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SHOW ME THE MONEY: FEDERAL R&D SUPPORT FOR ACADEMIC CHEMISTRY, 1990-2009

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ABSTRACT

We examine the distribution of Federal support for chemistry Research and Development (R&D) performed at U.S. universities from 1990-2009. Federal R&D funding is an essential source of funds for investigator-driven research at the nation's universities. Previous studies have documented that aggregated federal R&D funding has become more dispersed over time and attributed this to political pressure to spread resources more evenly. There have, however, been few studies of the allocation of funds within narrowly defined scientific disciplines. By narrowing the focus and exploiting the panel nature of our data we are better able to analyze the correlates of funding variation, yielding a number of new insights not apparent in studies using more aggregated data. First, we find that R&D expenditures at the discipline level are considerably more volatile than aggregate funding. Second, we show a strong positive association between several measures of institutional research capacity and future funding. In particular, we find a positive association between the employment of postdoctoral researchers and higher future research funding.

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A data appendix is available at http://www.nber.org/data-appendix/w23555

1. Introduction

Despite the central role of federal Research& Development (R&D) funding in supporting basic scientific research conducted at the nation's universities, relatively little attention has been given to how these federal funds are allocated. Attracting research funding is important for university leaders not only because it signals the reputation and prestige of their faculty, but because this support typically includes payments for research overhead costs that cannot be allocated to specific research projects. These payments for "Facilities and Administration" (F&A) costs are commonly in the range of 50% or more of the direct costs of the research being performed. For public institutions grappling with shrinking state appropriations and private institutions seeking to control the growth of tuition, this stream of funding has become increasingly important for stabilizing budgets. Collectively the nation's universities advocate for expansion of the federal research budget, while individually they are all seeking to capture a larger slice of the pie and move up in the rankings. This paper studies the allocation of federal research funding in chemistry to research universities, and finds that research capacity is a key determinant of funding.

While it is true that the ultimate goal of federal support for basic research is to advance the frontiers of knowledge, the allocation of federal R&D funds also has a number of other important implications for higher education institutions. Grant funds provide much of the support for the training of doctoral and post-doctoral scholars, so the way in which funds are allocated plays an important role in determining where the next generation of scholars will be educated. At the same time, the linkage between F&A payments and the direct costs of science means that the allocation of funds has implications for the support of scientific infrastructure.

Together these factors influence institutional reputations and resources that affect faculty recruiting, and shape the structure of the higher education enterprise.[1]

Most discussions of the allocation of Federal R&D funding have been purely descriptive and concerned with aggregate funding across all disciplines. There has been little attention to the factors that influence the distribution of funding to individual universities. The premise of the merit-review process used by the National Science Foundation (NSF), the National Institutes of Health (NIH) and other federal agencies is that funding should be allocated to support the best science as judged by other scientists. Yet the primacy of merit review has not fully insulated science funding from the pressure of members of Congress seeking to steer more federal science funds to their own districts. These pressures are manifested both in earmarks for certain projects and in programs like NSF's Experimental Program to Stimulate Competitive Research (EPSCoR) and NIH's Institutional Development Award (IDeA) Program, both of which target funding to scientists in states receiving disproportionately low levels of funding.

Universities are, of course, concerned about their rankings in the National Science Foundation's annual survey of Higher Education R&D Expenditures, citing high levels of funding as a marker of prestige. There is a small literature that has used these aggregate data to explore what might be called the political economy of federal science funding. Geiger and Feller (1995), Graham and Diamond (1997) and Feller (2001) have used aggregate Federal R&D funding to states or universities to document the growth of national research capacity and the expansion of the group of research universities beyond the small group of elite universities that

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[1] Research universities are themselves sources of local economic development spillovers. As attention to the innovation systems that have emerged in Silicon Valley, Route 128 around Boston, the Research Triangle and in Austin, Texas suggests, fostering robust university research enterprises is seen as one key to innovation-led economic growth strategies.

dominated research and graduate training in the 1950s. In the 1950s and 1960s, as a result of federal investments in science after Sputnik, the group of research universities expanded significantly (Graham and Diamond 1997, ch. 2). Since the mid-1970s, however, as the growth of federal R&D funding slowed, the group of research universities has more or less stabilized, and competition between them to move up the rankings has intensified. This literature is, however, more descriptive than analytical, and offers few empirical insights about the factors that influence the distribution of funding across universities or variations in a university's funding over time.

In addition to this work there have also been some studies that explored the interactions between federal and non-federal sources of funding. Mostly this research has been motivated by the question of whether federal funding is a substitute or complement for non-federal funding. Using somewhat different approaches Blume-Kohout, Kumar, and Sood (2014), Payne (2001), and Lanahan, et al. (2016) have all concluded that increased federal funding tends to increase research expenditures from other sources rather than crowding them out.[2] Ehrenberg, Rizzo, and Jakubson (2003) have pointed out that in aggregate, since the 1980s the share of university research expenses supported by federal funds has declined, dropping from over 60% to under 55%. Analyzing panel data for 228 universities, they conclude that universities have responded to the falling levels of federal support by reducing faculty-student ratios, and increasing tuition, in effect subsidizing research expenditures by increasing the costs and reducing the quality of instruction.

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[2] David, Hall, and Toole (2000) survey the literature on the relationship between federal and industrial R&D spending.

Aggregate descriptions of the sort noted above are helpful in sketching the broad outlines of federal research support, but because they combine data on funding across a broad range of scientific disciplines they cannot yield much insight about the factors influencing the patterns that they describe. Wachtel (2000) has analyzed the distribution of the National Science Foundation's funding of economics research. Given that economics funding has been concentrated among a few institutions, he argued that funding decisions are not being made objectively. In contrast, Feinberg and Price (2004) controlled for proposal quality and found that researchers affiliated with the National Bureau of Economic Research (NBER) were more likely to receive funding than otherwise comparable applicants.

Focusing at the level of individual investigators, Ginther et al. (2011, 2012, 2016) examined race/ethnicity and gender differences in the probability of receiving NIH funding. After controlling for several individual and institutional covariates, these studies found that the NIH funding rank of the institution was associated with a higher probability of funding. In other words, the wealthier the institution in terms of NIH funding, the more likely a proposal from an investigator affiliated with that institution was to receive funding. However, these studies do not control for the fact that the best researchers are more likely to be employed by the best-funded institutions.

With the exception of these few studies, we are not aware of other work that has sought to analyze the distribution of federal R&D funding within a single scientific discipline. If we are going to gain greater insight about the factors that influence the allocation of funding, however, it is necessary to study funding at this more disaggregated disciplinary level. In this article we provide what we believe is one of the first empirical examinations of the determinants of the distribution of research funding, examining the factors that influence federally funded R&D expenditures in chemistry at a panel of 147 U.S. universities between 1990 and 2009.

Because of disciplinary differences in publication and citation practices, as well as variation in laboratory structure and organization we believe it is essential that any effort to identify the determinants of funding must be conducted at a disaggregated level, rather than attempting to encompass aggregate R&D Funding. Chemistry provides an excellent area for our exploration. It is a foundational discipline that receives a relatively large level of federal R&D funding, amounting to over $1 billion annually, or close to 4% of federally funded university-performed R&D in the period we are considering. In addition, chemistry research includes a broad range of topics, from fundamental scientific exploration to highly applied areas in biochemistry and chemical engineering. Also, the organization of the Chemistry discipline allowed us to compile the necessary data to analyze inputs in the knowledge production process. The American Chemical Society keeps a roster of members that allows us to identify Chemistry and Chemical engineering faculty at research universities over several decades. These data are not readily available in other disciplines.

