reduces the number of institutions to 147. Not every discipline considered here is represented at each university in the sample, so numbers of observations are lower for some fields of study.

psychology, and (7) economics.[5] These seven fields of study span a wide range of approaches to research and provide insight into differences in the utilization of postdocs in scientific production.

Concentration of Postdocs and Other Inputs

A good place to begin is by considering the distribution of our key measures of inputs across institutions. A striking result of this analysis is the extent to which research expenditures and postdocs are concentrated at a small number of universities. In comparison, faculty and graduate students are considerably more evenly distributed across institutions. Table 1 reports for each field of study the share of discipline postdocs, federal R&D expenditures, faculty and graduate students accounted for by the top 10 percent of universities in each two-year period from 2009-10 through 2017-18.

Funding is most concentrated in electrical engineering, computer science, and economics, where 50-60 percent of expenditures are concentrated at the top 10 percent of institutions. Funding is most equitably distributed in chemistry, chemical engineering, and psychology, where the top 10 percent of institutions account for about 30 percent of expenditures. Biomedical sciences fall somewhere in between, and appear to have experienced a growing concentration of funding at the top over time (a trend that is apparent in a number of other disciplines as well).

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[5] Because of the way the Academic Analytics data are collected, assigning individuals to universities and academic disciplines is not always straightforward. In particular, individuals may appear in the database multiple times with affiliations to different universities, as well as appearing multiple times within a university if they are associated with more than one department or field of study.

The concentration of postdocs is also consistently high across all disciplines. In Biomedicine, which has historically been the largest employer of postdocs, they are even more concentrated than R&D expenditures, with the top 10 percent of institutions accounting for nearly 40 percent of the postdocs. Levels of concentration are similar in the other disciplines. In contrast to the concentration of research activity at a relatively small number of universities, faculty and graduate training are relatively dispersed. In most fields, the top 10 percent of institutions account for less than 25 percent of the regular tenure-track faculty, and graduate student numbers parallel faculty distribution.

Postdoc-Faculty Ratios

Another reflection of variations in the distribution of postdocs is the ratio of postdocs to faculty across universities. Combining the faculty counts derived from Academic Analytics with reported numbers of postdocs I calculate the ratio of postdocs to faculty in each discipline at each university. Figure 5 shows time series plots of the mean and median of the distribution of the postdoc-faculty ratio across universities along with the values at the 10th and 90th percentiles of the distribution. Panel A contains plots for biomedicine, chemical engineering and chemistry, the fields in which reliance on postdocs is greatest, while Panel B plots the remaining disciplines, where ratios are substantially lower.

In biomedicine, chemistry and chemical engineering (Figure 5A), the median department typically has about 0.5 postdoc for per faculty, while the department at the 90th percentile has between 1.5 and 2 postdocs per faculty. With the exception of chemistry, where there is a slight downward trend in reliance on postdocs, there is no suggestion of substantial change over the period covered by the data. In comparison to the fields plotted in Figure 5A, the utilization of postdocs is much more limited in the remaining disciplines. The highest ratio is found in electrical engineering, where the faculty outnumber postdocs by 5 or 6 to one at the median department, and the department at the 10th percentile of the distribution has no postdocs. Economics is the discipline with the fewest postdocs; indeed the median department has none, and those at the 90th percentile have fewer than one per every 10 faculty. In all cases the skewness of the distribution is apparent in the divergence between mean and median values, as well as in the larger gap in postdoc-faculty ratios between institutions at the 90th percentile and those at the median than between the median and 10th percentile institution. Finally, there appears to be few changes over time in the characteristics of the distributions.

Postdoc and Scientific production

One implication of the increased reliance of academic science on postdocs is that they are making an important contribution to the production of new scientific knowledge. Measuring contributions to knowledge is difficult, but we can use numbers of publications per faculty member as a proxy. In every discipline there is a strong positive association between publications per faculty and postdocs per faculty, which is reflected in the upward slope of the binscatter plots reproduced in Figure 6. The positive relationship is suggestive, but should not be interpreted as reflecting the causal effects of increasing the number of postdocs on knowledge production. It may simply be that more productive faculty both publish more and attract more postdocs. Without some quasi-experimental variation that approximates the effect of exogenous variations in postdoc numbers holding other factors constant we cannot conclude that postdocs are directly contributing to the production of more articles.

Much of the association in the plots in Figure 6 arises from across university differences in publications and postdocs. One way to see this is by estimating a fixed effects panel regression of the correlates of articles per faculty member (p):

$$(1) \qquad p_{it} = \alpha_i + \tau_t + \beta_1 pd_{it} + \beta_2 r_{it} + \beta_3 gs_{it} + \varepsilon_{it}$$

Where i indexes universities, t indexes time, pd is the number of postdocs per faculty, r is federal R&D funding per faculty, and gs is the number of graduate students per faculty. In addition equation (1) includes a university fixed effect, α, which captures non-time varying differences across universities, and a year fixed effect, τ, that captures common temporal shocks that affect all universities in the same way. In this specification, the impact of variations in postdocs, research funding and graduate students per faculty are identified based on year-to-year changes within each university, while systematic differences across universities are absorbed by the fixed effects.

Table 2 reports the results of this estimation. In contrast to the pronounced positive relationship between publications and postdocs in the raw data there is little indication that variations in postdoc numbers over time are related to rates of publication. There is somewhat more evidence of a relationship between graduate student numbers and federal funding and publications. But again we cannot interpret these as causal. One striking feature of these regressions is the positive trend in numbers of publications over time reflected in the increase in coefficients on the year effects. Rosenbloom at al (2015) found a similar upward trend in publications in academic chemistry in the years 1990-2009. These results suggest that this result has persisted to the present and is more general.

Factors Affecting the Distribution of Postdocs

As we have seen the number of postdoctoral researchers varies considerably across universities. To a first approximation we can interpret this variation within a discipline as reflecting variations in the demand for postdocs at that institution.[6] Factors affecting the demand for postdocs are likely to include the number of faculty researchers at the university and the level of funding available to support their research activity. To the extent that pre-doctoral students act either as substitutes for or complements to postdocs in producing knowledge, the number of graduate students may also affect the demand for postdocs. Demand also depends on variations in the wage rate for postdocs, but we don't have a good measures of this, and will assume that variations in wages are common across institutions and thus will be absorbed in common time-effects. Formally then we can write the demand for postdocs at institution i, in year t as:

$$(2) \qquad D_{it} = f(F_{it}, R_{it}, G_{it}, \alpha_i, \tau_t, \varepsilon_{it})$$

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[6] Individual universities are small relative to the total market, so they can be thought of as facing a more or less perfectly elastic supply.

Where F is the number of tenured or tenure-track faculty, R is a measure of research funding, G is the number of graduate students, α is time-invariant university fixed effect, τ reflects common temporal effects across all universities, and ε is an idiosyncratic error term.

