The Effects of Research & Development Funding On Scientific Productivity: Academic Chemistry, 1990-2009

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In 2011 the federal government supported nearly $40 billion dollars of university research and development (R&D) activities. Other sources of funding – including industry, state government and the universities themselves – provided over $22 billion in support for university R&D. It is natural to wonder what these investments produce or, put slightly differently, what is the return on this investment?[1] In large part public investments in R&D are motivated by the conviction that advances in scientific understanding will contribute to the nation's economic well-being. However, the connections between scientific discovery and economic applications are often complex, indirect and occur with a considerable time lag. Of necessity, then, the focus must be on intermediate products, such as scientific publications.

In this article we offer new estimates of the relationship between funding and productivity in academic chemistry (including chemical engineering) over the 20 years from 1990 to 2009. Measuring output either by the raw number of publications or adjusting for the quality of publications by weighting publications by the number of citations they receive, we find that there was a strong positive association between funding and output. Equally strikingly we find that over the period of our study there was a large increase in academic output that is not explained by any observed increase in inputs to the academic production process. Although we cannot yet link this increase to particular technological advances in the

[1] A recent National Science and Technology Council (2008, pp. 6, 14) report, for example, observes: "The pragmatic reality facing Federal agencies is that the resources available for investing in research are limited…" and argues that there is a need for more systematic, quantitative models relating funding inputs to a variety of significant scientific outputs.

methods used by chemists it is possible that this increase in productivity was at least partially attributable to the diffusion of computer technology in the laboratory as well as the effects of the move toward online publication of research results.

Literature Review

Several recent studies have exploited administrative data on grant applications to explore the impact of the receipt of research funding on the productivity of individual researchers. These studies have generally found a relatively modest impact of funding on subsequent publication. Jacob and Lefgren (2007) analyzed data on all National Institutes of Health (NIH) training and standard grant proposals submitted between 1980 and 2000. Using a regression discontinuity approach predicated on the similar quality of funded and unfunded proposals with similar priority scores they concluded that the award of a grant resulted in approximately one additional publication in the subsequent 5 years. Arora and Gambardella (1998) studied applications to the National Science Foundation's (NSF) Economics program. They too found that receipt of grant could account for approximately one additional publication, but did note some differences by investigator characteristics.

These studies are illuminating, but as their authors have noted, they are subject to important limitations. Most importantly, it is not possible, given the empirical set up, to determine whether investigators that they categorize as not receiving support were later able to obtain resources for their research from another source. To the extent that the control-group includes investigators who subsequently obtained funding the measured effects of receiving a grant will be biased downward.

A second issue that also produces a downward bias is the likely effect of leakages and spillovers in the effects of funding. Research support is provided not just to support individual investigators, but to support the broader scientific enterprise. Federal grants cover not just the direct costs of an investigator's research but also indirect costs (Facilities & Administration) of the institution at which the research is conducted. These resources presumably support a broader set of researchers. Further, the activity and resources of funded investigators may more indirectly encourage research output by unfunded colleagues as well as supporting the research activity of graduate students and postdoctoral researchers.

Because of these spillovers it is important to look not just at how funding effects individual investigators, but at how funding affects outputs at the level of universities and of the university system as a whole. This is the approach taken by Adams and Griliches (1998), who analyze R&D funding and research publications at 109 universities in the period 1981-1993. Adams and Griliches analyzed aggregate spending and publications in 8 broad disciplinary categories. Relying on an informal analysis of graphs showing the growth of R&D expenditures and publications or citations in each discipline they concluded that at the aggregate, university-system, level funding and scholarly outputs grew roughly in parallel with one another in most of the disciplines they considered. They then used panel regressions for a subset of universities with complete data to estimate the elasticity of publications or citations relative to funding. In contrast to the elasticity near one suggested by the aggregate data they found cross-section elasticities in the range of about 0.4 up to a high of 0.9. They suggested that this discrepancy might be attributable to the leakages and spillovers alluded to earlier.

More recently Payne and Siow (2003) have also examined the connections between federal R&D funding and research output. Their analysis is more aggregated than Adams and Griliches, however, reporting a single aggregate estimate for all disciplines of the effect of federal R&D funds on research output using a panel of 57 universities for the period 1981-1998. Payne and Siow recognize that because R&D funding is not allocated randomly across institutions OLS regression results cannot be interpreted as reflecting the causal effect of funding on output. To resolve this latter problem they propose an Instrumental Variables approach that relies on the effect of university alumni representation on key congressional appropriations committees. Using this instrument they found that an additional $1 million in federal R&D funding results in an increase of approximately 10 publications. Further, they concluded that there was no relationship between the level of funding and the number of citations per article. Payne and Siow's instrument lacks power, however, and the impact of congressional representation on the award of merit based scientific R&D awards might be questioned a priori.

Contributions of this Paper

Like Adams and Griliches (1998) and Payne and Siow (2003) we exploit variations in funding levels over time across a panel of universities. Focusing on the behavior of the university-system broadly and on the output of individual universities is more likely to capture the ways in which research funding supports the broader scientific system. But because of differences across disciplines in knowledge production and the uses of funding we believe it is important to look at these effects at the level of individual disciplines. This approach is supported by the differences in the funding-output relationship documented by Adams and Griliches in their earlier study.

For this paper we have collected data on the levels of research funding along with publication and citation data in chemistry (our sample includes R&D expenditures and other data for both chemistry and chemical engineering, but we will refer to these combined fields as chemistry for purposes of brevity) for a sample of 147 universities over twenty years, from 1990 through 2009. The chemical sciences are large, well-established and widely represented across the spectrum of U.S. universities and they include a breadth of research topics from basic science to highly applied topics. As such they offer an excellent opportunity to explore the impact of federal and other sources of funding on scientific productivity. It would be of interest to consider these results in the context of other disciplines as well, but because of the data requirements of our approach we have opted to begin with a single discipline and then expand our study.

Our sample was selected to include those universities that accounted for the bulk of sponsored Research & Development expenditure. We selected the institutions included in our sample on the basis of the total federally funded chemistry R&D expenditures (in constant dollars) over the 20 years covered by our study. Initially we selected the top 150 institutions, but later concluded it was necessary to drop three of these for which the data were incomplete or appeared inconsistent.[2] After identifying the universe of our study we collected additional data on degrees awarded, graduate student enrollment and postdoctoral researchers from publicly available sources and merged these with the R&D expenditure data. Data on publications and citations were provided by Thomson Reuters, Research Analytics group from the Web of Science citation data base. We worked closely with Thomson Reuters to identify and match publications to our sample institutions.[3]

Sample Characteristics

A list of each of the institutions included in our sample is provided in Table 1, which also summarizes a number of key dimensions of R&D expenditures and outputs. As this tabulation illustrates our sample incorporates a considerable degree of institutional variation. At the top of the list are institutions such as the MIT, Cal Tech, and the University of California Berkeley, with average annual R&D expenditures in the $20-$30 million range, employing more than 100 postdoctoral researchers, training more than 50 doctoral recipients per year and producing many hundreds of publications. At the bottom of our list are institutions such as Cleveland

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[2] 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 data after 2001.

[3] Additional details of the construction of the dataset used in our analysis are provided in the appendix to this paper.

State University or North Carolina Agricultural & Technical State University, with total R&D expenditures of little more than $1 million per year, with few or no postdoctoral researchers and doctoral recipients, and producing just tens of publications.

Although the 147 institutions we study do not comprise the full extent of academic research in chemistry they account for the vast majority of the measurable research and training activities in the United States. As Figure 1 illustrates, their shares of total U.S. research expenditures, Ph.D.s awarded and postdoctoral researchers hovered around 90-95 percent, although their share of non-federally funded research expenditures was somewhat lower at about 87 percent. In comparison to R&D expenditures and graduate education the number of publications is relatively less concentrated. Our sample institutions produced between 70 and 75 percent of chemistry publications in most years. These publications, however, received 80 to 85 percent of citations to U.S. publications over this period, suggesting that researchers affiliated with these institutions produced a greater proportion of the more important publications.

It should be noted that while our sample institutions accounted for a stable or slightly rising share of U.S. publications and citations, the United States share of total global publications in chemistry appears to have been declining somewhat over time. From 1990 through the early 2000s, U.S. publications accounted for about 30 percent of all chemistry publications, but after 2003 this figure began to drop, falling closer to 25 percent by 2009. U.S. publications do, however, receive a greater proportion of total citations, suggesting that they remain more important in global chemistry than the raw publication count would indicate. This share share was also declining, however, over the last decade or so.

Table 2 provides additional details about the characteristics of both the full sample and several important subsets of universities, reporting average annual values of key variable for the periods 1990-1999 and 2000-2009. Across all universities average annual chemistry R&D expenditures increased from an average of about $8 million in the 1990s to almost $11 million in 2000s. Federal sources supported just under two-thirds of R&D spending in both periods, and grew at roughly the same rate as overall R&D spending. In contrast to this growth in expenditures, average numbers of graduate students enrolled, Ph.D.'s awarded and employment of postdoctoral researchers held relatively steady across the two decades. On the other hand the average number of publications produced and the number of citations to those publications both nearly doubled.[4]

Comparing across subsets of universities some important differences begin to emerge. As we might expect all of the indicators of both inputs and outputs of the chemical sciences are much larger at those universities in the Carnegie Research I classification than at the other, non-Research I, institutions in our sample. The Research I universities accounted on average for about 2.5 times as much research expenditures and produced nearly three times as many doctorates as the non-Research I universities. They also employed more than three times as many postdoctoral researchers and produced more than three times as many publications.

[4] The growth in the number of publications reflects both a rapid increase in the number of chemistry journals included in the Web of Science database, which increased from 244 in 1990 to 568 by 2009, and an approximately 80 percent increase in the number of publications in already established journals.

The imbalance in citations to publications was even more striking: for 2000-2009 publications produced by the Research I institutions received almost 4.5 times as many citations as those produced by the non-Research I group, down from a ratio of more than 6 in the 1990s.

Although average research expenditures at public and private universities were similar in the 1990s, their composition was somewhat different, with non-federal funding making up almost 40 percent of total expenditures at public universities, compared to less than 30 percent at the private universities. These differences persisted over time, but funding received by the public universities grew more quickly than did funding at the private universities. Average numbers of graduate students enrolled were also higher at the public universities, but the numbers of doctorates awarded and postdoctoral researchers were comparable across the two groups. The average number of publications produced by public and private universities were quite similar, but private university publications received on average more citations than did those produced by the public universities. If citations provide a measure of the significance of publications, this result suggests that private universities were on average producing research of somewhat higher quality than their public counterparts.