Our empirical results offer a number of intriguing and policy-relevant insights about the allocation of funding in this field. First, we document that scientific capacity plays a large role in the distribution of funding. Faculty numbers, graduate program size, and numbers of postdoctoral scholars are all positively associated with Federal R&D funding. Of these relationships, however, only the number of postdoctoral scholars is consistently statistically significant. The effect of an additional postdoc is also economically large, implying an increase in funding of nearly $14,000 in Federal R&D funding. Second, consistent with the focus of most federal agencies on scientific merit, we find holding personnel numbers constant, higher rates of publication are associated with more funding. Third, we find that higher levels of non-federal R&D funding are associated with more federal funding, a result with the complementarity between these funding sources found by Blume-Kohout, Kumar, and Sood (2014) and Payne (2001).

We begin in the next section by describing in more detail the data that we use, and present a number of summary and descriptive statistics. We show that federal support for chemistry research is quite unevenly distributed across universities and that the overall size distribution of funding has remained stable over time. Looking at the performance of individual institutions, however, belies the initial impression of stability. The fortunes of particular universities have changed quite a bit since the early 1990s. In section 3, we introduce a dynamic panel regression framework to systematically analyze the determinants of funding at the university level. This analysis points to several important conclusions. Section 4 places these results in context and considers their significance for our understanding of federal support for university-based R&D.

2. An Overview of the Research Funding Landscape for Academic Chemistry

Our analysis sample consists of the 147 institutions with the highest aggregate value of real federally financed academic chemistry R&D expenditures over the 20-year period from 1990 to 2009. We initially focused on the top 150 institutions, but were subsequently obliged to drop three of them because the available data were incomplete or appeared inconsistent.[3] In aggregate, our sample accounted for over 90% of federally supported and total chemistry R&D expenditures in each year, produced more than 90% of research doctorates earned in chemistry annually, and employed almost 95% of the postdoctoral researchers. The institutions in our sample also represent a highly diverse population ranging from chemistry powerhouses such as MIT, which averaged close to $37 million (in constant 2005 prices) in total chemistry R&D expenditures annually, to Cleveland State University, which averaged under $1.2 million in chemistry R&D expenditures in the same period.

Insert Figure 1 about here

Table 1 lists the 147 institutions in out sample, ranked from highest to lowest in total real federally financed chemistry R&D expenditures over the entire twenty-year period 1990-2009. The table also reports average federally financed R&D expenditures for 5 year periods. It is apparent that funds are distributed relatively unequally, with the top 10 institutions receiving approximately 20% of funds in each period, and the top 20 accounting for more than one-third of total funding. In Figure 1 we have plotted Lorenz curves illustrating the distribution of Federal R&D Expenditures in 5 year periods from 1990 through 2009. Were funds equally distributed the plot would lie along the 45-degree line, which is also graphed for reference.

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[3] The three institutions dropped from our sample included two academic medical centers: the University of California San Francisco and the University of Texas M.D. Anderson Cancer Center—which reported no chemistry faculty, graduate students or postdocs for much of the study period—and the Oregon Institute of Science and Technology, which disappears from the HERD data after 2001.

Reflecting the concentration of funding at a relatively small number of institutions each of the plots lies well below the 45 degree line. Although the magnitude of the changes does not appear to be too great, there has been a small tendency toward an increase in the levels of R&D expenditures at institutions in the middle of the distribution over the period we are considering.

Insert Table 1 about here

The stability of the overall distribution of funding conceals, however, a much more dynamic pattern of funding at individual institutions. The last two columns of Table 1 report the highest and lowest ordinal rankings of each institution in annual R&D expenditures over the period 1990-2009. Over the 20 years covered by our data, many institutions moved up or down by as much as 10 or 20 places in the rankings. The extent of this temporal variation is illustrated in Figure 2, which plots 5-year average expenditures (measured in constant 2005 dollars) at each institution against its rank in the 1990-1994 period. The solid circles, plotting the 1990-1994 average values follow a steadily declining gradient, but there is considerable dispersion in values around this line as time progresses. Rising levels of federal funding for chemistry R&D mean that the overall tendency is for expenditures to move up, but there are a substantial number of institutions that experienced declines in federal R&D funding, and even among those that experienced increases in funding the magnitude of increases varied considerably over time.

Insert Figure 2 About here

These data raise several important questions. First, what factors account for the pronounced inequality of federal funding across universities at each point in time? Second, why does funding at individual universities vary so substantially over time? In the next section we implement an estimation strategy that allows us to offer at least a partial answer to these questions.

3. Modeling the Distribution of Federal Funding

3.1 Estimation

There are at least 14 different federal agencies that support some extramural R&D. However, the primary federal sources of funding for university research are the National Institutes of Health (NIH) and the National Science Foundation (NSF).[4] At both of these agencies funding is distributed through a number of different mechanisms, but the dominant paradigm is to fund investigator-driven projects that are evaluated largely on their scientific merit. Both agencies rely heavily on the judgment of university scientists to assess the strengths of the proposals they receive. At the National Science Foundation, proposed research projects are evaluated based on the criteria of intellectual merit and broader impacts of the proposed activity. Although the terminology NIH uses to articulate its criteria—significance, approach, innovation, investigator qualifications, and environment—is somewhat different

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[4] See Gans and Murray (2012) for a detailed discussion of the range and objectives of federal extramural R&D funding.

from that used by NSF, the two agencies are, as Gans and Murray observe (2012, p. 61) "…strikingly similar…" in the qualities that they seek to emphasize.

While both NSF and NIH selection processes are fundamentally forward-looking, in the sense that they emphasize the potential significance of the activities that are proposed, they also give weight to the qualifications of the investigators to successfully carry out the proposed research and to institutional characteristics, such as the presence of specialized facilities that may be necessary to conduct the research. To investigate how these factors affect the allocation of funding we postulate a model of the determinants of federally financed R&D expenditures, which we denote as r, at institution i in year t as:

(1) $r_{it} = f(X_{it-1}, \alpha_{i,} \beta_t; \varepsilon_{it})$

where X is a vector of time and institution varying characteristics, α captures any fixed institution-specific effects on funding, β is a year effect that captures common temporal shocks to funding, and ε is a stochastic error term. The variables in X are lagged one year, to reflect the fact that expenditures in t are determined by the success of past funding applications, so it is characteristics in the previous period that will affect available funding.

Because most federal grants are awarded for periods of anywhere from 3 to 5 years these is likely to be considerable serial correlation in institutional expenditures between successive years. Taking account of the these lags, and assuming a linear approximation to equation (1) our estimating equation becomes:

(2) $r_{it} \ = \ \alpha_i + \beta_t + \gamma_1 r_{it-1} + \ \gamma_2 r_{it-2} + \sum \delta \, X_{it-1} + \varepsilon_{it}$

To the extent that institutional reputations affect the allocation of funding this effect will be captured by the panel variable, α_i, which will absorb all fixed university-specific influences on funding. Similarly, the inclusion of a full set of time dummies will absorb any common, time-dependent influences on research funding, such as increases in overall federal R&D funding.

Because of the autoregressive nature of research funding as expressed in equation (2), conventional approaches to fixed effects panel estimation are inappropriate (Cameron and Trivedi 2010, p. 293-94). Instead it is necessary to deal with fixed effects by taking the first difference of equation (2). The time invariant effects, represented by α_i, are cancelled out, resulting in the transformed equation:

$$\Delta r_{it} = \Delta\beta_t + \gamma_1 \Delta r_{it-1} + \gamma_2 \Delta r_{it-2} + \sum \gamma \, \Delta X_{it-1} + \Delta\varepsilon_{it} \tag{3}$$

First differencing removes university fixed effects from the estimating equation, but introduces a new estimation problem because by construction the lagged dependent variables are no longer exogenous with respect to the error term $\Delta\varepsilon_{it}$. A number of approaches have been suggested for estimating the autoregressive relationship using instrumental variables. The most widely used approach, proposed by Arellano and Bond (1991), uses longer lags of the dependent variable as instruments. We use the Arellano-Bond method to estimate the factors associated with university chemistry funding.