Assuming a linear approximation to equation (2) we can estimate this relationship in a panel fixed-effects regression. Table 3 reports the results of estimating equation (1) separately by discipline. There is a positive and statistically significant relationship between federal R&D expenditures and employment of postdocs in chemistry and psychology. Because of the fixed-effect specification, the slope coefficients are identified based on year-to-year variation within each university, and across-university correlation between average funding levels and postdocs is ignored. Estimated coefficients for biomedicine and chemical engineering are economically large and positive but are not estimated with enough precision to be statistically significant. These are the fields in which postdocs are relatively common. In contrast, there is little association between the funding and the number of postdocs in computer science, electrical engineering and economics.

Turning to the other variables in the regression, after controlling for university fixed effects, there is little suggestion that there is any relationship between variations in faculty size or graduate student population and the number of postdocs. This may simply reflect the fact that there is not enough temporal variation in these quantities within universities to analyze their effect on postdoc numbers. The year effects capture temporal trends, and indicate that other things equal postdoc numbers in chemistry and biomedicine were on a downward trend after 2009. In electrical engineering, on the other hand there seems to be an upward trend over time.

If variations individual university level variations in funding from year to year are effectively random, then the coefficients on R&D expenditures could be interpreted as causal. But it seems reasonable to suppose that the quality of research proposals (which remains unobserved) affects both funding and the demand for postdocs. An additional complication is the possibility of reverse causality. Since postdoc appointments are typically longer than one year, departments with more postdocs in prior years may have been able to garner more research support through grants written in whole or in part by the postdocs.

5. Conclusion

Research inevitably involves continuing investment in human capital as investigators grapple with new questions on the frontiers of human knowledge. Postdoctoral research positions emerged first as a period in which scholars could invest heavily in the development of the human capital necessary for success in their chosen field. The value of these skills acquired by postdocs in biomedical science, chemistry, physics and some related fields made postdoctoral appointments an important step on the path to an independent research career. This situation persisted from the late nineteenth century through the 1960s.

During the 1960s the rapid growth of U.S. higher education spurred by the arrival of the baby boom generation on college campuses, supported by the expansion of federal R&D Funding in the wake of Sputnik, and further encouraged by individuals seeking draft deferments led to considerable growth in numbers of graduate students, postdocs and faculty. Beginning in the early 1970s, slowing undergraduate enrollments and a deceleration of federal funding resulted in a slow down in the creation of faculty positions. More recent doctorates entered postdoc positions, and found it harder to exit them into the desired independent faculty research roles they sought. By the late 1970s this imbalance was becoming apparent to those concerned with higher education and the health of the scientific workforce (National Research Council 1981).

Since the 1980s the lack of articulation between the forces affecting the supply of postdocs entering positions and the factors affecting the creation of new faculty positions into which postdocs can exit has resulted in the relatively more rapid growth of postdocs than faculty, and shifted the make-up of the U.S. scientific workforce toward larger research teams with more postdocs. As the length of time spent in postdocs has increased, and the proportion successfully exiting into faculty positions has declined, there are feedback loops that may have helped to slow the number of students seeking Ph.D.s and entering the supply of postdocs. However, the long lags between decisions to enter Ph.D. programs and degree completion, combined with the challenges of forecasting and imperfect information have not been terribly effective. Meanwhile, fluctuations in the availability of research funding, such as the well-publicized doubling of NIH expenditures beginning in the late 1990s supported a substantial expansion of funding for graduate student research assistants in the biomedical sciences which produced with a lag of 5 or more years an increase in aspirants for faculty positions, who saw no other route to these positions than to take postdoc positions.

These broad outlines of the growing reliance of the U.S. scientific enterprise on postdoctoral researchers are discernable from aggregate data. But to make further progress we need to develop better disaggregated data that provide a higher resolution picture of where postdocs are employed and what their role is in the production of scientific knowledge. The second part of this paper has combined newly available data on individual faculty productivity from Academic Analytics with publicly available data on postdocs graduate, students, and research funding to begin such an exploration.

This investigation demonstrates first that the training and employment of postdocs is much more highly concentrated across universities than are numbers of faculty or graduate students. It also reveals substantial variations across disciplines in the use of postdocs. As reflected in the aggregate data, reliance on postdocs is most prominent in the biomedical sciences, chemistry, and chemical engineering. Postdocs remain relatively rare in psychology and electrical engineering, and quite rare in economics and computer science.

The data make clear that postdocs are associated with higher levels of faculty research output. Across all seven disciplines considered in this analysis, there is a clear positive association between the ratio of postdocs to faculty and the number of articles each faculty member produces, as demonstrated in bin scatter diagrams in Figure 6. In the absence of exogenous variation in the numbers of postdocs, we cannot say for sure that this effect is causal. That is, would providing more postdocs at randomly selected universities stimulate more research? Instead, it may be that more productive faculty concentrate in those same universities that attract more postdocs. The panel regressions in Table 2, suggest that this sorting is an important factor in the correlation of productivity and postdocs. After controlling for university fixed effects the correlation between postdocs and publications is negative in 3 of 7 cases, and statistically significant in only one discipline – computer science.

Analyzing the factors affecting the distribution of postdocs across universities, I find some additional support for the role of variations in funding on the numbers of postdocs after controlling for numbers of faculty and graduate students. In panel data estimates of the determinants of the number of postdocs the estimated effect of federal R&D expenditures are positive and economically significant in 5 disciplines—suggesting that every additional million dollars in R&D expenditures results in employment of between 0.26 and 0.88 additional postdocs. These estimates rely on intertemporal variation in funding within universities to identify this effect, and the short time horizon of the panels along with limited variation in funding mean that the point estimates are not terribly precise. Nonetheless two of the estimated coefficients are statistically significant. Taken together with the historical narrative of the first part of this paper these results add support to the view that variations in research funding have play an important part in the expansion of postdoc numbers over time and across space.