Aggregate Characteristics of Academic Chemistry

Before exploring in more detail the panel data it is useful to consider some of the aggregate characteristics of research funding and scholarly outputs of academic chemistry over the last two decades. We begin with the growth of funding and personnel. Figure 2 compares the growth of R&D expenditures (federally financed and total) with the number of doctorates awarded and postdoctoral researchers employed.[5] To facilitate comparison each series is graphed as an index (set equal to 100 in 1990). Over most of the period federal and non-federal funding grew at comparable rates, but since 2006 federal funding has stabilized while funding from non-federal sources has continued to increase.

In comparison to the nearly 70 percent increase in total R&D funding the number of postdoctoral researchers increased modestly. Their numbers were essentially flat until 1996 and then began to rise slowly, increasing roughly 20 percent by 2009. The number of doctorates awarded fluctuated with no clear trend until the early 2000s when it also began to rise slowly. Again, however, this increase was modest compared to the increase in R&D expenditures.

In Figure 3 we shift the focus to measures of research output, graphing the growth in numbers of publications and citations to those publications for our sample institutions. As in Figure 2, we have plotted these series as an index with 1990 set equal to 100, and we have included the indexes for federally-funded and total R&D expenditures for comparison. It is apparent that the outputs of academic chemistry increased much more rapidly than did funding in this period. The index of publication numbers increases consistently and reaches a value of 268 by 2009, nearly a threefold increase. Meanwhile the index of citations to these publications

[5] Aggregate faculty numbers were essentially constant over these 20 years. We are in the process of hand collecting data from biannual faculty directories produced by the American Chemical Society, but because individual departments are not represented in all years the data are not yet of sufficient quality to be reported here. Nonetheless we can rule out the possibility that there was any significant increase in aggregate faculty numbers.

grows even more quickly, achieving a value of 422 in 2008 (the last year for which we can calculate a three-year citation count).

The relationships in Figure 3 can be compared with those reported by Adams and Griliches (1998, p. 136). They found that between 1981 and 1993 publications and R&D expenditures in chemistry increased at very nearly the same rate; both increasing approximately 50 percent. Thus there appears to be shift in the relationship of inputs and outputs at the aggregate level for the field in the more recent period.

The data on outputs and expenditures shown in Figure 3 make it clear that at the aggregate level the cost per publication was declining over time. In Figures 4 and 5 we look more closely at the relationship between inputs and outputs over time. For these figures we first calculated dollars of R&D expenditures per publication at each university in each year, and then calculated the average and median of this distribution. Both measures fell appreciably between 1990 and 1998 then leveled off (see Figure 4). The median fell from just under $60,000 per article to around $30,000 per article. The divergence between the mean and the median reflects the impact of a few extremely high cost universities, and the convergence of these two measures over time suggests that costs per publication were becoming somewhat less skewed over time.

Figure 5 compares the median cost of publications across subsets of universities. In each group the time trends are similar and the differences in levels appear reasonable, with costs lowest at the more research intensive universities and the public universities. Perhaps of greater interest, however, is the apparent convergence of costs across the different groups over time. Median costs fell much more sharply at less research intensive and public universities, however, and the result was a considerable convergence by the late 1990s. Costs per publication appear to have risen again at the non-Research I universities during the early 2000s, but then began to fall after the early 2000s.

Research Funding and Scientific Productivity at the University Level

The motivation of this paper is to understand the relationship between R&D funding and the outputs produced by academic chemistry. The aggregate trends we have been focused on so far are intriguing, but much more can be learned by exploiting patterns of variation over time and across universities in funding, other inputs and the measurable outputs of academic chemistry. In this section we explore these relationships more thoroughly using a panel regression framework.

Estimating Framework

Our estimates of the effects of R&D funding on scientific outputs (y_{it}) of university i in year t all adopt the following basic specification

(1) $y_{it} = \alpha_i + \beta_t + \gamma_f F_{it}(R^f) + \gamma_n F_{it}(R^n) + \delta X_{it} + \varepsilon_{it}$

where α_i is a university specific intercept, β_t is a year-specific effect that captures temporal shocks that are common to all universities in a particular year, F(R) is a function of lagged values of federal (f) or non-federal (n) R&D funding, X is a vector of other university and year specific factors that might affect scientific output, and ε is a stochastic error term that is assumed to be independently distributed.

To measure scientific output we use both the raw number of publications produced in year t, and a citation-weighted count that uses the total number of citations received by publication t over a three-year horizon that includes the publication year and the following two years.[6]

Because of the time involved in producing, and publishing scientific results we assume that publications produced in year t are the result of activities conducted mainly in previous years. Consequently we measure inputs of R&D funding using lagged values of R&D funding. In the results reported below F(R) employs a set of declining weights to aggregate R&D funding over the previous five years.[7] Estimated coefficients are not sensitive, however, to the choice of weighting scheme or the length of this lag. We have also estimated equation (1) using an unweighted average, an inverted-V set of weights and a single lag of R&D funding with qualitatively similar results. The reason for this is that R&D funding levels are highly correlated from one year to the next.[8] In part this is due to the fact that most research grants are awarded for multiple years, and in part because universities and faculty who are successful in securing funding in the past are likely to be successful in obtaining funding for future projects.

The vector X includes measures of the number of postdoctoral researchers employed and the number of graduate students enrolled. In the results reported below we measure each of these variables as a weighted sum of the numbers over

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[6] We have also used a five-year horizon for citation counts with very similar results.
[7] The weights used are 0.4, 0.3, 0.15, 0.1, 0.05 for years t-1 through t-5.
[8] At first we attempted to estimate the relationship in equation (1) including several lags of R&D funding to assess the lag structure of effects, but the high degree of correlation between the lagged values resulted in symptoms of multicollinearity that made the resulting estimates difficult to interpret.

the previous five years, using the same declining weights used to aggregate past R&D funding levels.

OLS Results

We begin by reporting OLS results. Because we would expect that investigators with promising research programs would be more likely to attract funding and that these resources would in turn allow them to be more productive we cannot interpret the OLS results as strictly causal. Nonetheless, the observed relationships are of considerable interest. At the minimum, finding a positive relationship between levels of funding and scientific productivity can be interpreted as a confirmation that those allocating funding are directing these funds towards the more productive researchers. After presenting the OLS results we develop an Instrumental Variable estimation strategy that will allow us to better assess the causal impact of funding on scientific productivity.

Table 3 reports parameter estimates from fixed effect OLS panel regressions for a variety of different specifications for the full sample of 147 universities.[9] In the first three columns output is measured by publications and in the next three columns we use citations as the output measure. Reading across each set of estimates, the first column includes only the lagged measures of federally-funded and non-federally funded R&D expenditures, the second column adds the number of postdoctoral researchers and graduate students, and the third column replaces separate federal and non-federal R&D expenditures with total expenditures.

[9] We used STATA's fixed effect xtreg routine with cluster robust standard errors.

In the initial specifications (columns 1 and 4) both federal and non-federal R&D expenditures are positive and significant. Because R&D expenditures are measured in $1,000s, they imply, for example, that an additional $1 million dollars of federal funding is associated with 7.44 additional publications and 72.8 additional citations. The effects of an additional $1 million of non-federal R&D expenditures would produce a slightly greater effect, 8.68 articles and 94.1 citations. Both of these effects are highly statistically significant.

Adding the number of graduate students and postdoctoral researchers (columns 2 and 5) reduces somewhat the magnitude of the coefficient on federally-funded R&D somewhat, and causes it to become statistically insignificant in the regression for citations, but has little effect on the coefficient for non-federally funded R&D expenditures. While the number of graduate students has little effect on the number of publications or citations, the number of postdoctoral researchers has a statistically and economically significant effect on both publication and citation numbers. The drop in the coefficient on federally funded R&D expenditures when we add controls for the number of graduate students and postdoctoral researchers suggests that increased numbers of postdoctoral researchers may be one important avenue through which increased federal R&D funding operates to increase scientific output.

Using a combined measure of R&D funding (columns 3 and 6) produces qualitatively similar results, with the coefficient falling somewhere between the values estimated when the measures of funding are included separately. We see no reason to prefer this specification to those that enter funding separately by source.

Overall, the model does a reasonably good job of accounting for the observed patterns of variation, explaining about three quarters of the variation in publications and close to two-thirds of the variation in citations. It should be pointed out that this is not simply a result of cross-sectional variation across institutions, as the R-squared values for within variation are also relatively high, indicating that temporal variations in funding at a university account for a good deal of the temporal variation in research output.

In Table 4 we report estimates of equation (1) for subsets of universities. For ease of comparison, each set of results begins by reproducing the full sample estimates of our preferred specification from Table 3. We then report results splitting the sample by control (private vs. public) and research intensity (non-Research I vs. Research I). For private universities (which as we have seen rely less on non-federal funding) only federally funded R&D expenditures enter significantly (column 2), and this effect vanishes when we add postdoctoral researchers to the explanatory variables. For public universities, on the other hand, both federal and non-federal sources of R&D funding appear to matter and their effect persists even after adding controls for the number of graduate students and postdoctoral researchers.

When the sample is split by research intensity none of the explanatory variables is statistically significant for the non-Research I universities, but we see that both federal and non-federal sources of R&D funding exert a positive and statistically significant effect on scientific productivity for the Research I universities along with the number of postdoctoral researchers.

Before concluding our discussion of the OLS results it is worth considering the pattern of year effects revealed in the various regressions. Figure 6 plots the coefficients on the year dummies for the full sample and subsets of universities obtained from regressions including the full set of explanatory variables. The top panel shows the year effects for publications, while the bottom panel shows the effects for citations.

As we might have anticipated based on the much more rapid increase of publications and citations than funding levels over this period, the year effects all indicate a substantial and as yet unexplained rise in productivity over time. This increase was most pronounced for the Research I universities and the private universities, while it was weaker for the non-Research I and public universities.

Instrumental Variable Estimation

As we noted earlier, because R&D funding is allocated in a purposeful manner we cannot use the resulting coefficient estimates to answer the question of how additional research funding would affect scientific productivity. Ideally, to answer this question we would want an experimental setting in which additional research funds could be randomly assigned to some universities and not to others. By comparing the impact of funds on the treated and control groups we could identify the impact of additional research funding on scientific output.

We cannot conduct such an experiment, but we can use instrumental variables to obtain estimates of the effects of such truly random variations in funding levels. The requirement for a good instrumental variable is that it be correlated with the explanatory variable of interest, but uncorrelated with the error term. In what follows we employ two instrumental variables to identify the causal effects of funding on research output. They are the university's non-chemistry federally-funded R&D expenditures and its non-chemistry non-federally funded R&D expenditures.[10] Together these variables capture both institution-specific and national trends in the funding environment that would be likely to give rise to truly exogenous shocks to the level of funding.

Table 5 reports estimates of several different specifications of the model estimated for the full sample. The top panel summarizes key results from the first-stage regressions of federally-funded and non-federally funded R&D expenditures on the instruments. The coefficient estimates from the first stage are estimated relatively precisely, the signs are sensible and the overall fit of the regressions is relatively good.