3.2 Data

To conduct our analysis, we have gathered annual data on federally funded and total academic chemistry and chemical engineering (for brevity we will refer to these combined fields as chemistry) R&D expenditures at U.S. universities and colleges between 1990 and 2009 from NSF's Higher Education Research and Development (HERD) survey (see Rosenbloom et al.

2015).[5] We link these to data on publications and citations to those publications derived from Thomson Reuters Web of Science database, counts of doctorates awarded and postdoctoral scholars from the NSF-NIH survey of Graduate Students and Postdoctoral scholars, and faculty counts that we hand collected from directories published by the American Chemical Society. Additional details concerning data sources and how we linked them are contained in the Data Appendix. We chose to focus on academic chemistry because it is well established, widely represented across the universe of higher education institutions, and accounts for a significant share (about 4%) of federally funded academic R&D.

In Table 2 we report sample means for federally funded R&D and for each of the institutional characteristics in our data for the full sample, and for various subsets of institutions. As we might expect institutions in the Carnegie Research I category have higher levels of chemistry R&D expenditures, employ more faculty and postdoctoral researchers, and produce more publications and doctoral degrees than do the non-Research I institutions. It is also notable that the average number of citations to articles published by the Research I institutions is higher than for the non-Research I universities. To the extent that the number of citations an article receives is a reflection of its quality or impact, the data in Table 2 also indicate that private universities produce higher quality publications than do public universities.

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[5] Although ideally one might want to analyze chemistry and chemical engineering separately, differences in the way disciplines are defined across our different data sources make it necessary to aggregate the two distinct fields. To illustrate this point, of the 150 institutions we initially examined, there were 102 that had chemical engineering departments that reported faculty numbers in the American Chemical Society directory and 48 that did not. However, only 22 institutions reported zero amounts of federally funded R&D expenditures for chemical engineering research in every year, and there are no institutions for which Web of Science recorded zero chemical engineering publications in all years. The mismatch in classification across the different sources used in our analysis suggests that attempting to analyze these fields separately would likely cause more problems than it solves.

Insert Table 2 about here

3.3 Results

We use the XTABOND procedure in STATA 14 to estimate equation (3).[6] The estimation procedure uses heteroscedasticity robust standard errors. STATA transforms the results to show the coefficients for the original specification in levels. The results are reported in Table 3 for a variety of different combinations of the explanatory variables. In columns (1) through (3) we add measures of faculty size, numbers of postdocs, and graduate program size. Column (4) adds non-federal R&D funding levels, and Columns (5) and (6) add our measures of research quality: publications and average citations per publication. Finally in Column (7) we drop the scientific capacity measures to test the stability of the other coefficients. Given the stability of the coefficient estimates across different specifications, we prefer specification (6), which includes the richest set of explanatory variables.

Insert Table 3 about here

Consistent with the expected serial correlation of R&D expenditures we find that in all cases the first lag of the dependent variable exerts a large and statistically significant effect.

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[6] For long panels the number of potential instruments available for the lagged dependent variable can become quite large. With the inclusion of two lags of the dependent variable among the regressors there would be two available instruments at t=4, three at t=5, and 18 at t=20. After some experimentation we opted to limit the number of instruments to a maximum of 5. Results are not sensitive, however, to changes in this maximum.

Consistent with the fact that most awards are for two or more years, roughly 50 percent of an increase in expenditures in one year persists for a second year. However, the coefficient on the second lag is smaller and negative, implying some regression toward the mean as the effects of any positive funding shock begin to wear off with the passage of time.

Turning to measures of research capacity we note that all three of the scale variables included in our model—the numbers of faculty, postdocs, and doctorates awarded—enter positively. Because the dependent variable is measured in $1,000s, the coefficients suggest that each additional faculty member is associated with about $10,000 in additional funding, each postdoc is also associated with between $10,000 and $15,000, and each additional doctorate awarded is associated with about $5,000 in additional funding. For faculty and graduate student numbers we cannot reject the hypothesis that the true effect is zero. But in all specifications the effect of additional postdoctoral scholars is both economically large and statistically significant.

The ability of universities to mobilize additional funding from their own institutional resources or through corporate or philanthropic funds could be either a complement to or substitute for federal funding. If higher levels of non-federal funding increase scientific capacity and signal higher faculty quality, then they should act as a complement, inducing additional federal support. On the other hand, the availability of non-federal funds may substitute for federal support, reducing the volume of research proposals submitted by an institution or discouraging agencies from awarding funds, in which case we would expect a negative effect on federal R&D funding. As we noted earlier, several previous studies have argued that non-federal R&D funding generally serves to leverage additional federal R&D funding. Our estimates also imply a positive and sometimes statistically significant effect of non-federal expenditures on federal funding. The estimated coefficients imply that every $100 dollars of non-federal funding leads to between $5 and $8 dollars of federal funding.

To measure research quality we have included both the number of publications in the prior year and the average number of citations to these publications. Holding faculty, postdoc, and graduate student numbers constant, higher numbers of publications should indicate more research activity, and more highly cited publications should be an indicator of higher impact publications.[7] Both these quality measures enter positively, but only publication numbers are statistically significant. The point estimates indicate that each additional publication in year t-1, is associated with approximately $4,000 of additional research funding in year t.

For consistent estimation, the Arellano-Bond estimation procedure requires that the errors, ε_{it}, be serially uncorrelated beyond order 1. This assumption can be tested using the fitted residuals (Cameron and Trivedi 2010, p. 300). At the bottom of the table we report the Z-statistic for the test of this hypothesis along the probability of obtaining a value at least this big. We do not reject the hypothesis of zero autocorrelation for any of our models.

3.4 Identification

We have shown the correlation between faculty, students, postdocs, publications, and lagged funding on current research funding. It is difficult to imagine a quasi-experimental setting that leads to an exogenous change in the number of faculty or research productivity at a

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[7] The number of citations received is measured over a three year window following publication, so this number would not be known to reviewers involved in the merit review process. Rather it is an indicator of the importance of the articles that these reviewers might infer from other sources.

given university while holding other characteristics constant to observe an unambiguously causal effect. But it is important to recall that the coefficient estimates we have reported are estimated from a panel model in first differences. Hence all of the effects reflect the impact on funding level at a single university of variations over time in the explanatory variables. All time-invariant effects such as institutional reputation or persistent differences in quality and size are absorbed in the panel fixed-effects, which are removed by first differencing. Moreover, because the explanatory variables are lagged one period, there is little chance for reverse causation. Prior years R&D funding might account for higher rates of publication activity in year t, but it is hard to see how articles published in year t could be caused by funding that was not received until year t+1.

The most plausible channel through which such reverse causation might enter is through feedbacks between funding and the number of postdoctoral scholars. Because postdocs are typically hired for several years, it is possible that a shock to funding in year t-1 might increase both the number of postdocs employed in year t-1 and volume of research expenditures in year t. In Table 4 we address this problem by using instrumental variables for the number of postdocs. Consistent with the dynamic panel model framework, our instruments are longer lags of the postdoc variable. After reproducing the baseline results in column (1) the next three columns report IV specifications using 3, 5, and 10 lagged values of postdocs as instruments. Point estimates of the coefficients are quite stable regardless of the number of instruments, but the magnitude of the effect of postdoctoral scholars increases with more instruments. With fewer IVs this effect is not statistically significant, but when we use 10 lags of the variable it becomes statistically significant at the 10 percent level.

Insert Table 4 about here

3.5 Stability Across University Types

So far we have concentrated on estimating an average within-institution effect on funding across our full sample of universities. But the sample comprises different types of institutions and it is reasonable to suppose that the effects of the research capacity, non-federal funds, and research quality might vary from one type of institution to another. By splitting our sample based on research intensity (whether the university is classified as a Carnegie Research I institution or not) and control (public or private), we can gain some insight into this question.