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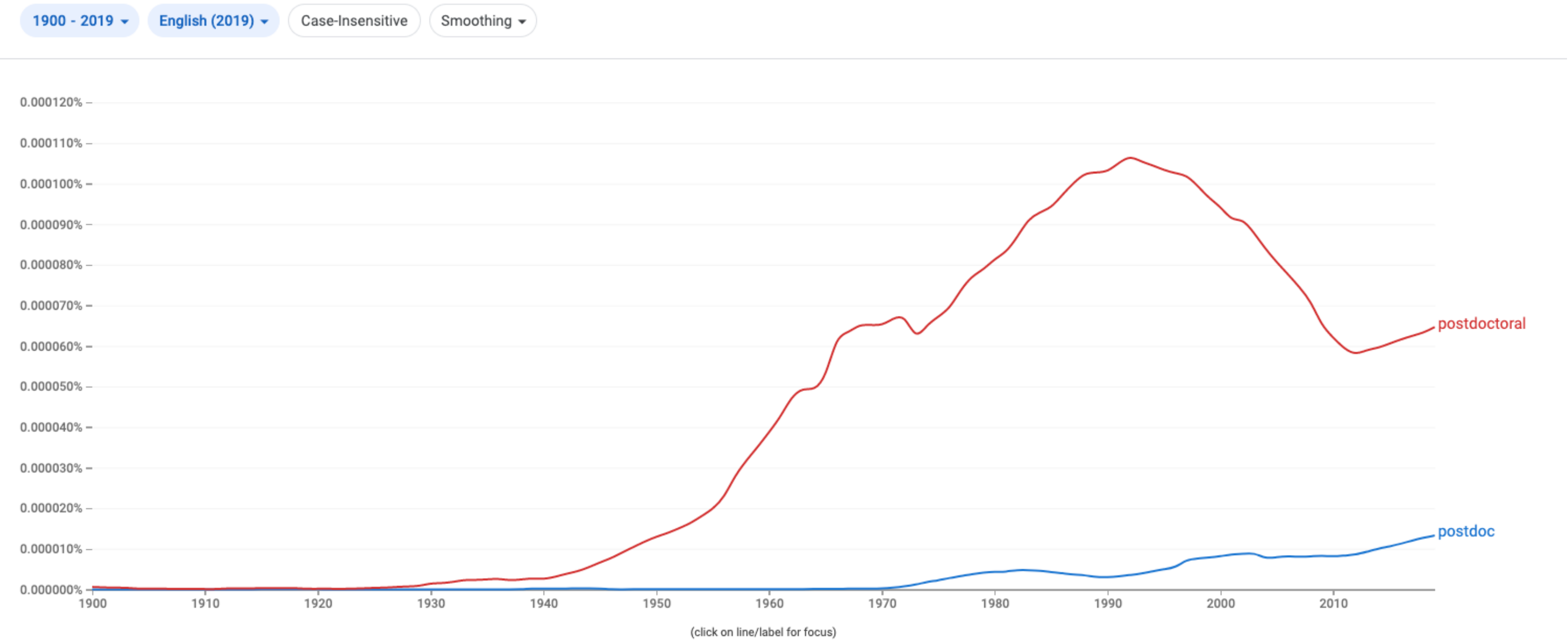
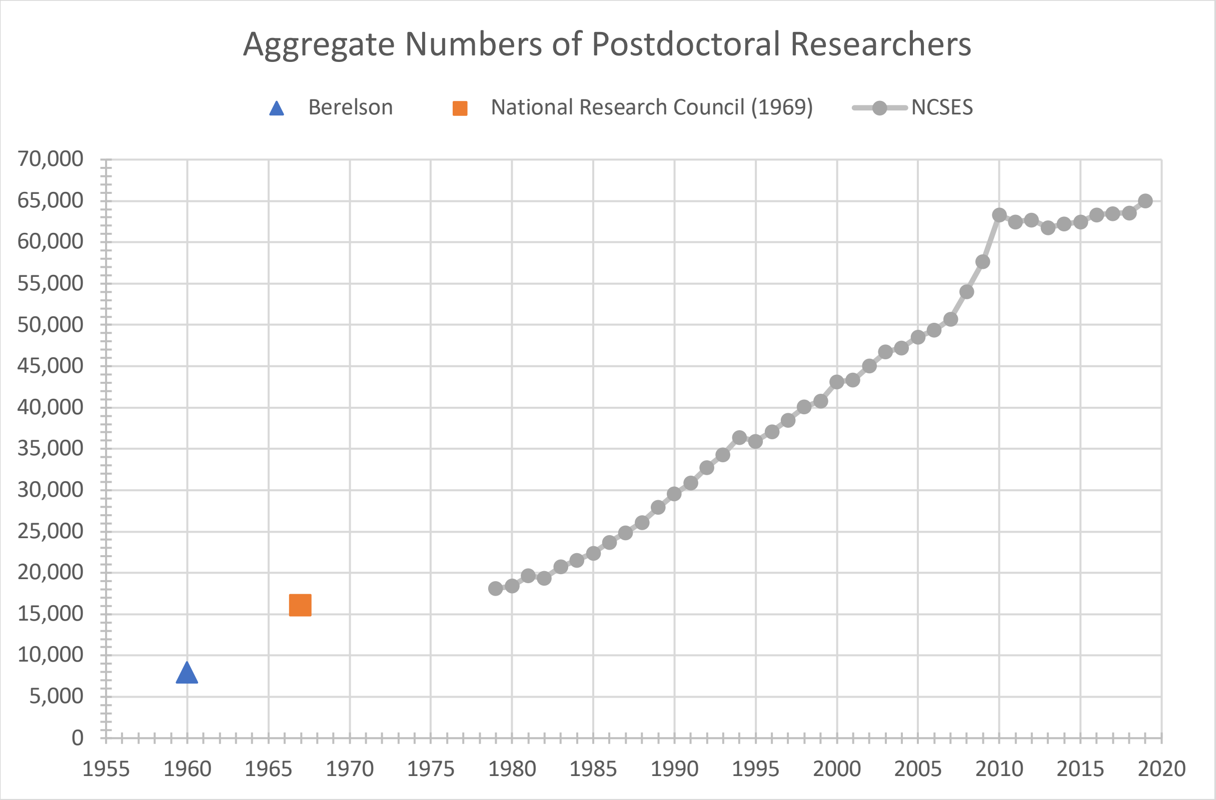
Figure 1:
Google N-Gram for postdoc or postdoctoral, 1900-2019