In the bottom panel of the table we report coefficient estimates from the second stage regression. The estimated coefficients are relatively stable across the different specifications and all imply a statistically and economically significant effect of R&D funding on scientific output. The implied effect of an additional $1 million in federal R&D expenditures lies between 40 and 50 additional publications, and an additional 397 or 464 citations.[11] The effects of non-federally funded R&D

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[10] In the regressions we use a five-year weighted lag of each of these variables, where the weights are the same as those used to construct the other R&D expenditure variables.

[11] While these effects may appear somewhat large their magnitudes are plausible in light of the evidence presented earlier. As we saw (Figure 5) the average cost per publication for the university system fell from around $60,000 to about $30,000.

expenditures are also statistically significant, but smaller in magnitude; the coefficients imply that an additional $1 million from non-federal sources would result in between 10 and 12 additional articles and 96 to 112 additional citations. Interestingly, the coefficients on both the number of graduate students and the number of postdoctoral researchers become negative in the Instrumental Variable regression.

Table 6 reports Instrumental Variable estimates for the same subsets of universities considered earlier. The effects of additional federal R&D funding implied by the coefficients reported here are relatively consistent across the different groups of universities. On the other hand it appears that non-federally funded R&D expenditures increase number of publications and citations only for public universities and Carnegie Research I universities.

In Figure 7 we plot the coefficients on the year dummies for the full sample and different subsets of universities. Again, the top panel shows the effects for publications and the bottom panel shows the effects of citations. The unexplained rise in output is still present for private universities and for Research I universities, but is much weaker for the full sample and for the public and non-Research I universities.

Conclusion

The estimated coefficients imply that the marginal cost of an additional publication would be roughly in the range of $20,000 to $25,000.

In light of the substantial investments made by both federal and non-federal sources in supporting university R&D activities it is quite reasonable to wonder whether these investments are productive. For the discipline of chemistry our analysis suggests that these investments do indeed increase measurable intermediate inputs. It remains, of course, to establish whether the increased production of scientific knowledge translates into comparable increases in commercially useful intellectual property or broader economic effects. OLS results show a positive association between the receipt of funding and subsequent research output. Of course, given the non-random allocation of funding, it is quite possible that the positive relationship simply confirms that funders are allocating money to the most productive researchers.

Our Instrumental Variable estimates indicate, however, that there is indeed a causal relationship between the receipt of funding and increased output. These results suggest that increasing funding would lead to higher levels of scholarly output, or that a reduction in support would reduce levels of output. Moreover, it appears that dollar for dollar federal funding is generally more productive than non-federal output.

In addition to finding a positive association between funding and research outputs, our investigation has highlighted another intriguing result. In contrast to the situation prior to 1993, since the early 1990s, the level of scholarly output of academic chemists has increased substantially relative to the level of all measured inputs. At the moment this residual increase in publication remains unexplained. It is possible, of course, that pressures to publish have lead to an increase in the number of publications that is out of proportion to the increase in the additions to the stock of chemical knowledge. But alternatively it seems possible that what we are observing is a genuine productivity shock. The 1990s were a period in which computers diffused increasingly widely into laboratories, facilitating a number of activities in the production and communication of chemical knowledge. Distinguishing between these competing interpretations will, however, require additional investigation.

DATA Appendix

The analysis in this paper rests on merging several different sources of data. We describe the sources and key characteristics of each briefly.

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 surveys 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 university of institutions represented in this data by summing real federally funded R&D expenditures (in prices of 2000) for chemistry and chemical engineering between 1990 and 2009 and then ranking institutions in descending order. We initially selected the top 150 institutions but 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.

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.

Graduate Students, 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 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. 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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Table 1
Annual Average values of R&D Expenditures and other characteristics of Sample Institutions,
by Total Federally Funded R&D Expenditures, 1990-2009

	R&D Expenditures by source ($1,000s)				Postdoctoral		Citations
University	Federal	Non-Federal	Total	Ph.D.s	Researchers	Publications	over 3 years
Massachusetts Institute of Technology	$28,262.9	$8,574.4	$36,837.3	66	141	522	5,126
California Institute of Technology	$21,095.5	$4,501.9	$25,597.4	35	103	301	2,830
Johns Hopkins University	$18,735.2	$1,273.9	$20,009.1	17	32	253	2,496
University of California-Berkeley	$18,705.6	$8,385.2	$27,090.8	76	166	632	5,681
Stanford University	$18,457.3	$4,082.3	$22,539.6	44	84	364	3,663
Harvard University	$17,334.5	$2,121.1	$19,455.6	27	129	509	7,795
Pennsylvania State U, All Campuses	$16,183.6	$11,788.7	$27,972.2	44	58	446	2,652
University of Illinois at Urbana-Champaign	$15,787.8	$8,835.3	$24,623.1	52	40	424	3,216
University of Texas at Austin	$15,527.6	$14,590.3	$30,117.9	64	91	349	2,714
University of California-Los Angeles	$15,171.2	$4,575.5	$19,746.7	35	85	330	3,439
University of Colorado, All Campuses	$14,894.9	$4,523.5	$19,418.4	29	83	256	1,855
University of Minnesota, All Campuses	$14,398.6	$6,406.9	$20,805.5	55	75	472	3,429
Cornell University, All Campuses	$13,828.9	$6,030.0	$19,858.9	35	55	357	3,093
University of Wisconsin-Madison	$13,779.3	$8,679.1	$22,458.4	56	45	426	3,101
University of Pennsylvania	$13,773.4	$2,316.6	$16,090.0	30	81	342	3,321
University of California-San Diego	$12,701.0	$2,962.1	$15,663.1	21	64	310	3,213
Northwestern Univ	$12,514.9	$4,934.9	$17,449.8	38	84	377	3,846
Rutgers the State Univ of NJ, All Campuses	$12,373.2	$5,572.0	$17,945.2	27	43	256	1,431
University of Washington - Seattle	$12,326.7	$4,411.5	$16,738.2	37	47	330	3,625
Purdue University, All Campuses	$12,134.1	$8,695.4	$20,829.5	67	45	401	2,535
University of Michigan, All Campuses	$11,832.4	$5,095.9	$16,928.2	48	47	452	4,162
Georgia Institute of Technology, All Campuses	$11,249.9	$11,690.5	$22,940.3	35	28	257	2,321
University of Utah	$11,060.0	$4,505.2	$15,565.1	30	52	297	2,315
University of Pittsburgh, All Campuses	$10,519.2	$2,503.7	$13,022.9	30	59	254	2,074
University of North Carolina at Chapel Hill	$10,319.3	$2,725.4	$13,044.7	35	57	328	3,039
Texas A&M University, All Campuses	$10,292.9	$18,344.9	$28,637.8	58	84	403	2,632
Ohio State University, All Campuses	$10,044.5	$9,894.5	$19,939.0	40	57	317	1,838
Princeton University	$9,976.0	$6,087.2	$16,063.3	28	62	181	1,206
University of Notre Dame	$9,974.5	$1,994.2	$11,968.7	17	44	177	1,316
University of Massachusetts at Amherst	$9,542.5	$8,312.0	$17,854.5	35	35	237	1,434
Arizona State University Main	$9,279.7	$6,821.6	$16,101.3	14	30	133	1,095
University of California-Irvine	$9,191.4	$3,516.3	$12,707.7	25	46	211	1,671
Columbia University in the City of New York	$8,969.1	$2,676.5	$11,645.6	25	59	259	2,501
University of California-Santa Barbara	$8,871.8	$3,185.1	$12,056.9	23	58	241	2,406

University of Arizona	$8,857.6	$4,843.1	$13,700.7	24	48	242	1,306
University of Florida	$8,704.1	$6,188.6	$14,892.7	46	59	371	2,134
University of Delaware	$8,665.0	$5,124.4	$13,789.4	27	39	256	1,388
University of South Carolina, All Campuses	$8,569.4	$6,292.3	$14,861.6	21	30	122	908
Yale University	$8,560.5	$2,002.2	$10,562.6	22	38	236	2,711
North Carolina State University at Raleigh	$8,496.7	$11,125.6	$19,622.3	26	47	264	1,382
University of Chicago	$8,460.5	$2,389.5	$10,850.0	21	25	185	1,650
University of California-Davis	$8,071.5	$3,523.2	$11,594.7	31	45	335	2,098
Michigan State University	$7,530.1	$8,531.5	$16,061.6	32	46	247	1,361
University of Virginia, All Campuses	$7,419.8	$1,689.0	$9,108.8	20	40	181	1,531
Case Western Reserve University	$7,389.1	$4,425.7	$11,814.8	26	15	195	1,616
Indiana University, All Campuses	$7,274.4	$6,195.9	$13,470.3	20	44	216	1,631
University of Tennessee Univ-Wide Adm Cent Off	$7,188.0	$3,434.5	$10,622.4	19	25	234	1,320
University of Maryland at College Park	$7,179.9	$5,100.2	$12,280.1	21	18	186	1,075
New Mexico State University, All Campuses	$7,061.8	$1,118.6	$8,180.4	6	4	50	362
Louisiana State Univ, All Campuses	$6,999.2	$7,160.4	$14,159.6	22	31	176	889
Colorado State University	$6,974.7	$2,495.8	$9,470.5	17	53	144	1,038
University of Southern California	$6,956.0	$3,270.7	$10,226.7	22	51	196	1,431
SUNY at Buffalo, All Campuses	$6,952.3	$5,981.4	$12,933.7	27	45	182	1,184
Virginia Polytechnic Institute and State Univ	$5,994.4	$7,191.8	$13,186.1	24	27	204	899
Carnegie Mellon University	$5,893.6	$1,875.6	$7,769.2	21	28	160	1,237
University of Rochester	$5,871.4	$942.1	$6,813.6	17	31	145	1,242
Rice University	$5,796.1	$2,454.0	$8,250.0	20	32	145	1,437
Emory University	$5,690.6	$2,680.7	$8,371.2	16	39	193	1,741
SUNY at Stony Brook, All Campuses	$5,449.7	$3,986.2	$9,435.9	16	19	198	1,422
University of Southern Mississippi	$5,425.5	$1,365.7	$6,791.1	11	17	91	276
University of Oklahoma, All Campuses	$5,292.0	$9,009.5	$14,301.4	15	29	120	670
Rensselaer Polytechnic Institute	$5,024.4	$2,522.7	$7,547.1	19	22	117	553
Washington University	$4,978.8	$2,397.4	$7,376.2	18	28	230	2,577
University of Kansas, All Campuses	$4,898.4	$4,978.9	$9,877.3	22	29	162	1,060
University of Nebraska Central Admin Sys Off	$4,779.8	$3,782.4	$8,562.2	12	17	149	846
University of Houston	$4,707.2	$5,677.1	$10,384.3	22	30	156	917
Vanderbilt University	$4,677.5	$927.0	$5,604.5	11	20	200	2,046
Wayne State University	$4,665.9	$4,238.4	$8,904.2	22	21	153	1,107
Clemson University	$4,541.9	$5,466.3	$10,008.2	14	12	147	695
University of Alabama in Huntsville	$4,192.9	$1,665.8	$5,858.7	0	1	27	81
Iowa State University	$4,150.9	$3,794.8	$7,945.7	35	22	335	1,906
University of California-Santa Cruz	$4,117.7	$1,602.1	$5,719.8	8	21	72	476
University of Oregon	$4,069.5	$1,291.8	$5,361.3	7	25	74	427
University of Illinois at Chicago	$3,983.0	$2,412.3	$6,395.4	22	15	187	1,346