Table 5 compares estimates of equation (3) for each of these subsamples of universities to the baseline estimates obtained for the full sample. Columns 2 and 3 report results separately for public and private universities, while Columns 4 and 5 show separate regression for institutions classified as Carnegie Research I and not Research I. The estimates for non-Research I universities reported in Column 4a violate the assumption of zero autocorrelation of the residuals at order 2. The solution to this problem is to add additional lags of the dependent variable until the assumption is satisfied. In Column 4b we show that after including a third lag of funding this assumption is satisfied. This modification does not, however, greatly affect any of the other estimated coefficients.

Insert Table 5 about here

As the summary data in Table 2 make clear, a number of the explanatory variables are correlated with research intensity or control, but comparison of the constant term across the different samples suggests that in the hypothetical case where these explanatory variables were held constant private universities would on average receive higher levels of federal funding ($2.82 million vs. $2.05 million). Interestingly the differences between Research I and non-Research I universities are quite small ($2.71 million vs. $2.51 million) once other factors are controlled. Turning to the explanatory variables, with the smaller sample sizes the precision of many of the point estimates falls so effects are not always statistically significant at standard levels. Interestingly, however the magnitude of the effect of the number of postdoctoral scholars is similar to the baseline estimates except in the case of private universities. For the latter subsample, our estimates suggest that variations in numbers of postdocs are not an important determinant of funding variation. On the other hand, variations in publications enter as a strong and positively significant factor for private universities, and have a much smaller and consistently statistically insignificant effect for public universities.[8]

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[8] Numbers of publications and numbers of postdocs are highly positively correlated, and dropping publications from the estimation for private universities results in a much stronger and statistically significant effect on the postdoc variable. This suggests that for private institutions, past research productivity is a more accurate predictor of future funding levels than scientific capacity, but that scientific capacity plays an important role in determining productivity.

4. Discussion

Federal R&D funding is an essential ingredient supporting individual researchers and the university research enterprise. Ask any university scientist about the importance of external research funding and she will tell you that it is essential to supporting her laboratory. Without funding it would not be possible to get the research done; there would be no money to pay for supplies or hire the graduate students and postdocs essential to conducting the experiments. One illustration of the importance of funding for the research enterprise is provided by a survey we recently conducted of academic chemists in the United States. In that survey we asked how a 25 percent reduction in funding would affect their research activities; over 75% of respondents said lower funding would result in fewer publications, 81% said they would be able to support fewer graduate students, 68% said they would employ fewer postdocs and 40% said that they would generate fewer patents.[9] Consistent with these views most econometric estimates find a positive effect of federal funding on research outputs (e.g., Payne and Siow 2003, Jacob and Lefgren 2011, Popp 2015, Rosenbloom et al. 2015).The results reported above represent a first attempt to understand how key inputs to the production of scientific knowledge—the quantity and quality of scientific personnel and other, non-federal resources—influence the distribution of federal funds. Consistent with the basic premises of the merit review process, we find evidence that increased capacity, especially greater numbers of postdocs, and higher numbers of publications are linked to increased funding levels.

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[9] The survey was conducted during the Spring of 2014. Email invitations to participate in an online survey were sent to all faculty in the United States with valid email addresses listed in the American Chemical Society's *Directory of Graduate Research* for 2013. Invitations were sent to 7,438 individuals and we received 1,544 completed survey responses.

The effect of postdocs on research funding is rather striking. The National Institutes of Health (NIH) and the National Science Foundation (NSF) define the postdoctoral scholar to be "individuals engaged in temporary periods of mentored advanced training to enhance the professional skills and research independence needed to pursue their chosen career paths."[10] However, the postdoc is controversial, and some have labeled the postdoc as "exploitation" given the low salaries, lack of benefits, and high rates of foregone earnings (Stephan 2013, Kahn and Ginther 2017). Stephan (2013) argued that the postdocs persists because faculty can hire inexpensive and temporary employees to conduct research. Our analysis provides the university's rationale for postdoctoral scholars: postdocs increase the future stream of research funding flowing to the university.

For public university leaders seeking to increase their share of the federal R&D pie, our results suggest that increasing the number of postdoctoral fellows and greater investments of non-federal funding for R&D will increase competitiveness. Correlation is not, of course, the same as causation. Our dynamic panel estimates account for a number of potential sources of reverse causation. In the absence of truly experimental variation or sources of large exogenous shocks to chemistry funding, however, it is difficult to argue that we have isolated truly causal relationships. Nonetheless, our results suggest that such relationships exist and ought to encourage further efforts to investigate them.

5. Conclusion

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[10] http://grants.nih.gov/training/Reed_Letter.pdf

This article offers an initial exploration of a topic that has so far been largely neglected in the Science of Science Policy literature: the factors influencing the allocation of federal R&D funding at the level of an individual scientific discipline. Past discussion has tended to focus on total R&D funding, an approach that makes it difficult to incorporate measures of scientific merit or scale. We have focused here on one discipline, chemistry, but believe that it would be fruitful to expand this research program to make comparisons across other disciplines.

The results of our investigation suggest that there are a number of systematic relationships that influence variations in funding across institutions, and these correspond to factors that were a priori expected to be important. Numbers of postdoctoral scholars, for example are both an indicator of the human capital capacity of an institution and an important input into the preparation of competitive research funding proposals. Since postdoctoral scholars are highly dependent on external funding to cover their salaries, it makes considerable sense that institutions that have large numbers of postdoctoral scholars would attract more funding. Similarly, given the importance of physical capital and specialized equipment the evidence that we find of positive effects of non-federally funded R&D on subsequent federal support makes a great deal of sense. Finally, given the emphasis on investigator qualifications it makes considerable sense that past publication positively affects subsequent funding. On the other hand, one might note that all of these relationships suggest mechanisms through which past success supports future success, a version of the so-called “Matthew effect, “where the rich get richer. However, the considerably mobility of institutions in funding ranks over time argues against a pure “Matthew effect” explanation. With the available data it is not possible to tease apart these two alternative interpretations of our results. On the other hand, the relationships we find suggest a need for further investigation using higher resolution data that will enable a sharper distinction between these interpretations.

Data Appendix

All data used in our analysis are available online. The dataset and documentation have have been deposited in the University of Kansas Digital Repository and can be accessed here: https://doi.org/10.17161/1808.18234. This appendix provides a brief explanation of the sources of each of the major data elements in our analysis and how they were linked.

Research & Development Expenditures

These data are derived from the National Science Foundation's Survey of Research and Development Expenditures at Universities and Colleges/Higher Education Research and Development Survey (http://webcaspar.nsf.gov). Data are available annually since 1973 for total and federally funded R&D expenditures by discipline. They are obtained from survey responses completed by institutions of higher education, which are responsible for classifying all research expenditures by discipline. We computed non-federally funded R&D expenditures as the difference between total and federally funded R&D expenditures.

Sample institutions were selected from the universe of institutions represented in this data by summing real federally funded R&D expenditures (in prices of 2005) for chemistry and chemical engineering between 1990 and 2009 and then ranking institutions in descending order. We initially selected the top 150 institutions but as described in the text were obliged to drop three of these from the analysis because of inconsistencies in coverage. Before adopting this sampling strategy, we examined several other rankings, using total R&D expenditures and using nominal rather than real expenditures. The lists produced in each case were quite similar.

The full list of institutions included in the study in declining order of federally-funded chemistry R&D expenditures is provided in Table 1.

Institutions report these data for the fiscal year corresponding most closely to the federal fiscal year. In most cases this is likely to run from July of one year to June of the following calendar year. Data are labeled with the calendar year in which the fiscal year ends. Hence data for 2009 most likely cover expenditures from July 2008 through June 2009.

In addition to the expenditures data, this source also contains information on type of control (private or public) and standardized Carnegie Classifications that we use to categorize university types.

Doctorates Awarded and Postdoctoral Researchers

These data are derived from the National Science Foundation and National Institutes of Health Survey of Graduate Students and Postdoctorates in Science and Engineering (graduate student survey) which is conducted annually by the National Center for Science and Engineering Statistics. The survey is conducted in the fall semester of each academic year and data are collected at the department level. These data are available from http://webcaspar.nsf.gov.