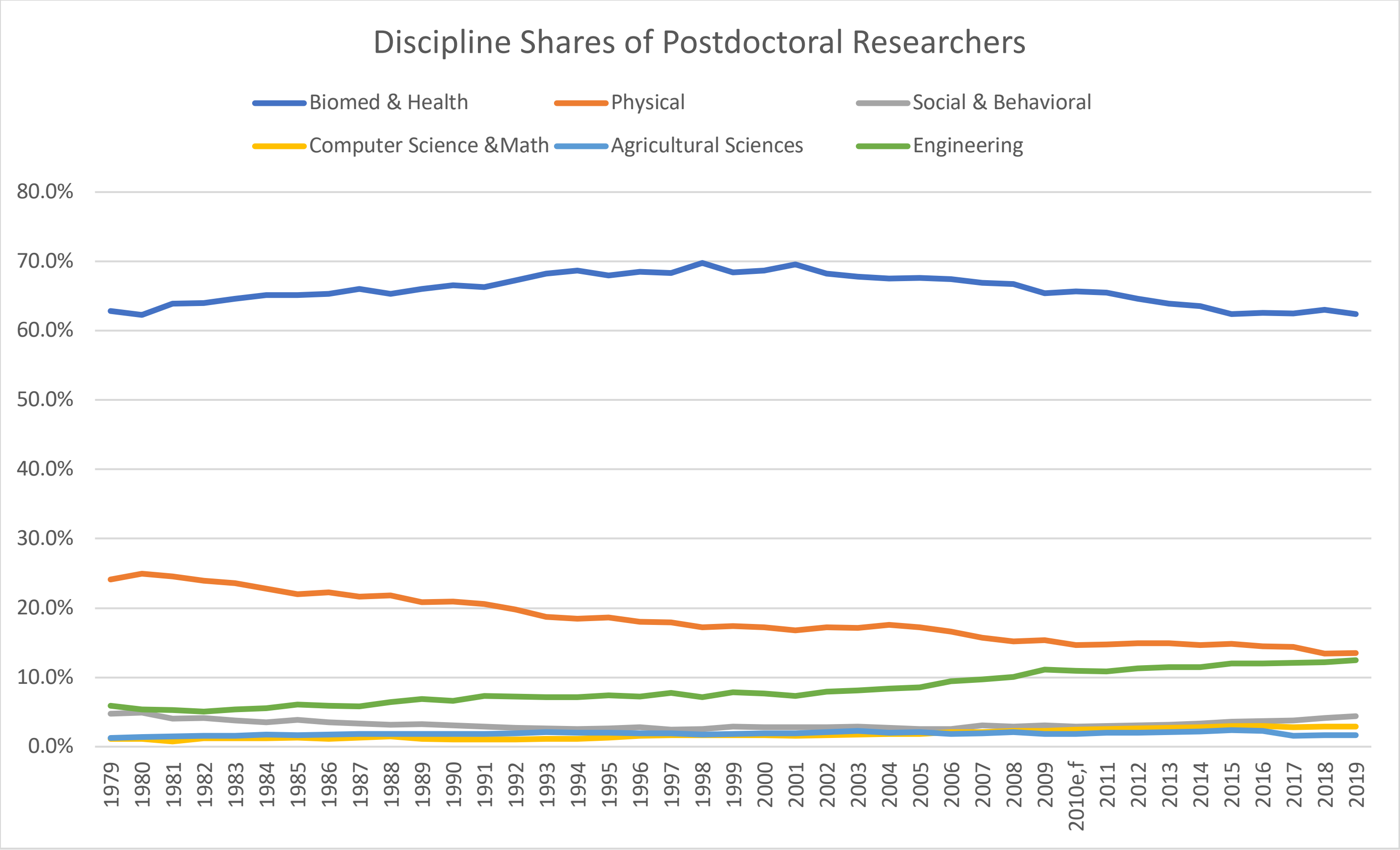
Retrieved July 28, 2021 https://books.google.com/ngrams

Figure 2:
Number of Postdoctoral Researchers at Academic Institutions, 1960-2019



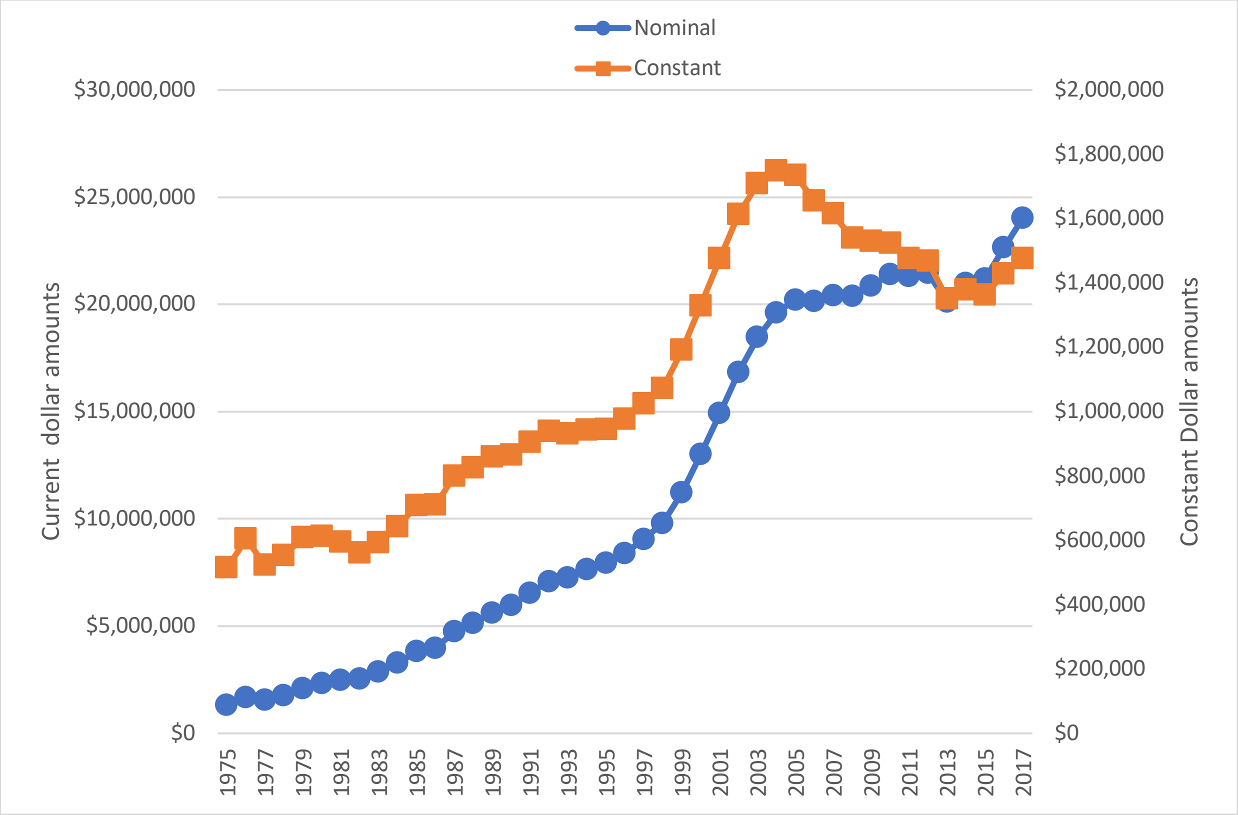
Sources and Notes: Berelson (1962); National Research Council (1969); National Center for Science and Engineering Statistics (2021). NCSES made several changes in their data collection methods that resulted in small shifts in aggregate numbers. These occurred in 2007, 2014, and 2017. Fortunately, in transition years numbers were reported based on both old and new methods. The continuous time series beginning in 1979 is constructed by extrapolating the 1979-2007 levels based on the growth rates of the new series for each subsequent transition.