University of Iowa	$3,951.2	$2,708.4	$6,659.6	19	21	171	1,340
Montana State University - Bozeman	$3,931.4	$1,260.0	$5,191.4	6	17	50	274
University of New Mexico, All Campuses	$3,910.9	$1,534.7	$5,445.7	11	15	115	768
University of California-Riverside	$3,896.9	$1,568.0	$5,464.9	11	34	156	1,221
Boston College	$3,887.5	$1,219.3	$5,106.8	9	19	63	611
Florida State University	$3,886.7	$5,761.0	$9,647.6	11	42	134	730
University of PR Rio Piedras Campus	$3,799.3	$386.2	$4,185.6	7	6	37	102
Kansas State University	$3,753.1	$1,303.4	$5,056.6	9	14	89	473
CUNY City College	$3,720.1	$707.1	$4,427.2	0	11	37	186
Brigham Young University, All Campuses	$3,579.1	$1,604.5	$5,183.5	10	12	86	390
Mississippi State University	$3,512.1	$3,248.1	$6,760.2	5	10	45	139
New York University	$3,475.1	$1,212.0	$4,687.1	8	24	116	1,024
University of Alabama	$3,451.5	$1,620.2	$5,071.7	10	13	85	476
Duke University	$3,447.2	$1,864.0	$5,311.2	14	32	205	2,459
University of Akron, All Campuses	$3,446.6	$8,058.6	$11,505.2	40	36	138	670
University of Dayton	$3,409.9	$594.0	$4,004.0	0	0	34	132
Washington State University	$3,344.5	$1,906.0	$5,250.6	7	12	126	665
University of Maryland Baltimore County	$3,326.2	$789.6	$4,115.8	5	13	126	968
Georgetown University	$3,275.2	$824.1	$4,099.4	6	6	88	709
Oregon State University	$3,269.4	$1,196.9	$4,466.3	12	12	102	500
Brown University	$3,219.0	$2,434.5	$5,653.5	11	11	82	541
University of Arkansas, Main Campus	$3,156.9	$2,457.6	$5,614.5	8	11	68	371
Northeastern University	$3,131.9	$1,836.6	$4,968.5	9	11	80	500
University of Kentucky, All Campuses	$3,103.8	$2,047.1	$5,150.9	14	18	180	1,100
Rockefeller University	$2,961.8	$2,024.1	$4,985.9	0	7	44	690
Auburn University, All Campuses	$2,959.0	$3,926.6	$6,885.6	13	9	84	327
University of Tulsa	$2,908.2	$3,263.4	$6,171.6	7	2	22	16
University of Cincinnati, All Campuses	$2,903.3	$3,477.4	$6,380.7	21	14	174	1,046
Boston University	$2,878.2	$346.1	$3,224.3	8	6	131	1,072
New Mexico Institute of Mining and Technology	$2,873.2	$3,732.8	$6,606.1	3	0	18	72
CUNY Hunter College	$2,839.1	$1,175.0	$4,014.1	0	0	41	224
Tufts University	$2,838.6	$934.3	$3,772.9	7	14	89	872
North Dakota State University, All Campuses	$2,815.6	$1,900.4	$4,716.0	6	12	87	349
Colorado School of Mines	$2,804.7	$2,410.7	$5,215.3	9	7	48	185
Virginia Commonwealth University	$2,727.7	$1,659.4	$4,387.1	7	8	110	625
Clark Atlanta University	$2,714.2	$398.8	$3,112.9	1	5	18	43
Lehigh University	$2,678.7	$3,227.4	$5,906.2	16	19	79	361
University of Georgia	$2,654.3	$5,099.0	$7,753.4	17	17	221	1,333
University of Connecticut, All Campuses	$2,532.5	$2,640.9	$5,173.4	23	16	178	928
Syracuse University, All Campuses	$2,479.3	$973.5	$3,452.8	10	12	79	410

West Virginia University	$2,440.8	$1,210.9	$3,651.7	7	9	67	308
Tulane University	$2,384.1	$1,896.6	$4,280.6	9	12	88	567
Oklahoma State University, All Campuses	$2,350.0	$2,376.0	$4,726.0	10	5	74	363
Brandeis University	$2,233.7	$659.7	$2,893.4	7	14	47	394
Jackson State University	$2,206.5	$327.0	$2,533.5	1	9	47	221
Illinois Institute of Technology	$2,169.6	$946.5	$3,116.1	9	5	34	125
Clarkson University	$2,144.8	$2,596.0	$4,740.8	10	21	57	288
New Jersey Institute Technology	$2,136.9	$2,441.3	$4,578.2	5	1	36	129
Texas Tech University	$2,104.0	$3,913.5	$6,017.5	11	22	85	433
University of Missouri, Columbia	$2,031.3	$3,841.1	$5,872.4	13	11	124	568
University of Wyoming	$1,804.3	$2,737.7	$4,542.0	8	12	44	197
University of Hawaii at Manoa	$1,744.4	$455.0	$2,199.4	4	10	72	398
Dartmouth College	$1,690.0	$747.9	$2,438.0	6	12	65	498
Drexel University	$1,653.9	$953.9	$2,607.8	6	6	71	435
Utah State University	$1,629.6	$898.0	$2,527.6	3	5	48	283
Norfolk State University	$1,629.3	$37.6	$1,666.9	0	0	6	4
University of New Hampshire	$1,583.8	$659.8	$2,243.6	5	4	40	152
San Francisco State University	$1,568.0	$99.2	$1,667.2	0	0	18	68
Howard University	$1,530.4	$293.0	$1,823.4	5	3	57	170
University of Denver	$1,510.9	$283.8	$1,794.8	2	5	13	49
Polytechnic University	$1,491.9	$1,253.2	$2,745.2	9	14	43	195
California State University-Los Angeles	$1,481.8	$76.8	$1,558.6	0	0	29	81
University of Idaho	$1,467.7	$1,414.4	$2,882.1	7	9	66	318
Georgia State University	$1,447.5	$1,659.7	$3,107.3	3	21	50	263
University of Missouri, Rolla	$1,446.9	$1,867.3	$3,314.3	10	4	60	232
University of Massachusetts Lowell	$1,379.7	$1,104.1	$2,483.8	12	6	59	175
University of Louisville	$1,378.5	$898.8	$2,277.4	7	7	51	369
University of Montana	$1,340.3	$448.6	$1,788.9	3	5	21	66
University of South Florida	$1,327.3	$1,743.8	$3,071.1	9	10	82	674
University of PR Mayaguez Campus	$1,300.6	$680.1	$1,980.6	1	0	25	35
North Carolina Agricultural & Tech State Univ	$1,281.5	$89.5	$1,371.0	0	0	13	24
Stevens Institute of Technology	$1,252.7	$400.2	$1,652.9	4	4	27	118
Cleveland State University	$1,178.6	$518.8	$1,697.4	5	4	24	107

Source: See Data Appendix.

Table 2
Annual Average Values of Key Variables, by Decade and University Characteristics

	Full Sample	Research Status		Control	
		Research I	Other	Private	Public
			1990-1999		
Federally Funded R&D (thousands)	$5,209	$7,200	$2,561	$6,015	$4,830
Non-Federally Funded R&D (thousands)	$2,824	$3,601	$1,792	$2,026	$3,200
Total R&D Expenditures (thousands)	$8,034	$10,800	$4,353	$8,041	$8,030
Percent R&D Federally Funded	64.6%	66.1%	62.5%	72.0%	61.1%
Graduate students enrolled	150	190	96	126	161
Ph.D.s awarded	18	25	8	16	19
Postdoctoral researchers	27	39	11	29	26
Number of publications	120	174	48	113	123
Number Citations over 3 years	832	1,295	211	1,041	734
			2000-2009		
Federally Funded R&D (thousands)	$6,981	$9,534	$3,577	$7,056	$6,945
Non-Federally Funded R&D (thousands)	$3,925	$5,237	$2,175	$2,368	$4,657
Total R&D Expenditures (thousands)	$10,906	$14,771	$5,752	$9,425	$11,602
Percent R&D Federally Funded	66.2%	66.2%	66.2%	73.9%	62.6%
Graduate students enrolled	158	205	95	135	168
Ph.D.s awarded	18	26	8	16	19
Postdoctoral researchers	31	44	13	34	29
Number of publications	209	297	92	200	213
Number Citations over 3 years	1,650	2,465	562	1,857	1,552
Number of Institutions	147	84	63	47	100

Table 3
OLS Panel Regressions
Determinants of Publications and Citations

	Number of Publications			Number of Citations (3 year horizon)		
	(1) Model I	(2) Model II	(3) Model III	(1) Model I	(2) Model II	(3) Model III
Federally Funded R&D	0.00744***	0.00533**		0.0728**	0.0418	
	(0.00171)	(0.00176)		(0.0234)	(0.0229)	
Non-Federally Funded R&D	0.00868***	0.00824***		0.0941**	0.0876**	
	(0.00236)	(0.00213)		(0.0337)	(0.0293)	
Total R&D			0.00662***			0.0621***
			(0.00139)			(0.0168)
Graduate Students		0.0615	0.0503		1.736	1.560
		(0.141)	(0.145)		(1.744)	(1.794)
Postdoctoral Researchers		1.319**	1.289**		16.73***	16.26***
		(0.393)	(0.395)		(4.796)	(4.788)
Institution Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
N	2929	2929	2929	2929	2929	2929
R-squared within	0.630	0.653	0.652	0.491	0.522	0.520
R-squared between	0.759	0.818	0.823	0.587	0.692	0.728
R-squared overall	0.647	0.763	0.767	0.519	0.643	0.668

Standard errors in parentheses
* p<0.05
** p<0.01
*** p<0.001"

Table 4
OLS Panel Regressions
Determinants of Publications and Citations, by University Type