The level of institutional detail provided in this survey is greater than in the R&D expenditure data. In the latter survey a number of multi-campus state systems report a single aggregated number. To link the data sets, we were obliged to aggregate the data in the student survey to match the level of aggregation of the R&D data.

Publications and Citations

Publication and citation data were computed by Thomson Reuters, Research Analytics from the data underlying the Web of Science publication and citation database. Thomson Reuters subject area experts categorize journals into subject classes based on detailed analysis of the content and focus of the journals. See http://wokinfo.com/media/essay/journal_selection_essay-en.pdf for additional details regarding the selection process used by Thomson Reuters in compiling the Web of Science data. The Web of Science is relatively selective about which journals are included, reflecting subject expert judgment and objective metrics of journal impact. Our research began with the full set of journals that Thomson Reuters categorizes as Chemistry and Chemical Engineering. We also conducted an analysis of all journal titles indexed by Thomson Reuters and added a small number of additional journals that contain significant chemistry content.

We then worked closely with Thomson Reuters staff to match publications by author affiliation to universities in our sample. In addition to institution name, we considered city, state and zip code information associated with authors to verify the accuracy of article linkages.

After verifying the full list of publications, Thomson Reuters analyzed them to produce summary statistics describing the number of publications each year produced by each institution, the number of citations that those publications received in 3 and 5 year windows beginning with the publication year, and a variety of other citation related metrics.

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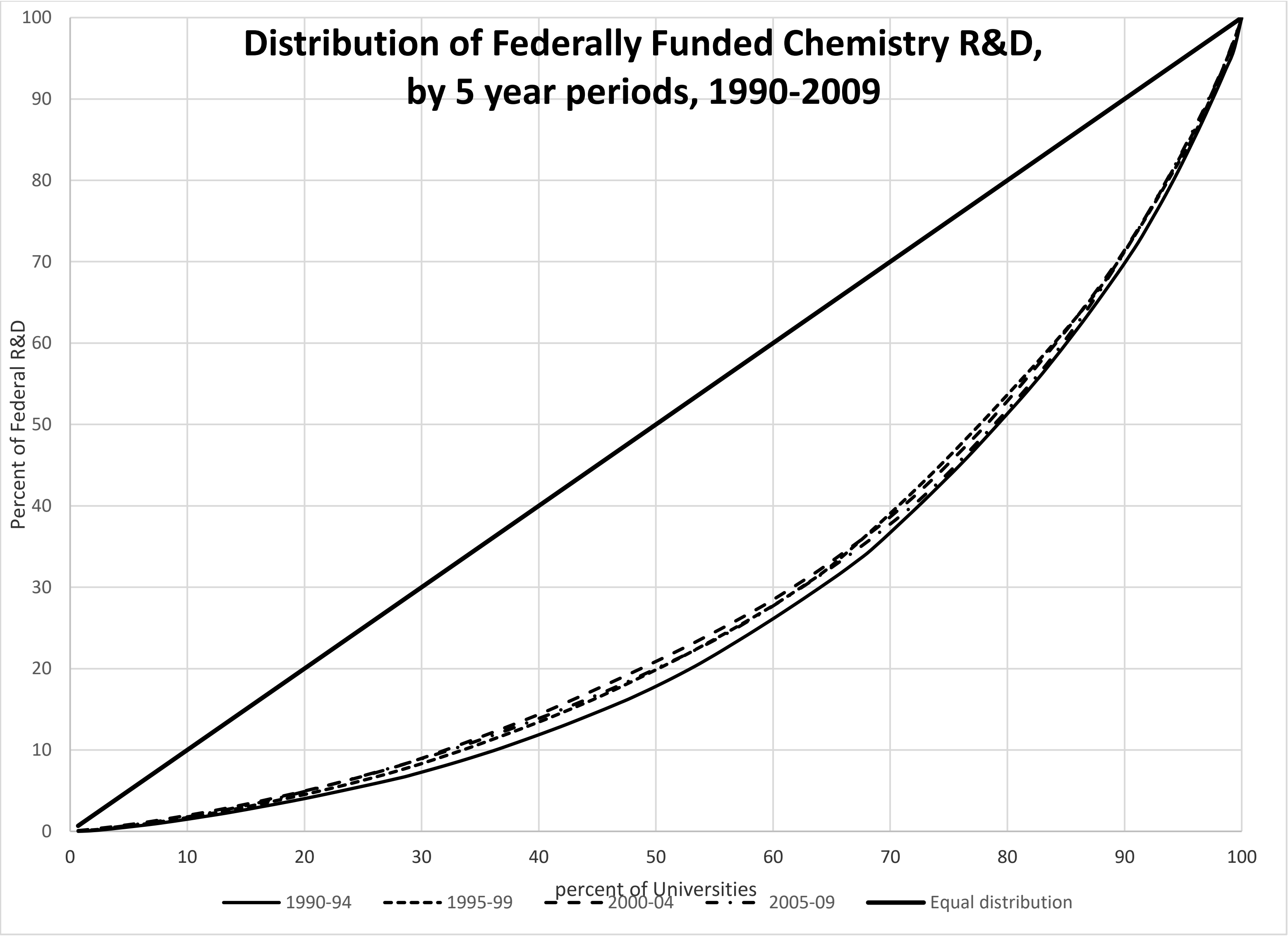

Figure 1: Lorenz Curve for Federally Funded Chemistry R&D, 5-year Periods, 1990-2009]