Figure 3:
Discipline Shares of Postdoctoral Researchers



Sources and notes: National Center for Science and Engineering Statistics (2021). Percentages expressed relative to total postdocs in Science, Health and Engineering. Biomed & Health is the sum of Biological and Biomedical Sciences and Health. From 2007 through 2017 Neurobiology and Neuroscience are enumerated separately in the source and are also part of the total. Physical sciences includes Geosciences, Atmospheric and Ocean Sciences, which are enumerated separately in the source.

Figure 4:
Nominal and Constant Dollar Value of NIH Research Grants, 1975-2017



Sources and Notes: National Institutes of Health, Office of External Research Table #304 NIH Research Grants. Constant dollar series deflated using the Biomedical Research and development Price Index (BRDPI), based on 1950 prices.

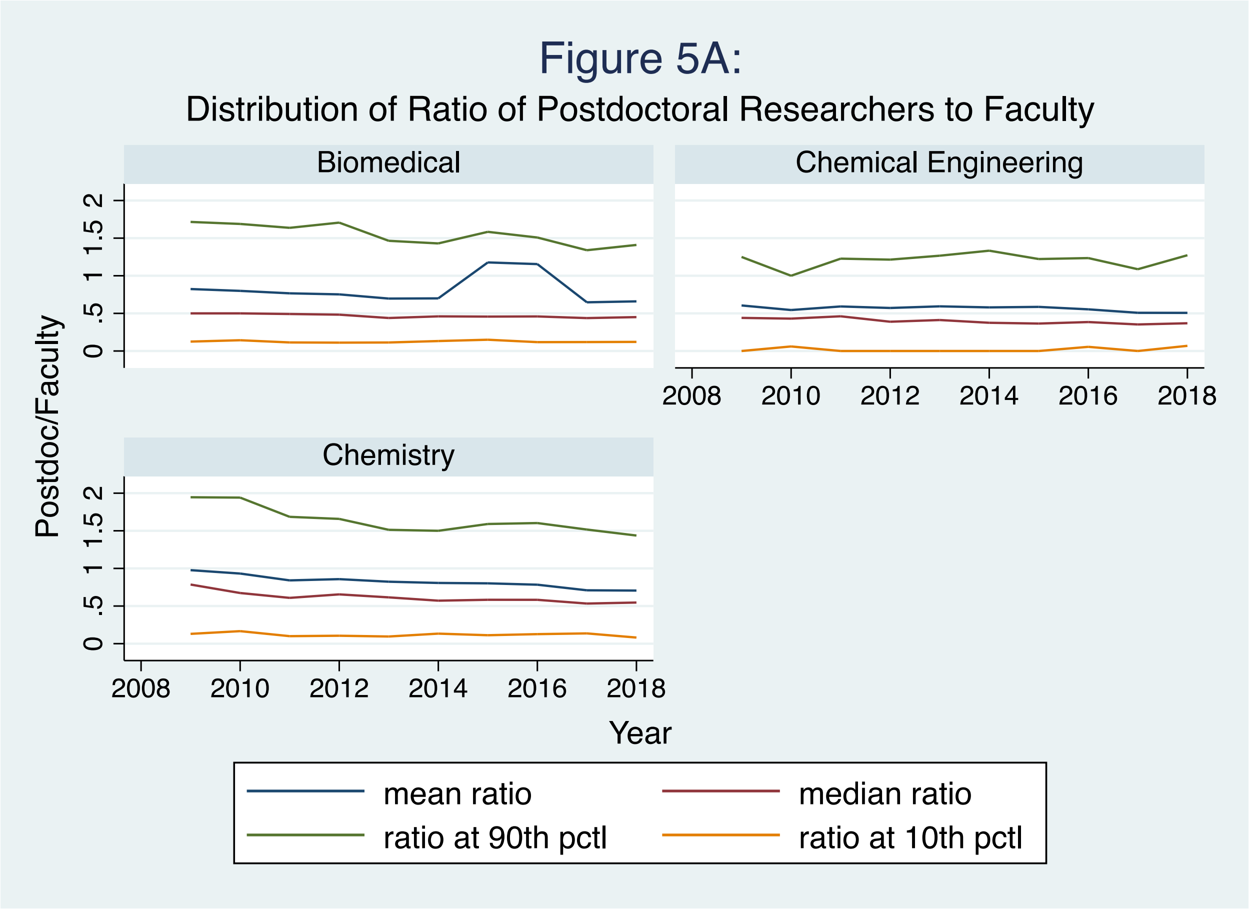


Figure 5A:
Distribution of Ratio of Postdoctoral Researchers to Faculty
Biomedical
Chemical Engineering
Chemistry
Postdoc/Faculty
0
.5
1
1.5
2
2008
2010
2012
2014
2016
2018
Year
mean ratio
median ratio
ratio at 90th pctl
ratio at 10th pctl

Figure 5B:

Distribution of Ratio of Postdoctoral Researchers to Faculty

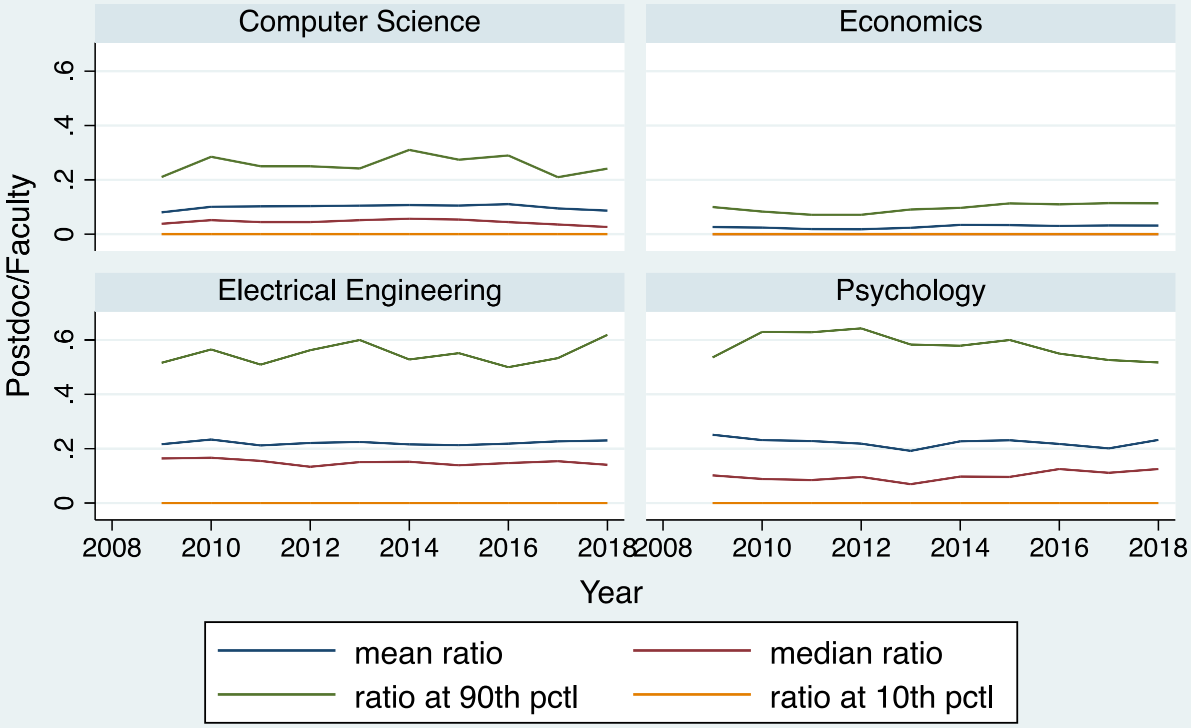
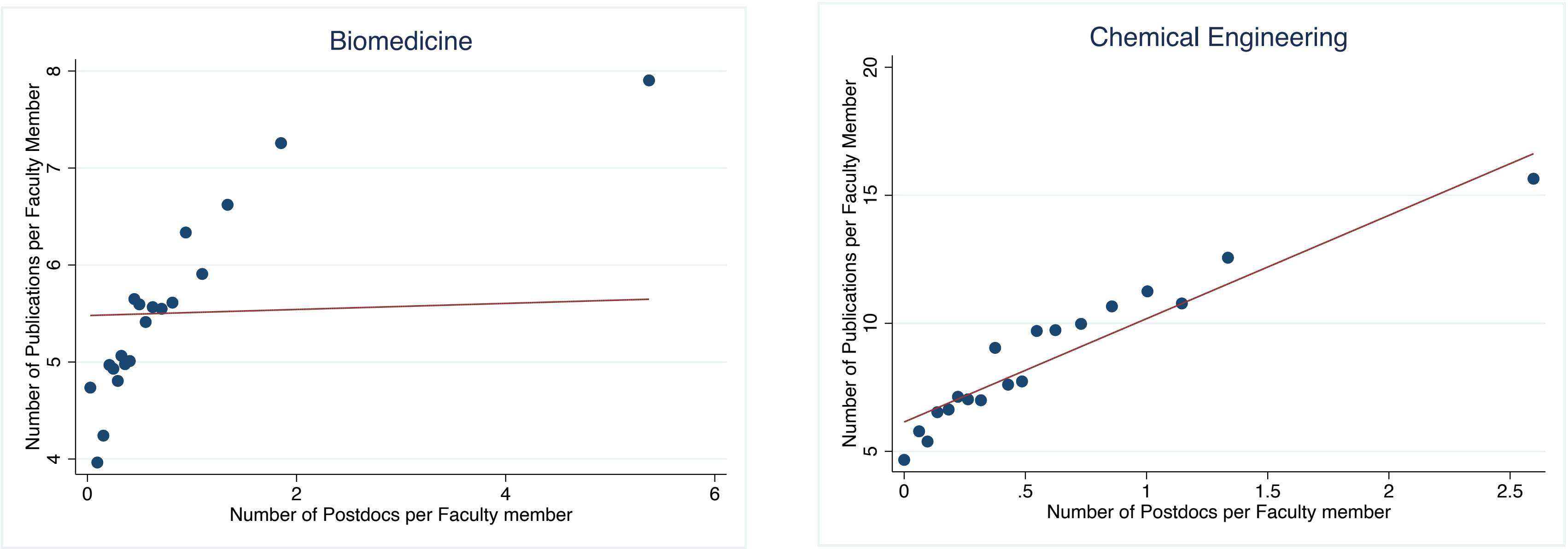


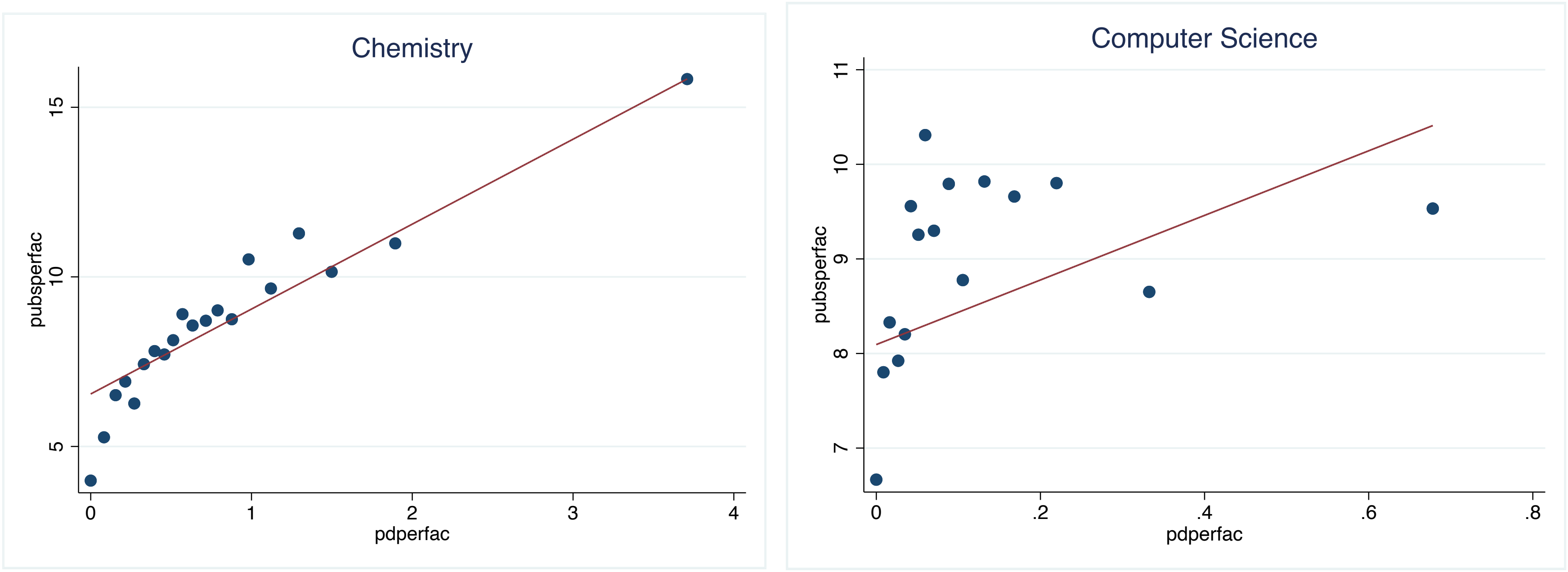
Figure 6:
Binscatter Diagrams of Relationship between
postdocs per faculty and publications per faculty, by field of study