		Private		Public		Not Research I		Research I	
		Panel A - Dependent Variable: Number of Publications							
Federally Funded R&D	0.00533**	0.00881***	0.00429	0.00723**	0.00585*	0.00552*	0.00424	0.00623***	0.00415*
	(0.00176)	(0.00249)	(0.00238)	(0.00231)	(0.00236)	(0.00222)	(0.00213)	(0.00175)	(0.00180)
Non-Federally Funded R&D	0.00824***	0.00414	0.00305	0.0102***	0.00976***	0.00375	0.00300	0.00720**	0.00705**
	(0.00213)	(0.00356)	(0.00394)	(0.00272)	(0.00243)	(0.00213)	(0.00207)	(0.00268)	(0.00235)
Graduate Students	0.0615		0.168		0.0463		0.104		0.0191
	(0.141)		(0.131)		(0.188)		(0.0753)		(0.188)
Postdoctoral Researchers	1.319**		2.262**		0.891		0.779		1.376***
	(0.393)		(0.726)		(0.454)		(0.483)		(0.390)
Institution Effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2929	940	940	1989	1989	1256	1256	1673	1673
R-squared within	0.653	0.588	0.652	0.655	0.666	0.581	0.599	0.716	0.738
R-squared between	0.818	0.794	0.870	0.734	0.790	0.591	0.717	0.670	0.739
R-squared overall	0.763	0.681	0.821	0.645	0.731	0.471	0.624	0.596	0.718
		Panel B - Dependent Variable: Number of Citations, 3 year window							
Federally Funded R&D	0.0418	0.0686	0.00824	0.0803**	0.0590*	0.0489*	0.0348	0.0615*	0.0271
	(0.0229)	(0.0488)	(0.0448)	(0.0262)	(0.0261)	(0.0193)	(0.0175)	(0.0263)	(0.0254)
Non-Federally Funded R&D	0.0876**	0.0886*	0.0615	0.105**	0.0993**	0.0309	0.0220	0.0865*	0.0831*

	(0.0293)	(0.0437)	(0.0470)	(0.0391)	(0.0341)	(0.0168)	(0.0168)	(0.0405)	(0.0347)
Graduate Students	1.736		3.636		1.208		0.854		2.135
	(1.744)		(2.348)		(2.291)		(0.692)		(2.442)
Postdoctoral Researchers	16.73***		27.65**		11.82*		9.641*		17.35***
	(4.796)		(8.712)		(5.468)		(4.567)		(5.062)
Institution Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2929	940	940	1989	1989	1256	1256	1673	1673
R-squared within	0.522	0.436	0.506	0.533	0.550	0.484	0.511	0.587	0.618
R-squared between	0.692	0.602	0.730	0.643	0.723	0.486	0.629	0.425	0.568
R-squared overall	0.643	0.485	0.679	0.586	0.665	0.434	0.566	0.456	0.588

Standard errors in parentheses
* $p<0.05$
** $p<0.01$
*** $p<0.001$"

Table 5
IV Panel Regressions
Determinants of Publications and Citations

	Publications		Citations, 3 Year Window	
	Model I	Model II	Model I	Model II
Panel A - First Stage Regressions Summary Characteristics				
	Federally Funded R&D			
Federal Non-Chem R&D	0.0136***	0.0101***	0.0136***	0.0101***
	(0.00099)	(0.00095)	(0.00099)	(0.00095)
Non-Federal Non-Chem R&D	0.0038**	0.0010	0.0038**	0.0010
	(.001424)	(0.00135)	(.001424)	(0.00135)
R-squared within	0.3327	0.4090	0.3327	0.4090
R-squared between	0.5409	0.8311	0.5409	0.8311
R-squared overall	0.4924	0.7704	0.4924	0.7704
	Non-Federally Funded R&D			
Federal Non-Chem R&D	-0.0053***	-0.0064***	-0.0053***	-0.0064***
	(0.00072)	(0.00073)	(0.00072)	(0.00073)
Non-Federal Non-Chem R&D	0.0309***	0.0300***	0.0309***	0.0300***
	(0.0010)	(0.00104)	(0.0010)	(0.00104)
R-squared within	0.3676	0.3803	0.3676	0.3803
R-squared between	0.4626	0.5872	0.4626	0.5872
R-squared overall	0.4465	0.5470	0.4465	0.5470
Panel B - IV Regressions				
Federally Funded R&D	0.0396***	0.0493***	0.397***	0.464***
	(0.00277)	(0.00456)	(0.0317)	(0.0488)
Non-Federally Funded R&D	0.0101***	0.0123***	0.0964***	0.112***
	(0.00212)	(0.00245)	(0.0242)	(0.0263)
Graduate Students		-0.756***		-6.014***
		(0.102)		(1.094)
Postdoctoral Researchers		-0.870**		-4.019
		(0.287)		(3.068)
Institution Effects	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes
N	2929	2929	2929	2929
R-squared within	0.0386	.	0.0418	.
R-squared between	0.776	0.603	0.716	0.662
R-squared overall	0.695	0.539	0.605	0.552

Standard errors in parentheses
* p<0.05
** p<0.01
*** p<0.001"

Table 6
IV Panel Regressions
Determinants of Publications and Citations, by University Type

		Private		Public		Not Research I		Research I	
	Panel A - Dependent Variable: Number of Publications								
Federally Funded R&D	0.0493***	0.0456***	0.0413***	0.0347***	0.0320***	0.0284***	0.0318***	0.0299***	0.0356***
	(0.00456)	(0.00661)	(0.00783)	(0.00208)	(0.00272)	(0.00671)	(0.00916)	(0.00345)	(0.00627)
Non-Federally Funded R&D	0.0123***	0.0239	-0.0128**		0.0196***	-0.00103	-0.00125	0.00807***	0.00997***
	(0.00245)	(0.0128)	(0.00437)		(0.00201)	(0.00442)	(0.00486)	(0.00220)	(0.00256)
Graduate Students	-0.756***		-0.306*		-0.439***		-0.106		-0.690***
	(0.102)		(0.149)		(0.0735)		(0.0794)		(0.160)
Postdoctoral Researchers	-0.870**		-0.00446		-0.530*		-0.515		-0.0179
	(0.287)		(0.564)		(0.214)		(0.410)		(0.338)
Institution Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2929	940	940	1989	1989	1256	1256	1673	1673
R-squared within	.	.	0.0634	0.308	0.251	0.144	0.0111	0.439	0.317
R-squared between	0.603	0.793	0.768	0.784	0.685	0.506	0.369	0.695	0.514
R-squared overall	0.539	0.690	0.681	0.707	0.625	0.460	0.361	0.648	0.512
	Panel B - Dependent Variable: Number of Citations, 3 year window								
Federally Funded R&D	0.464***	0.415***	0.504***	0.325***	0.354***	0.256***	0.281***	0.294***	0.294***
	(0.0488)	(0.0700)	(0.142)	(0.0257)	(0.0321)	(0.0637)	(0.0853)	(0.0419)	(0.0685)
Non-Federally Funded R&D	0.112***	0.107	0.311	0.174***	0.192***	-0.0525	-0.0576	0.0821**	0.0874**
	(0.0263)	(0.136)	(0.243)	(0.0224)	(0.0237)	(0.0419)	(0.0452)	(0.0267)	(0.0279)
Graduate Students	-6.014***		-10.06		-4.188***		-0.904		-3.706*
	(1.094)		(5.752)		(0.868)		(0.739)		(1.749)
Postdoctoral Researchers	-4.019		-2.909		-3.666		-0.223		5.786
	(3.068)		(9.843)		(2.522)		(3.819)		(3.688)

Institution Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2929	940	940	1989	1989	1256	1256	1673	1673
R-squared within	.	.	.	0.211	0.141	0.0644	.	0.399	0.407
R-squared between	0.662	0.651	0.612	0.745	0.681	0.450	0.381	0.603	0.615
R-squared overall	0.552	0.564	0.516	0.632	0.580	0.384	0.337	0.552	0.563

Standard errors in parentheses
* p<0.05
 ** p<0.01
 *** p<0.001"