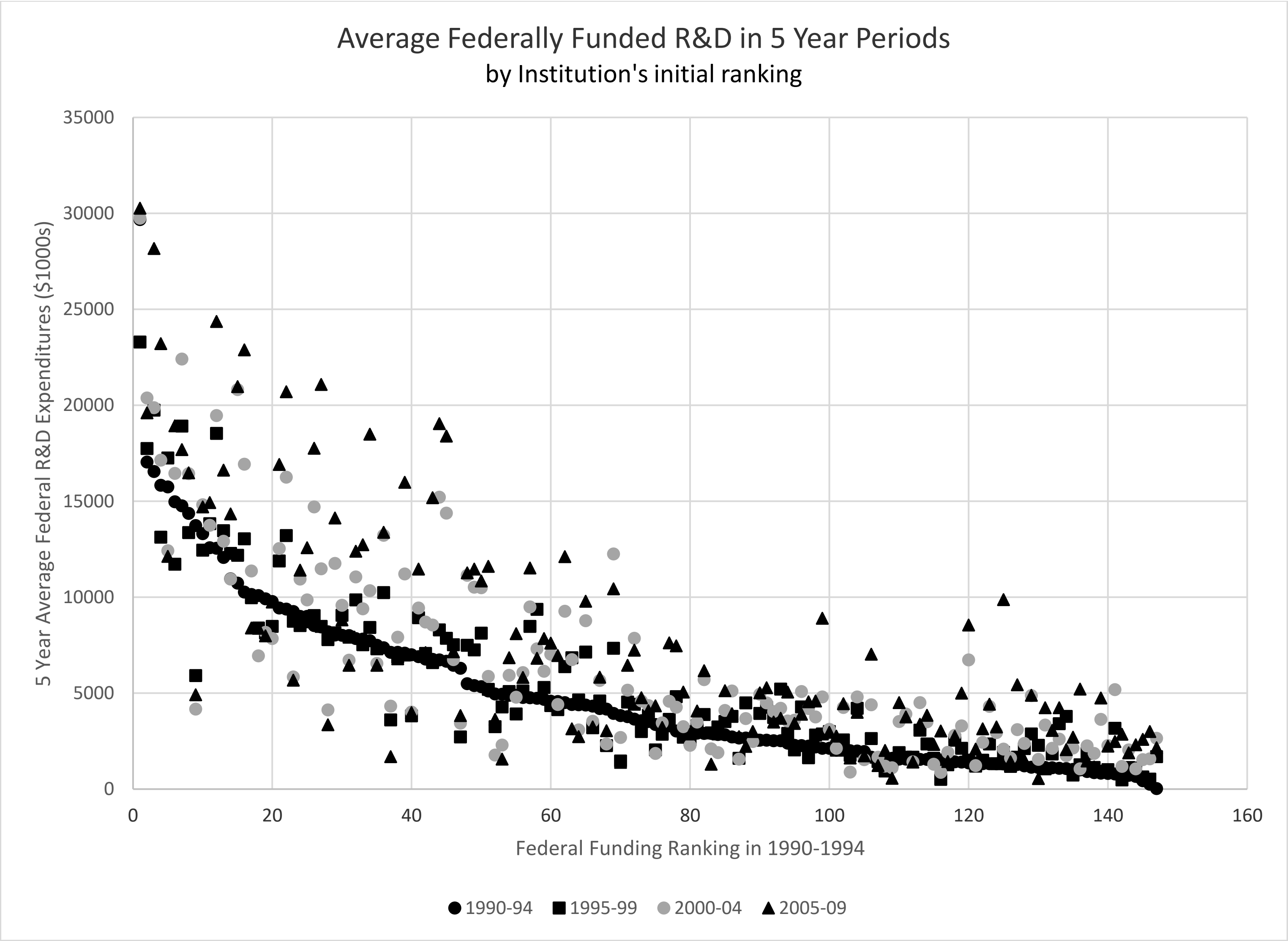

Figure 2: University Five Year Average Federally Funded Chemistry R&D vs. Initial Federal Funding Rank, 5-Year Periods, 1990-2009

Table 1: Federally Funded Chemistry R&D Rankings, 1990-2009

	Average annual Federally Funded R&D Expenditures (1000s)					Funding Rankings	
University	**1990-2009**	**1990-94**	**1995-99**	**2000-04**	**2005-09**	**Highest**	**Lowest**
Massachusetts Institute of Technology	$28,250	$29,677	$23,303	$29,754	$30,268	1	7
California Institute of Technology	$21,087	$16,553	$19,750	$19,876	$28,170	1	9
Johns Hopkins University	$18,728	$12,545	$18,533	$19,467	$24,368	1	16
University of California-Berkeley	$18,697	$17,047	$17,746	$20,385	$19,609	2	20
Stanford University	$18,448	$14,767	$18,912	$22,418	$17,697	2	22
Harvard University	$17,327	$15,834	$13,124	$17,136	$23,216	2	19
Pennsylvania State U, All Campuses	$16,177	$10,734	$12,181	$20,825	$20,971	2	20
University of Illinois at Urbana-Champaign	$15,783	$10,267	$13,044	$16,929	$22,891	3	19
University of Texas at Austin	$15,521	$14,979	$11,718	$16,456	$18,932	3	35
University of California-Los Angeles	$15,164	$14,367	$13,374	$16,433	$16,483	6	22
University of Colorado, All Campuses	$14,890	$9,387	$13,212	$16,260	$20,700	5	29
University of Minnesota, All Campuses	$14,391	$15,754	$17,259	$12,419	$12,132	2	36
Cornell University, All Campuses	$13,823	$13,308	$12,460	$14,822	$14,702	7	27
University of Wisconsin-Madison	$13,773	$12,580	$13,829	$13,754	$14,931	7	26
University of Pennsylvania	$13,767	$12,071	$13,461	$12,920	$16,618	6	28
University of California-San Diego	$12,696	$9,435	$11,892	$12,542	$16,916	7	36
Northwestern Univ	$12,511	$8,529	$9,044	$14,701	$17,769	10	40
Rutgers the State Univ of NJ, All Campuses	$12,370	$8,446	$8,478	$11,476	$21,082	2	37
University of Washington - Seattle	$12,323	$6,741	$8,295	$15,212	$19,045	6	49
Purdue University, All Campuses	$12,129	$10,954	$12,280	$10,940	$14,342	10	39
University of Michigan, All Campuses	$11,829	$6,670	$7,860	$14,386	$18,399	7	48
Georgia Institute of Technology, All Campuses	$11,247	$7,738	$8,421	$10,337	$18,492	7	48
University of Utah	$11,056	$7,369	$10,246	$13,226	$13,381	9	40
University of Pittsburgh, All Campuses	$10,515	$8,024	$8,148	$11,763	$14,126	17	43
University of North Carolina at Chapel Hill	$10,316	$7,085	$6,982	$11,206	$15,991	12	47
Texas A&M University, All Campuses	$10,289	$7,848	$9,862	$11,053	$12,392	13	40
Ohio State University, All Campuses	$10,041	$9,002	$8,719	$9,868	$12,574	14	52
Princeton University	$9,972	$9,005	$8,523	$10,949	$11,409	18	43

University of Notre Dame	$9,969	$10,136	$9,976	$11,373	$8,392	16	64
University of Massachusetts at Amherst	$9,540	$7,820	$7,521	$9,394	$12,736	21	47
Arizona State University Main	$9,277	$6,762	$6,599	$8,557	$15,189	14	54
University of California-Irvine	$9,188	$6,907	$8,933	$9,445	$11,466	20	46
Columbia University in the City of New York	$8,965	$9,776	$8,480	$7,851	$9,753	16	52
University of California-Santa Barbara	$8,868	$8,013	$9,057	$9,581	$8,819	21	58
University of Arizona	$8,854	$5,493	$7,499	$11,150	$11,275	19	55
University of Florida	$8,701	$5,336	$8,131	$10,488	$10,847	18	55
University of Delaware	$8,662	$5,402	$7,262	$10,517	$11,467	17	71
University of South Carolina, All Campuses	$8,566	$4,757	$8,485	$9,500	$11,523	21	65
Yale University	$8,556	$9,924	$8,136	$8,171	$7,994	17	52
North Carolina State University at Raleigh	$8,493	$3,941	$7,340	$12,252	$10,440	10	73
University of Chicago	$8,456	$10,090	$8,399	$6,951	$8,386	13	54
University of California-Davis	$8,069	$4,514	$6,384	$9,271	$12,108	26	69
Michigan State University	$7,527	$4,387	$7,149	$8,781	$9,792	26	81
University of Virginia, All Campuses	$7,416	$6,776	$7,078	$8,702	$7,109	32	64
Case Western Reserve University	$7,385	$9,261	$8,750	$5,850	$5,679	19	90
Indiana University, All Campuses	$7,271	$7,999	$7,913	$6,723	$6,449	21	73
University of Tennessee Univ-Wide Adm Cent Off	$7,184	$13,740	$5,910	$4,167	$4,918	5	93
University of Maryland at College Park	$7,176	$7,129	$6,872	$7,913	$6,791	25	63
New Mexico State University, All Campuses	$7,058	$4,732	$9,370	$7,308	$6,824	13	96
Colorado State University	$6,972	$6,456	$7,527	$6,753	$7,150	32	60
University of Southern California	$6,952	$7,496	$7,310	$6,546	$6,457	28	70
SUNY at Buffalo, All Campuses	$6,950	$5,119	$5,197	$5,871	$11,613	15	95
Virginia Polytechnic Institute and State Univ	$5,992	$4,671	$5,295	$6,148	$7,854	45	82
Carnegie Mellon University	$5,892	$4,573	$4,347	$7,034	$7,613	37	72
University of Rochester	$5,868	$8,205	$7,788	$4,131	$3,347	27	112
Rice University	$5,794	$3,652	$4,427	$7,861	$7,236	38	82
Emory University	$5,688	$4,893	$5,091	$5,928	$6,841	45	67
SUNY at Stony Brook, All Campuses	$5,447	$4,782	$5,110	$6,078	$5,820	48	72
University of Southern Mississippi	$5,424	$4,886	$3,914	$4,797	$8,098	33	88
University of Oklahoma, All Campuses	$5,289	$4,417	$6,849	$6,751	$3,139	23	122
Louisiana State Univ, All Campuses	$5,067	$4,193	$4,592	$5,658	$5,827	46	89
Rensselaer Polytechnic Institute	$5,022	$4,569	$4,144	$4,416	$6,961	44	98
Washington University	$4,977	$3,769	$4,537	$5,155	$6,447	55	75
University of Kansas, All Campuses	$4,897	$3,032	$4,822	$4,264	$7,469	47	104