(a) Biomedicine

(b) Chemical Engineering

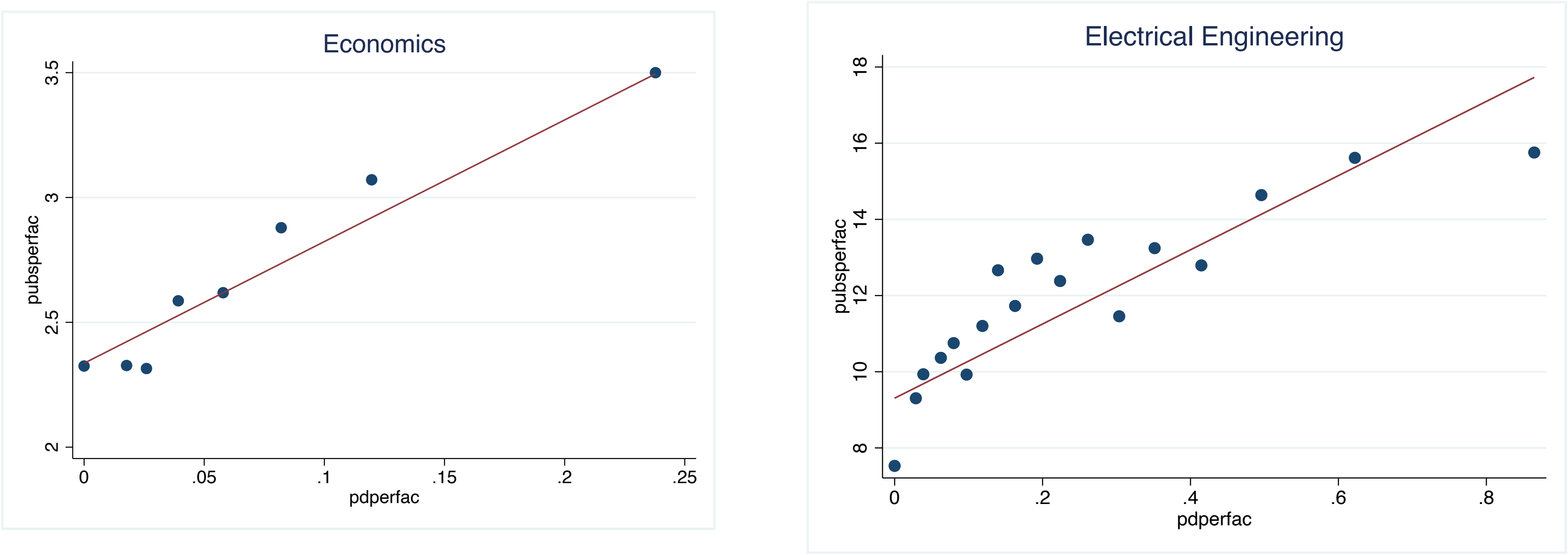
Figure 6 (continued)



(c) Chemistry

(d) Computer Science

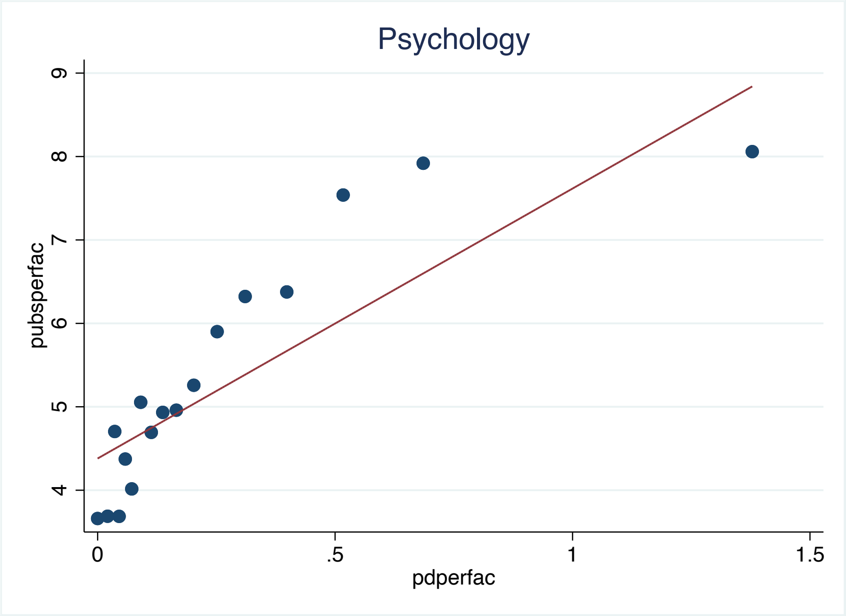
Figure 6 (continued)



(e) Economics

(f) Electrical Engineering

Figure 6 (continued)



(g) Psychology

Table 1

Percentage of Students, Postdocs, Faculty and Federal R&D Expenditures
at the top 10% of institutions in each category

	2009-10	2011-12	2013-14	2015-16	2017-18
Biomedical					
Graduate Students	24.62	23.86	23.37	22.84	24.13
Postdocs	38.07	39.53	39.20	38.39	39.10
Faculty	19.36	20.10	20.90	21.56	20.24
Fed R&D	33.05	33.70	36.13	37.31	36.82
Chemical Eng					
Graduate Students	23.60	24.90	24.66	22.77	21.45
Postdocs	37.86	39.65	39.83	38.85	36.12
Faculty	17.63	20.73	20.98	19.76	18.49
Fed R&D	23.68	29.85	34.30	31.13	30.27
Chemistry					
Graduate Students	21.67	21.68	21.39	21.22	21.62
Postdocs	34.85	36.56	38.38	36.97	36.53
Faculty	16.51	18.61	19.11	17.78	17.53
Fed R&D	28.15	29.99	30.75	28.82	26.19
Computer Science					
Graduate Students	30.72	32.69	36.00	40.91	35.98
Postdocs	46.83	48.28	48.93	48.65	67.29
Faculty	25.77	25.64	25.00	24.99	24.16
Fed R&D	55.79	58.41	56.69	56.55	56.07
Economics					
Graduate Students	26.14	25.64	26.06	28.53	26.56
Postdocs	44.95	55.49	51.91	52.70	52.19
Faculty	20.80	20.87	21.15	21.28	20.79
Fed R&D	50.57	57.17	64.48	58.90	53.10
Electrical Engineering					
Graduate Students	30.90	31.23	31.15	29.90	30.48
Postdocs	35.58	41.21	45.03	41.52	38.14
Faculty	24.51	24.72	24.24	24.38	22.84
Fed R&D	52.50	52.73	62.18	60.31	61.55
Psychology					
Graduate Students	23.73	24.00	23.94	24.55	25.76
Postdocs	39.04	35.85	37.02	34.81	33.07
Faculty	20.11	20.73	21.89	20.49	20.21
Fed R&D	27.85	29.21	32.21	31.49	29.54