Figure 1: Sample Institution Shares of Key Input and Output Variables, 1990-2009

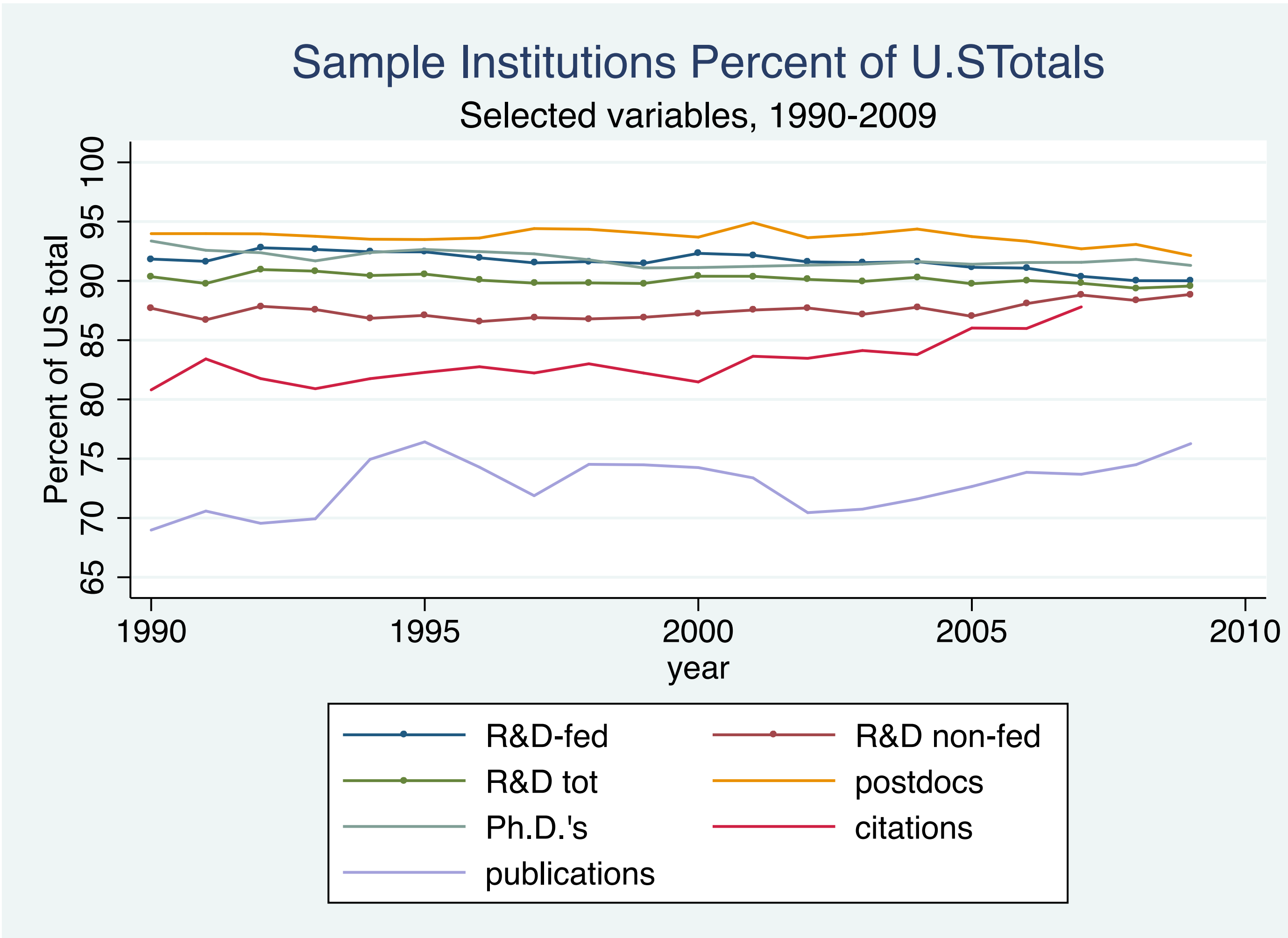
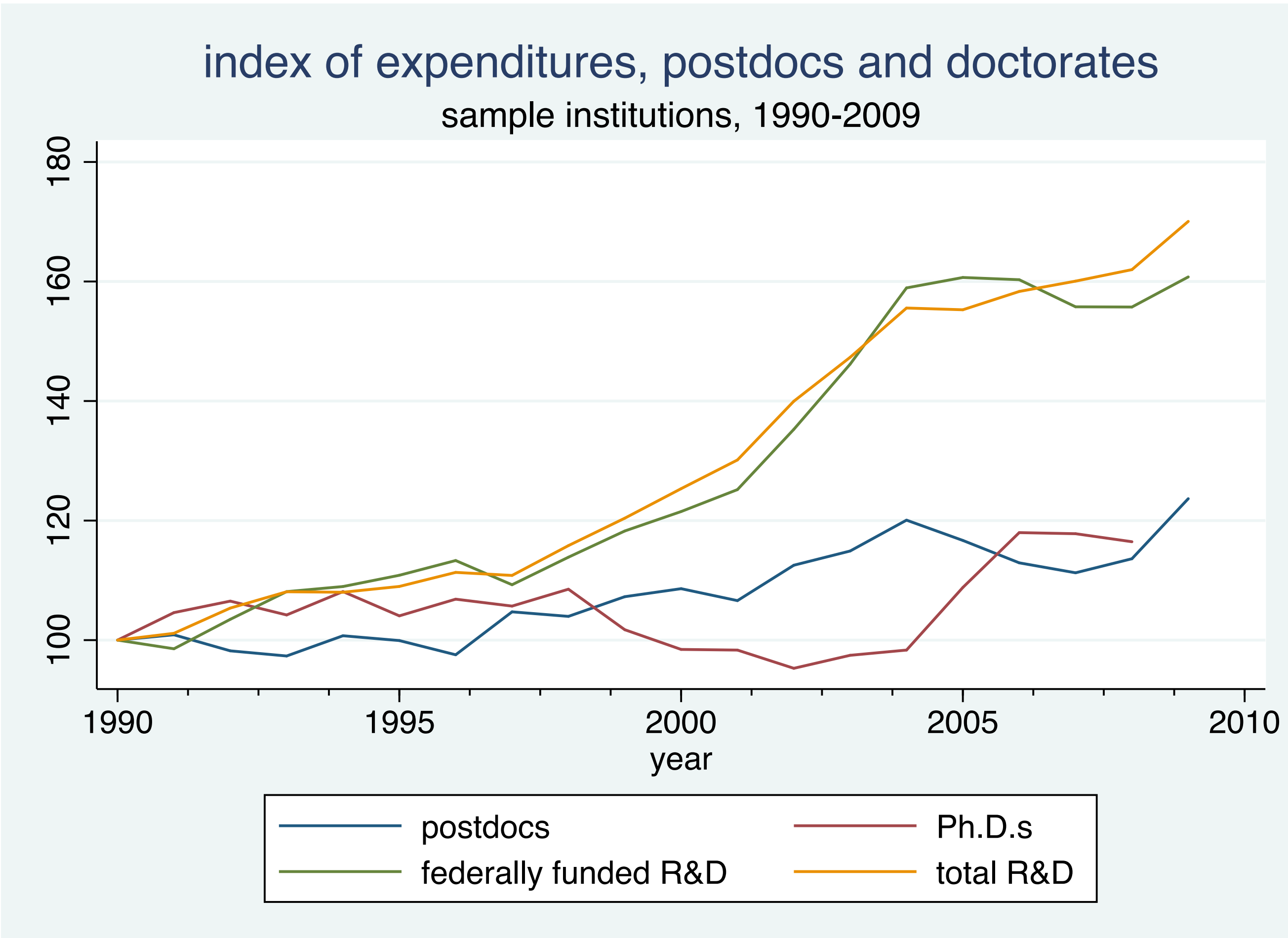


Figure 2: Indexes of R&D Expenditures, Postdoctoral Researchers, and Ph.D.s Awarded, Sample Institutions, 1990-2009 (1990 = 100)



x

Figure 3: Indexes of R&D Expenditures, Publications, and Citations (three-year window), 1990-2009 (1990=100)