University of Nebraska Central Admin Sys Off	$4,778	$3,292	$3,630	$4,573	$7,618	42	96
University of Houston	$4,705	$7,006	$3,813	$4,012	$3,988	4	106
Vanderbilt University	$4,677	$2,129	$2,870	$4,809	$8,899	27	107
Wayne State University	$4,664	$2,903	$3,887	$5,701	$6,165	54	96
Clemson University	$4,541	$1,372	$1,510	$6,730	$8,552	36	136
University of Alabama in Huntsville	$4,190	$7,133	$3,609	$4,321	$1,698	27	146
Iowa State University	$4,149	$2,553	$4,267	$4,490	$5,286	57	99
University of California-Santa Cruz	$4,116	$2,557	$3,945	$4,942	$5,021	55	98
University of Oregon	$4,068	$6,291	$2,720	$3,434	$3,825	35	120
University of Illinois at Chicago	$3,981	$3,571	$2,996	$4,599	$4,759	57	94
University of Iowa	$3,949	$3,522	$3,844	$4,350	$4,081	59	108
Montana State University - Bozeman	$3,931	$1,657	$2,628	$4,402	$7,034	44	123
University of New Mexico, All Campuses	$3,909	$2,516	$5,208	$4,217	$3,695	54	119
University of California-Riverside	$3,895	$2,829	$3,525	$4,099	$5,128	68	96
Boston College	$3,886	$2,715	$3,788	$5,111	$3,929	63	102
Florida State University	$3,885	$2,273	$4,283	$5,085	$3,899	56	121
University of PR Rio Piedras Campus	$3,799	$1,309	$1,914	$2,092	$9,882	21	139
Kansas State University	$3,752	$1,990	$4,215	$4,801	$4,000	56	119
CUNY City College	$3,718	$4,399	$4,649	$3,087	$2,736	56	126
Brigham Young University, All Campuses	$3,577	$4,326	$3,202	$3,540	$3,241	57	123
Mississippi State University	$3,511	$3,015	$2,707	$3,262	$5,060	57	118
New York University	$3,474	$2,402	$2,897	$3,544	$5,053	66	107
University of Alabama	$3,450	$2,526	$3,733	$4,047	$3,494	62	117
Duke University	$3,446	$2,915	$3,309	$3,491	$4,068	73	100
University of Akron, All Campuses	$3,445	$1,137	$2,877	$4,880	$4,889	62	136
University of Dayton	$3,408	$4,957	$3,260	$1,781	$3,635	50	143
Washington State University	$3,343	$2,203	$2,818	$3,763	$4,589	76	112
University of Maryland Baltimore County	$3,325	$2,023	$2,568	$4,250	$4,459	57	128
Georgetown University	$3,273	$4,950	$4,278	$2,302	$1,562	46	144
Oregon State University	$3,267	$2,665	$4,499	$3,675	$2,232	59	135
Brown University	$3,217	$3,342	$2,864	$3,455	$3,209	68	120
University of Arkansas, Main Campus	$3,156	$2,242	$1,634	$4,202	$4,545	54	132
Northeastern University	$3,131	$1,546	$3,075	$4,515	$3,385	56	131
University of Kentucky, All Campuses	$3,103	$1,326	$2,352	$4,314	$4,419	63	126
Rockefeller University	$2,960	$4,169	$2,275	$2,358	$3,038	44	133
Auburn University, All Campuses	$2,958	$1,411	$2,128	$3,298	$4,996	63	134

University of Tulsa	$2,907	$791	$3,173	$5,185	$2,478	53	143
University of Cincinnati, All Campuses	$2,902	$3,365	$2,048	$1,859	$4,338	68	136
Boston University	$2,877	$1,570	$1,909	$3,523	$4,508	65	128
New Mexico Institute of Mining and Technology	$2,873	$1,277	$1,670	$3,105	$5,439	52	136
CUNY Hunter College	$2,838	$2,282	$2,049	$3,596	$3,425	73	123
Tufts University	$2,838	$1,081	$3,416	$2,611	$4,243	62	139
North Dakota State University, All Campuses	$2,815	$1,545	$2,353	$3,511	$3,850	75	135
Colorado School of Mines	$2,804	$2,125	$3,005	$3,121	$2,962	83	130
Virginia Commonwealth University	$2,727	$1,563	$1,664	$3,923	$3,756	71	130
Clark Atlanta University	$2,713	$2,844	$3,239	$1,900	$2,869	73	143
Lehigh University	$2,678	$2,983	$2,569	$2,283	$2,876	71	137
University of Georgia	$2,653	$2,588	$2,545	$2,484	$2,996	76	123
University of Connecticut, All Campuses	$2,532	$826	$928	$3,631	$4,742	67	144
West Virginia University	$2,440	$1,127	$1,052	$3,341	$4,241	64	141
Tulane University	$2,383	$1,431	$2,549	$2,808	$2,745	82	140
Oklahoma State University, All Campuses	$2,349	$3,830	$1,470	$2,696	$1,398	47	142
Syracuse University, All Campuses	$2,309	$2,899	$2,935	$2,099	$1,304	74	145
Brandeis University	$2,233	$2,028	$2,023	$2,123	$2,756	90	131
Jackson State University	$2,206	$1,325	$1,324	$2,940	$3,235	86	143
Illinois Institute of Technology	$2,168	$1,073	$3,788	$1,751	$2,062	53	142
Clarkson University	$2,144	$2,669	$1,608	$1,561	$2,738	71	140
New Jersey Institute Technology	$2,137	$1,008	$1,271	$1,051	$5,217	48	145
Texas Tech University	$2,103	$1,326	$1,511	$2,441	$3,136	100	134
University of Missouri, Columbia	$2,031	$1,112	$1,830	$2,124	$3,056	93	135
University of Wyoming	$1,803	$1,207	$2,117	$2,379	$1,510	97	143
University of Hawaii at Manoa	$1,744	$1,958	$1,752	$1,532	$1,732	89	143
Dartmouth College	$1,690	$1,525	$1,607	$1,297	$2,330	89	141
Drexel University	$1,653	$1,023	$736	$2,147	$2,708	101	147
Utah State University	$1,629	$923	$1,876	$2,251	$1,466	101	145
Norfolk State University	$1,629	$35	$1,685	$2,645	$2,149	97	147
University of New Hampshire	$1,583	$815	$1,010	$2,272	$2,237	96	141
San Francisco State University	$1,567	$2,008	$1,757	$888	$1,616	98	147
Howard University	$1,530	$1,491	$1,275	$1,920	$1,433	65	146
University of Denver	$1,510	$1,560	$1,661	$1,417	$1,403	103	144
Polytechnic University	$1,491	$1,645	$1,437	$1,658	$1,224	84	147
California State University-Los Angeles	$1,481	$1,517	$515	$871	$3,023	95	147

University of Idaho	$1,467	$1,367	$1,194	$1,223	$2,085	98	143
Georgia State University	$1,447	$1,633	$947	$1,199	$2,009	104	146
University of Missouri, Rolla	$1,446	$727	$1,127	$2,048	$1,885	111	144
University of Massachusetts Lowell	$1,379	$1,127	$2,287	$1,556	$545	96	147
University of Louisville	$1,378	$1,282	$1,189	$1,615	$1,427	108	144
University of Montana	$1,340	$253	$524	$1,578	$3,005	103	147
University of South Florida	$1,327	$788	$477	$1,179	$2,865	110	147
University of PR Mayaguez Campus	$1,300	$433	$640	$1,538	$2,590	111	147
North Carolina Agricultural & Tech State Univ	$1,281	$660	$1,094	$1,060	$2,311	94	144
Stevens Institute of Technology	$1,252	$854	$1,132	$1,860	$1,162	113	147
Cleveland State University	$1,178	$1,605	$1,435	$1,110	$561	104	147