Table 2:
Fixed Effect Panel Regressions of Publications per Faculty Member

	Biomedicine	Chemical Engineering	Chemistry	Computer Science	Economics	Electrical Engineering	Psychology
Postdoc per faculty	0.314	-0.038	-0.689	1.740 **	2.024	0.831	-0.101
	(0.234)	(0.729)	(0.425)	(0.836)	(1.759)	(0.839)	(0.570)
Federal R&D Expend per facuty ($ million)	1.779 **	0.974	2.057	1.880 ***	6.016	0.074	1.038
	(0.816)	(0.700)	(1.310)	(0.568)	(4.844)	(0.046)	(0.953)
Graduate Students per faculty	0.009	0.238 ***	0.473 **	0.108 ***	0.132 ***	0.237 ***	0.139 ***
	(0.067)	(0.088)	(0.208)	(0.041)	(0.046)	(0.056)	(0.024)
Year Effects							
2010	1.620 ***	2.583 ***	3.042 ***	2.796 ***	0.788 ***	3.794 ***	1.533 ***
	(0.061)	(0.174)	(0.254)	(0.124)	(0.047)	(0.208)	(0.067)
2011	3.659 ***	5.583 ***	5.977 ***	5.779 ***	1.670 ***	8.153 ***	3.245 ***
	(0.115)	(0.310)	(0.319)	(0.245)	(0.080)	(0.374)	(0.139)
2012	4.098 ***	6.028 ***	6.517 ***	6.060 ***	1.830 ***	8.587 ***	3.489 ***
	(0.147)	(0.346)	(0.338)	(0.248)	(0.089)	(0.356)	(0.146)
2013	4.308 ***	6.186 ***	6.612 ***	6.435 ***	1.947 ***	8.889 ***	3.877 ***
	(0.166)	(0.370)	(0.284)	(0.248)	(0.089)	(0.365)	(0.161)
2014	4.478 ***	6.724 ***	6.968 ***	6.631 ***	2.094 ***	9.203 ***	4.349 ***
	(0.191)	(0.406)	(0.306)	(0.245)	(0.124)	(0.386)	(0.180)
2015	4.642 ***	7.206 ***	7.282 ***	6.813 ***	2.096 ***	9.319 ***	4.705 ***
	(0.178)	(0.419)	(0.321)	(0.267)	(0.106)	(0.389)	(0.184)
2016	4.694 ***	7.441 ***	7.608 ***	6.901 ***	2.103 ***	9.473 ***	4.736 ***
	(0.168)	(0.460)	(0.368)	(0.292)	(0.124)	(0.419)	(0.166)
2017	4.768 ***	7.841 ***	7.671 ***	7.380 ***	2.159 ***	10.064 ***	5.187 ***
	(0.179)	(0.479)	(0.364)	(0.381)	(0.122)	(0.445)	(0.173)

	Biomedicine		Chemical Engineering		Chemistry		Computer Science		Economics		Electrical Engineering		Psychology	
2018	5.083	***	8.726	***	8.212	***	7.582	***	2.235	***	10.972	***	5.746	***
	(0.203)		(0.496)		(0.397)		(0.344)		(0.113)		(0.446)		(0.183)	
Intercept	1.063	***	1.488	**	0.761		1.816	***	0.199		1.662	***	0.919	***
	(0.293)		(0.601)		(1.055)		(0.286)		(0.271)		(0.451)		(0.222)	
Number of observations	1358		858		1196		1048		1044		1053		1156	
R-squared	0.68		0.63		0.60		0.71		0.50		0.70		0.75	

*** p<.01, ** p<.05, * p<.1

Table 3:
Fixed Effects Panel Regression
Correlates of Postdoc Employment

	Biomedicine	Chemical Engineering	Chemistry	Computer Science	Economics	Electrical Engineering	Psychology
Faculty No.	0.103	0.118	0.048	0.014	0.013	0.045	0.014
	(0.074)	(0.092)	(0.113)	(0.016)	(0.015)	(0.047)	(0.027)
Federal R&D expenditure ($ million)	0.292	0.261	0.876 ***	0.000	0.037	-0.003	0.415 ***
	(0.180)	(0.171)	(0.230)	(0.028)	(0.108)	(0.021)	(0.152)
Graduate student numbers	0.020	0.011	0.069 **	-0.001	0.005	0.007	0.008
	(0.027)	(0.016)	(0.030)	(0.001)	(0.003)	(0.007)	(0.007)
Year Effects							
2010	7.427	-0.714	-0.752	1.163 ***	-0.014	0.605	-0.304
	(4.846)	(0.708)	(0.951)	(0.399)	(0.170)	(0.575)	(0.719)
2011	7.682 *	-0.323	-1.946 **	1.173 **	-0.186	0.034	-0.402
	(4.610)	(0.926)	(0.936)	(0.451)	(0.183)	(0.660)	(0.720)
2012	1.846	-0.573	-1.686	1.155 **	-0.043	0.898	-0.117
	(5.991)	(1.145)	(1.025)	(0.454)	(0.205)	(0.960)	(0.808)
2013	-2.109	0.513	-2.531 ***	1.330 **	0.151	1.279	-0.941
	(6.062)	(1.132)	(0.947)	(0.613)	(0.235)	(1.074)	(0.849)
2014	-4.779	0.484	-3.179 ***	1.954 ***	0.321	1.486	-0.380
	(5.660)	(1.375)	(1.075)	(0.678)	(0.202)	(1.147)	(0.937)
2015	-7.156	0.565	-3.619 **	2.253 ***	0.356 *	1.016	0.018
	(5.649)	(1.304)	(1.422)	(0.709)	(0.211)	(1.053)	(0.831)
2016	-5.648	0.310	-4.238 **	2.433 ***	0.436	0.830	0.291
	(6.065)	(1.554)	(1.743)	(0.766)	(0.266)	(1.135)	(0.762)
2017	-5.981	-0.432	-6.522 ***	0.025	0.418 *	1.102	-0.348
	(6.752)	(1.565)	(1.736)	(0.830)	(0.231)	(1.211)	(1.213)

2018	-9.398	-0.832	-7.726 ***	-0.375	0.491 **	1.393	0.075
	(6.731)	(1.430)	(1.626)	(0.915)	(0.233)	(1.099)	(0.968)
Intercept	97.386 ***	7.956 ***	12.965 **	4.246 ***	-0.077	5.182 **	4.754 ***
	(18.900)	(2.004)	(4.974)	(0.852)	(0.681)	(2.172)	(1.667)
Number of observations	1358	858	1196	1048	1044	1053	1156
R-squared	0.04	0.03	0.13	0.05	0.04	0.02	0.04

*** p<.01, ** p<.05, * p<.1