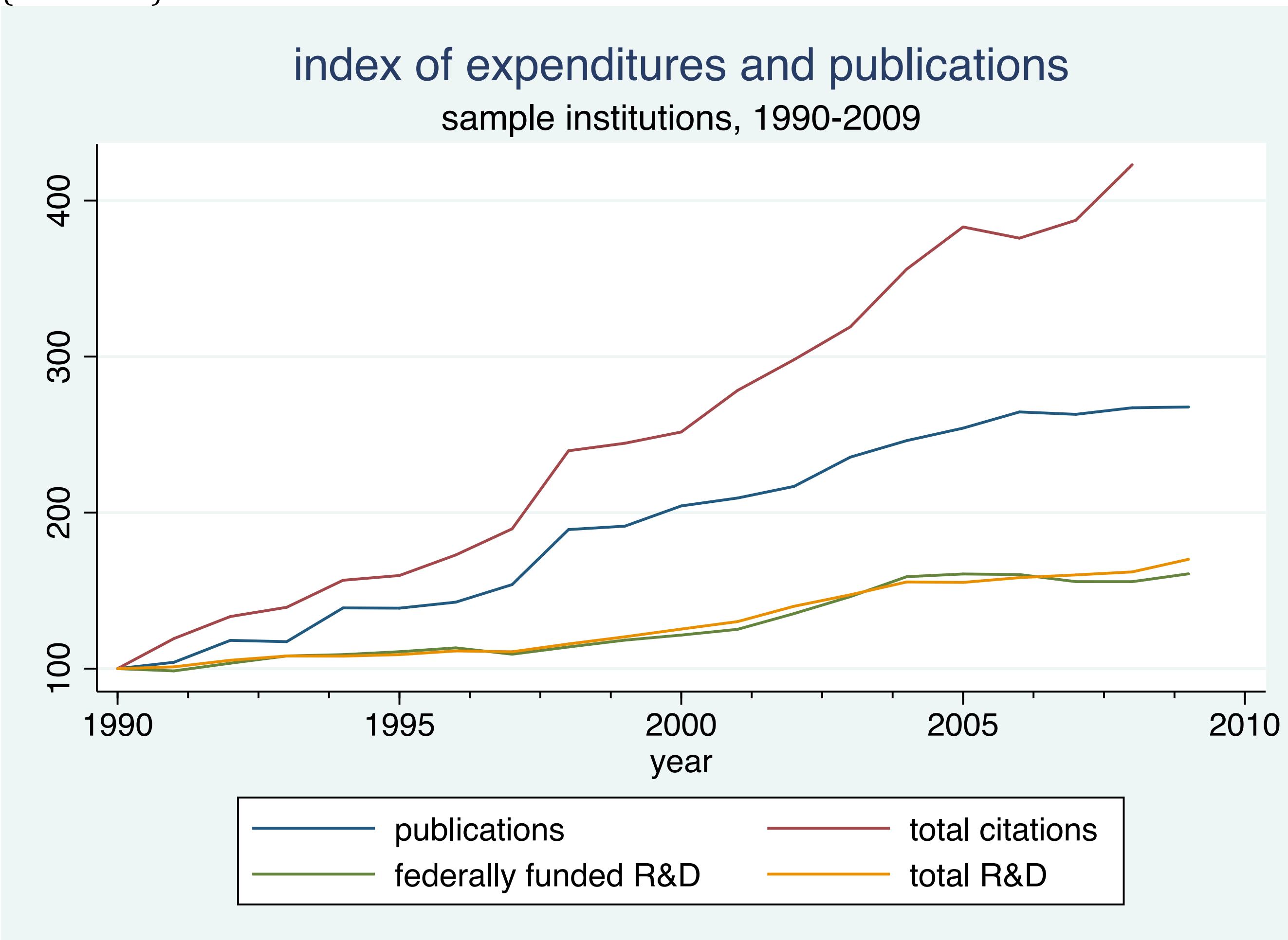


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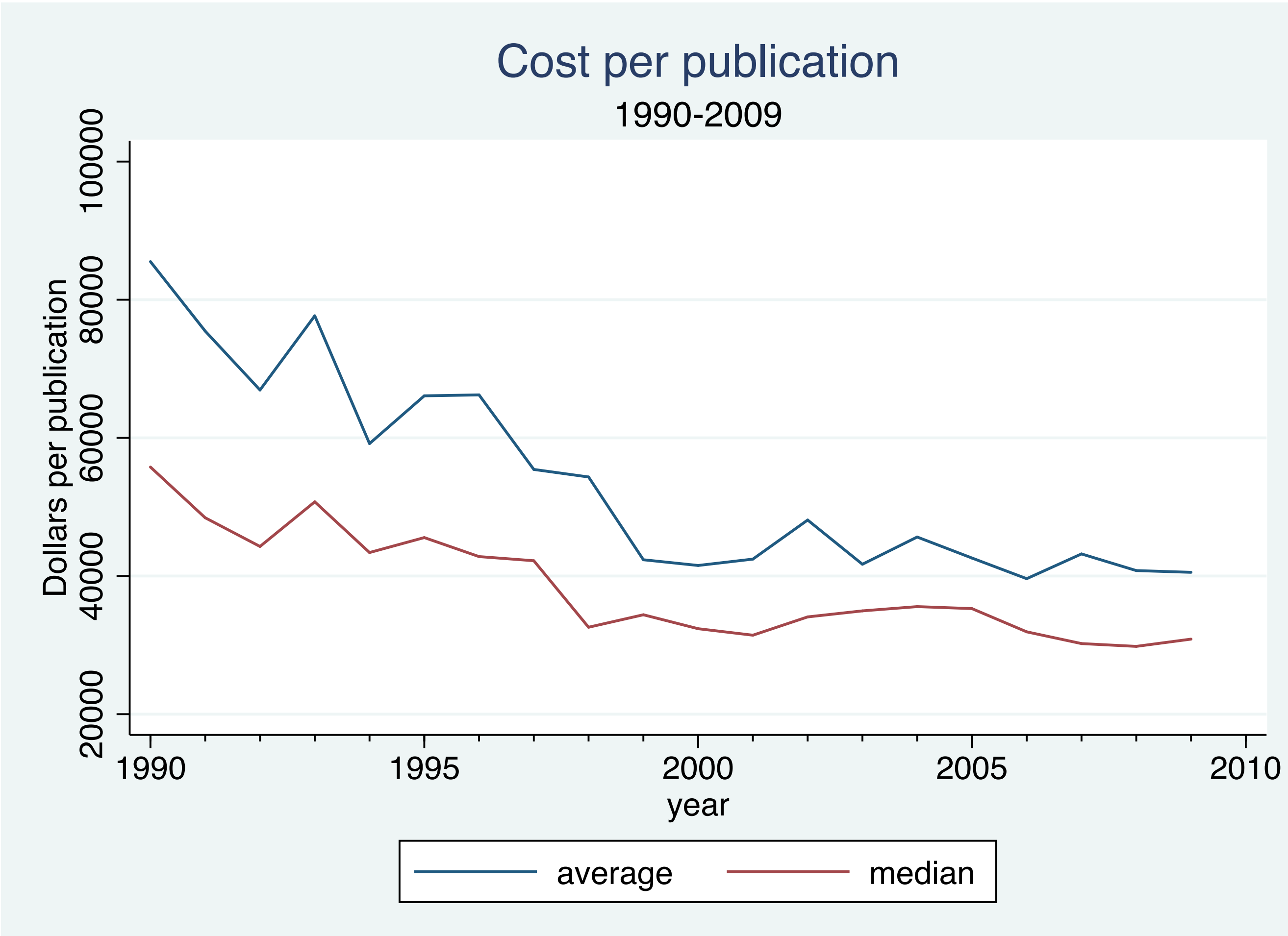
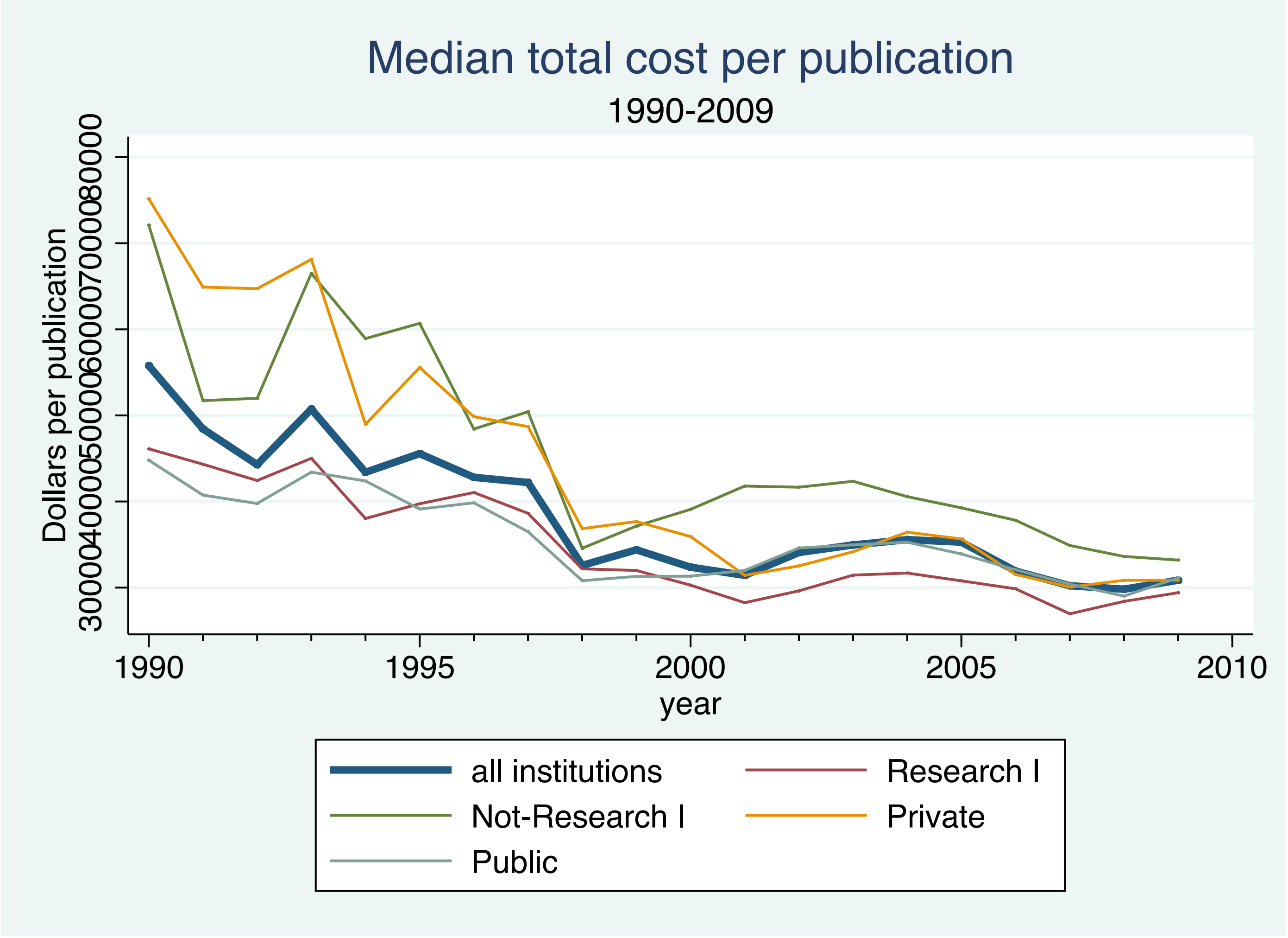
Figure 4: Average and Median Cost per Publication (Constant 2000 $), Sample Institutions, 1990-2009



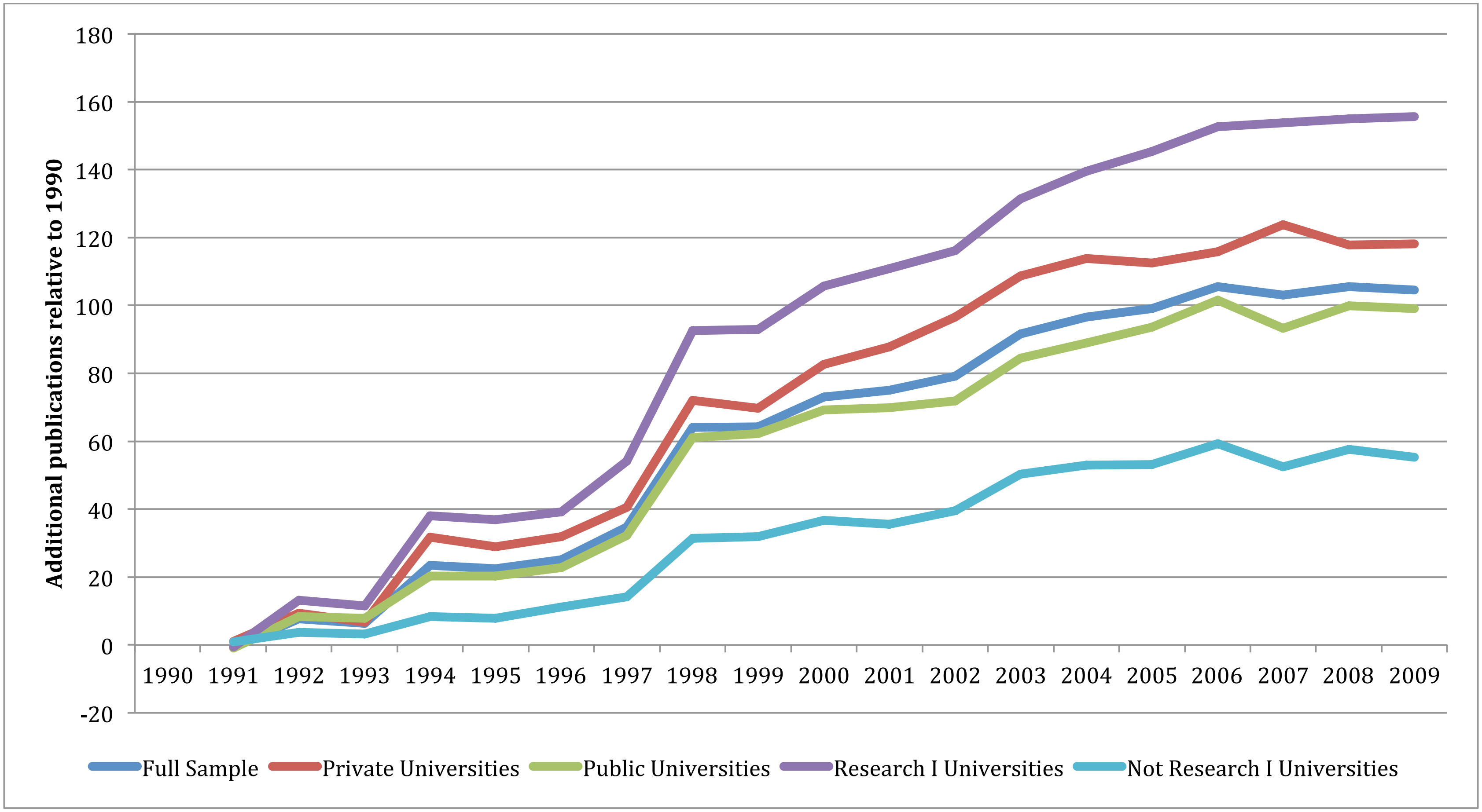
x

Figure 5: Median Cost per Publication (constant 2000 $), Full Sample and by type of University, 1990-2009