Table 2: Summary Statistics

	Federally Funded R&D (1000s)	Faculty	Postdocs	PhDs Awarded	Non-Federally Funded R&D (1000s)	Publications	Average citations per article
Full Sample	$6,078.9	33.5	28.9	18.2	$3,362.0	164.6	9.0
Private	$6,529.0	28.9	31.4	16.1	$2,197.3	156.6	10.7
Public	$5,867.1	35.7	27.7	19.2	$3,909.9	168.4	8.3
Not Research I	$3,065.2	24.9	12.4	8.4	$1,984.1	69.9	7.1
Research I	$8,341.8	40.0	41.3	25.6	$4,396.6	235.5	10.5

Table 3: Dynamic Panel Estimates of the Determinants of Federally Funded R&D Expenditures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Fed R&D (t-1)	0.555***	0.532***	0.530***	0.514***	0.485***	0.484***	0.504***
	(6.09)	(5.85)	(5.85)	(5.69)	(5.50)	(5.52)	(5.79)
Fed R&D (t-2)	-0.0800*	-0.0850*	-0.0874*	-0.0948**	-0.109**	-0.109**	-0.105**
	(-1.74)	(-1.84)	(-1.83)	(-1.97)	(-2.18)	(-2.19)	(-2.16)
Faculty (t-1)	10.58	10.67	10.95	11.03	11.54	11.50	
	(1.15)	(1.16)	(1.17)	(1.19)	(1.22)	(1.22)	
Postdocs (t-1)		14.45***	14.24***	13.59***	10.02**	10.05**	
		(2.79)	(2.81)	(2.67)	(2.25)	(2.26)	
Doctorates awarded (t-1)			5.571	5.364	5.145	5.119	
			(0.67)	(0.65)	(0.63)	(0.63)	
Non-Fed R&D(t-1)				0.0821**	0.0541	0.0538	0.0559*
				(2.11)	(1.63)	(1.62)	(1.66)
Publications (t-1)					3.808*	3.793*	4.179**
					(1.90)	(1.90)	(2.06)
Avg. Citations (t-1)						6.895	5.493
						(0.41)	(0.32)
_cons	2341.7***	2083.8***	2000.9***	1904.6***	1935.2***	1886.7***	2491.1***
	(5.08)	(4.61)	(4.05)	(3.75)	(3.75)	(3.39)	(4.74)
N	2497	2497	2497	2497	2493	2493	2493
Test for autocorrelation of first differenced errors at order 2							
Z	0.41	0.32	0.33	0.42	1.30	1.30	1.39
Prob >Z	0.68	0.75	0.74	0.68	0.19	0.19	0.16

T-Statistics in parentheses

* p<0.10   ** p<0.05 *** p<0.01

Notes to Table 3
All specifications estimated using the XTABOND procedure in STATA 14, using robust standard errors and specifying a maximum of 5 lags of the dependent variable as instruments. All regressions include year fixed effects.

Table 4: Alternative Specifications of Federally Funded R&D Expenditures

	Baseline	IV Regressions with postdocs Endogenous		
	(1)	(2)	(3)	(4)
Fed R&D (t-1)	0.630***	0.553***	0.580***	0.620***
	(6.91)	(7.56)	-8.54	-10.08
Fed R&D (t-2)	-0.0900*	-0.101*	-0.0982*	-0.0940*
	(-1.76)	(-1.94)	(-1.89)	(-1.80)
Faculty (t-1)	15.68	6.33	7.494	7.32
	(1.55)	(0.69)	(0.85)	(0.82)
Postdocs (t-1)	10.20**	12.48	15.35	16.68*
	(2.19)	(1.03)	(1.51)	(1.76)
Doctorates awarded (t-1)	-0.840	2.622	1.209	1.241
	(-0.09)	(0.31)	(0.14)	(0.14)
Non-Fed R&D(t-1)	0.0719**	0.0549	0.0481	0.0524
	(2.03)	(1.63)	(1.41)	(1.54)
Publications (t-1)	5.599***	4.026**	3.966**	4.100**
	(3.44)	(2.17)	(2.12)	(2.22)
Avg. Citations (t-1)	38.84**	-1.699	-1.989	-5.301
	(2.26)	(-0.10)	(-0.11)	(-0.29)
_cons	616.6	1713.8***	1509.6***	1270.5***
	(1.38)	(3.1)	(3.02)	(2.76)
	2493	2493	2493	2493
Autocorrelation of first differenced errors at order 2				
Z	1.00	1.04	0.93	0.82
Prob >Z	0.32	0.30	0.35	0.41

t statistics in parentheses
* p<0.10 ** p<0.05 *** p<0.01"

Notes: All specifications estimated using the XTABOND procedure in STATA 14, using robust standard errors and specifying a maximum of 5 lags of the dependent variable as instruments. All regressions include year fixed effects. In specifications (2)-(4) Postdocs(t-1) is treated as endogenous, and instrumented with lagged values. Specifications differ only in the number of lags used. Specification (2) uses 3 lags as instruments, specification (3) uses 5 lags, and specification (4) uses 10 lags.

Table 5: Dynamic Panel estimates of Determinants of Federally Funded R&D, by type of insititution

	(1)Baseline	(2)Private	(3)Public	(4) Not R 1		(5)R1
				(a)	(b)	
Fed R&D (t-1)	0.484***	0.589***	0.342***	0.412***	0.391***	0.515***
	(5.52)	(9.30)	(3.22)	(3.66)	(3.55)	(6.55)
Fed R&D (t-2)	-0.109**	-0.282***	-0.0210	0.0637	0.0813	-0.168***
	(-2.19)	(-3.98)	(-0.60)	(1.42)	(1.46)	(-2.88)
Fed R&D (t-3)					-0.0756	
					(-1.62)	
Faculty (t-1)	11.50	12.69	9.399	-9.101	-15.42	12.32
	(1.22)	(0.91)	(0.82)	(-0.68)	(-1.05)	(1.11)
Postdocs (t-1)	10.05**	0.286	12.11***	7.281	8.278	10.66**
	(2.26)	(0.04)	(2.62)	(0.72)	(0.75)	(2.09)
Doctorates awarded (t-1)	5.119	5.875	2.251	-8.512	-16.02	10.42
	(0.63)	(0.30)	(0.32)	(-0.77)	(-1.28)	(1.17)
Non-Fed R&D(t-1)	0.0538	-0.0242	0.0765*	-0.0450	-0.0469	0.0652*
	(1.62)	(-0.29)	(1.96)	(-0.98)	(-0.98)	(1.65)
Publications (t-1)	3.793*	8.058***	2.081	-4.483*	-4.146	2.466
	(1.90)	(2.71)	(0.75)	(-1.66)	(-1.62)	(1.12)
Avg. Citations (t-1)	6.895	18.50	0.563	0.826	8.105	16.56
	(0.41)	(0.74)	(0.03)	(0.05)	(0.51)	(0.51)
_cons	1886.7***	2812.6***	2053.5***	1765.2***	2511.7***	2711.0***
	(3.39)	(3.09)	(3.18)	(3.19)	(3.36)	(3.13)
N	2493	799	1694	1067	1006	1426
Test for autocorrelation of first differenced errors at order 2						
Z	0.41	0.61	0.77	2.03	0.39	0.28
Prob >Z	0.68	0.54	0.44	0.04	0.70	0.78

T-statistics in parentheses

*p<0.10 ** p<0.05 *** p<0.01