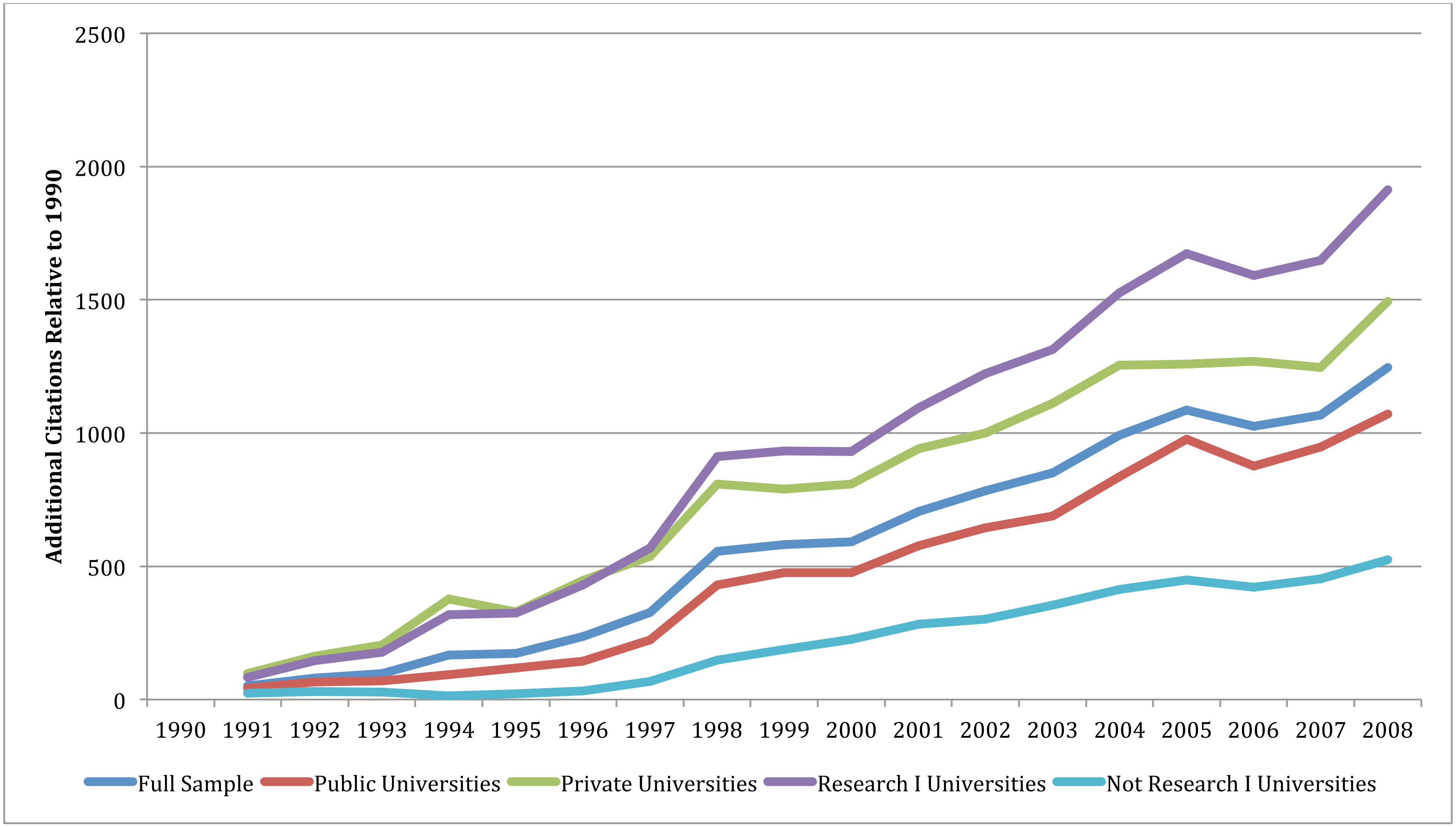
x

Figure 6a: Year Effects on Number of Publications from OLS Regression



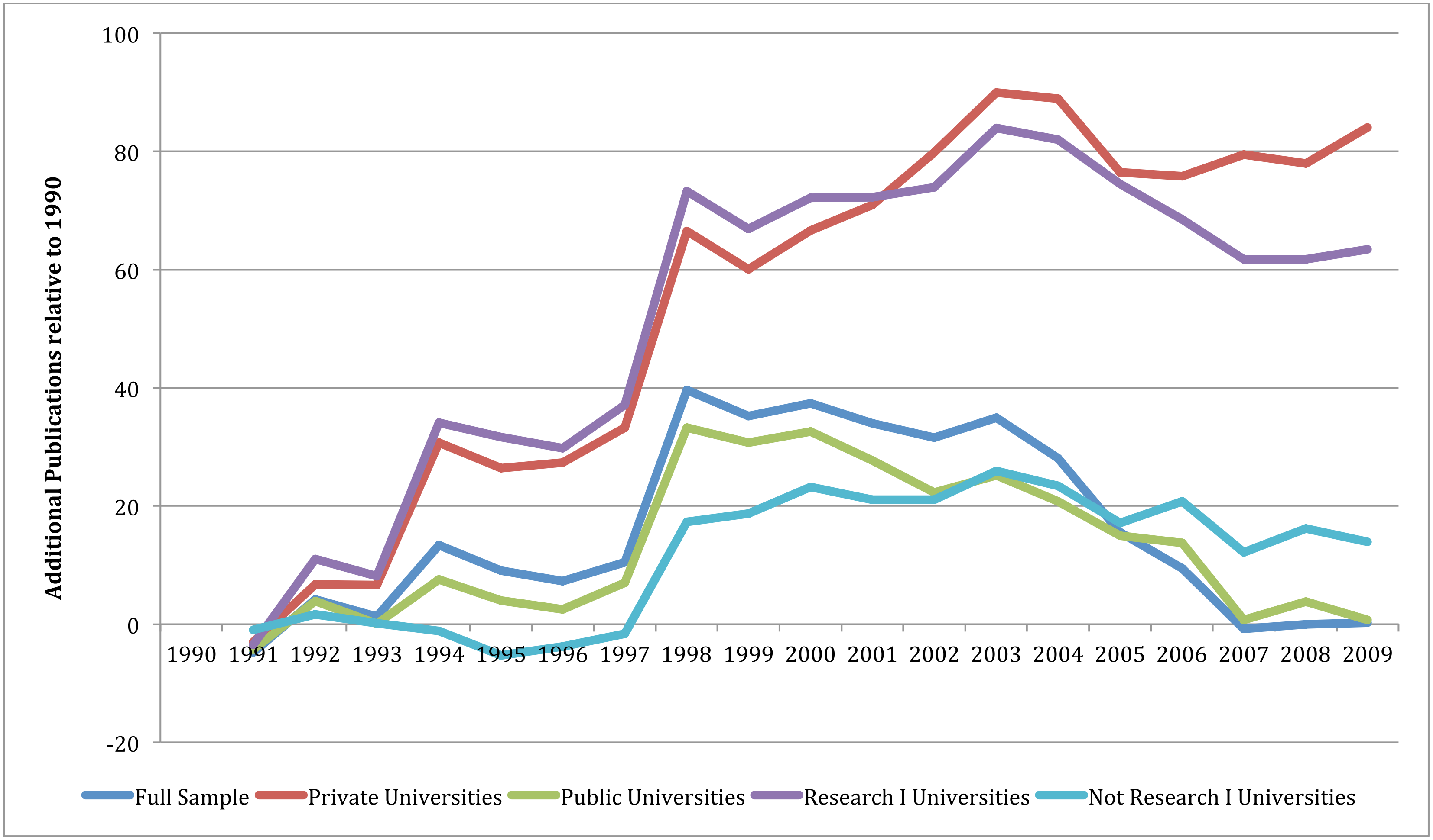
X

Figure 6b: Year Effects on Number of Citations from OLS Regressions



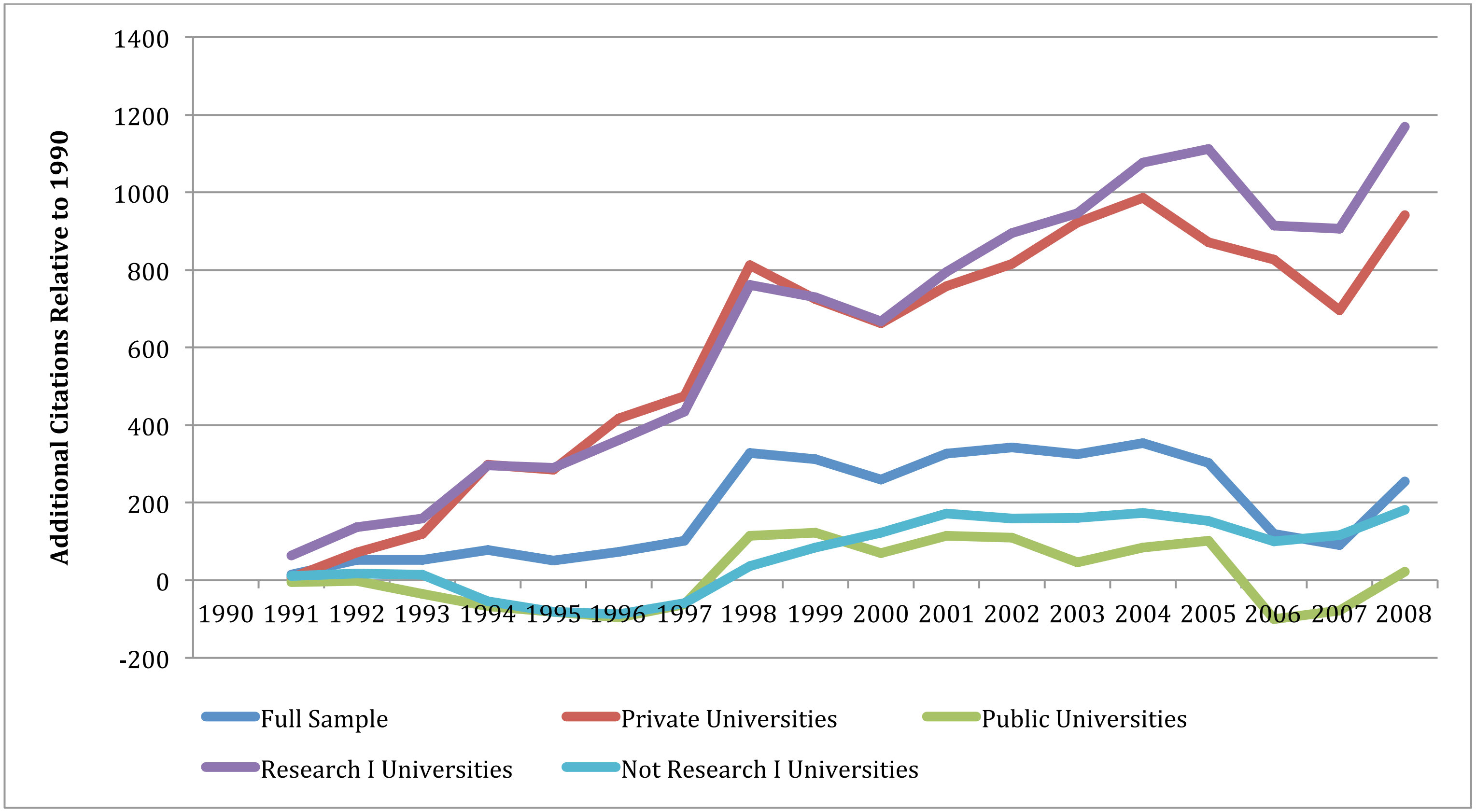
X

Figure 7a: Year Effects on Number of Publications from IV Regressions



X

Figure 7b: Year Effects on Citations from IV Regressions



X