Estimating the Effects of Federal Research Funding on Universities using Alumni Representation on Congressional Appropriations Committees

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Abstract: This paper estimates the effects of federal research funding on 71 research universities. We focus on the number of articles published, citations per article, patents issued, and faculty salaries. Using a panel data set that spans from 1972 to 1994, we control for potential endogeneity and omitted variables bias in our regressions by using a data set that links U.S. Congress members on the appropriations committee with their undergraduate alma mater. Alumni representation lowers the shadow price of federal funding. Using our preferred instrumental variables specification, we find an increase of $1 million in federal research funding (1993$) to a university results, on average, in 12 more articles, .50 more patents, and $152,015 more in total faculty salaries. The change in citations per article is small and imprecisely estimated. So when the shadow price of federal research funding falls, as a first approximation, universities buy more federal research funding and produce more but not necessarily higher quality research output.

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For over 50 years, the U.S. federal government has systematically funded research and development (R&D) at universities. Its role in this regard has increased substantially during this same period so that today federal funding accounts for approximately 60 percent of total research funding to universities (Gieger (1993)). Figure 1 shows the recent trends in real federal R&D expenditure (1993$) per research and doctoral university. From the mid-1980s, there is a slow steady increase in average R&D funding to these universities.

Surprisingly, there is little systematic evidence on how federal funding affects universities.[1] Panels A through D of Figure 2 depict the relationship between our four outcome measures of universities to real federal R&D expenditures (1993$ in millions) to those schools.[2] Panels A and B examines the relationship between the number of articles published and the number of citations per articles published, respectively. Panel A suggests a positive correlation between articles and federal funding. The relationship is panel B is more ambiguous. Panel C depicts the distribution of patents relative to federal funding. It suggests a weak positive relationship. Panel D graphs the relationship between average real faculty salary and federal funding and again, suggests a positive relationship between these two measures. Whether these positive correlations persist under closer scrutiny is the subject of this paper.

A notable precursor to our study is Adams and Griliches (1998).[3] Using longitudinal data by school, they could not reject the hypothesis that the positive correlation between research output (number of articles published and citations to those articles) and research funding is due primarily to differences across schools.

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[1] In her comprehensive survey on the economics of science, Stephan (1996) has no estimate of the returns to federal research funding of universities.
[2] Data construction is discussed in Section III of the paper.
[3] Drew (1985) summarizes other studies that examine the relationship between federal research funding and various output measures.

This paper complements and extends their research in four ways. First, we have a larger sample of schools and more years of data, allowing us to employ both school and year fixed effects in our estimation. Second, we include two new outcome measures, patent counts and faculty salaries.[4] We study patent counts because it is comparable to studies of patent counts and research expenditure in the private sector. The rationale for investigating faculty salaries is to study the pecuniary return to professors for obtaining federal research funding. Third, we use instruments, alumni representation on U.S. Congressional appropriations committees, to alleviate problems of endogeneity and omitted variable bias in estimating these relationships. Finally, we provide a new interpretation for the instrumental variables (IV) estimate of the coefficient on expenditures when we regress an outcome measure on federal research expenditures. The IV estimate captures the total change in outcome when a university buys an additional unit of federal research funding due to a change in the shadow price of funding.

Our empirical findings which control for school and year effects, endogeneity, and omitted input bias suggest the following: for three of our four outcome measures (faculty salaries, number of articles published and patents issued) there is a strong positive correlation between outcome and research funding. Under the preferred empirical specifications, an increase of $1 million in federal research funding (1993$) to a university results in 12 more articles, .50 more patents, and $152,015 more in total faculty salaries. With the number of citations per articles published, a $1 million increase in federal funding has a small and imprecisely measured change in the number of citations per article. Thus, as a first approximation, additional federal research funding results in more but not necessarily higher quality research output.

[4] They analyzed outcomes by academic disciplines whereas we aggregate outcomes across all disciplines. They also study the impact on graduate enrollment.

Using for profit firm level data and a log-linear specification, estimated elasticities of the number of patents issued with respect to research expenditures range from .37 to .61 (Bound et al. (1984), Pakes and Griliches (1984)). With the same functional form, our IV estimate of the elasticity of patents with respect to federal research funding is 1.2.[5] Since the shadow price of federal research funding to society is approximately $1, the returns, as measured by patent counts, to federal research funding of universities are comparable to the returns to research expenditure in the private sector.[6]

The paper is set out as follows. Section I discusses the empirical framework. Section II provides a brief overview of the role of Congress in affecting federal research funding and how we construct our instruments. Section III explains the other data sources. Empirical results are presented in Section IV and the conclusion is in Section V.

I Empirical Framework

To study the relationship between outcomes and federal research funding, consider regressing an outcome measure on funding using school level data.[7] We have a semi-reduced form where unmeasured inputs are be captured by the error term of the regression:

(1) $y_{jt} = \lambda f_{jt} + v_{jt}$

y_{jt} : measure of output of production unit j at time t.

f_{jt} : measure of an input of production unit j at time t.

v_{jt} : error term of regression.

In the above equation, f_{jt} is potentially correlated with the error term of the regression which includes other inputs in the production process and production unit specific effects. With panel

[5] Using data since 1980, the elasticity drops to less than one.

[6] This estimate ignores spillover effects, an important focus of recent research (E.g. Henderson, Jaffe, and Trajtenberg (1998), Jaffe (1989), Trajtenberg, Henderson, Jaffe (1997)).

data on different production units, researchers control for permanent differences across production units with fixed effects. We also control for fixed effects in our estimation and abstract from fixed effects for the rest of this discussion.[8]

To deal with the potential correlation between the f_{jt} and the error term, researchers employ an instrumental variable estimator to estimate λ.[9] There are at least two interpretations of the instrumental variable estimator of λ, λ_{IV} :[10]

A. λ_{IV} estimates the total effect on y_{jt} from an exogenous marginal increase in f_{jt} . It incorporates optimal adjustments by all other inputs to the increase in f_{jt} .

B. λ_{IV} estimates the marginal product of f_{jt} .

The confusion about what λ_{IV} estimates is due to the lack of an economic model in which (1) is embedded.[11] We provide an economic model to resolve this ambiguity.

Dealing with the empirical context of this paper, we model universities as profit maximizing institutions for appropriately chosen shadow prices. University j at time t chooses federal funding, F_{jt} , and other inputs, represented as a composite input X_{jt} , to solve:

(2) $\text{Max } \mathbf{E}\{ Y_{jt} (F_{jt} , X_{jt})Z_{jt} – W_{jt} F_{jt} – \underline{R}_{jt} X_{jt} \}$

E : Expectations operator at time t by school j.

Y_{jt} : Research output at time t by school j.

Z_{jt} : Random productivity shock to school j at time t.

W_{jt} : Shadow price of federal funding at time t to school j.

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[7] This is a common strategy among empirical researchers who often regress the output of a production process on some but not all inputs.
[8] It is important to control for school effects because the peer review process allocates more federal research funds to schools which are more productive in research (Cole and Cole (1981)).
[9] Examples include Angrist (1990), Angrist and Lavy (1997), Card (1995), Cutler and Glaeser (1997), Hoxby (1996), Kane and Rouse (1993), Mairesse and Hall (1996).
[10] The classic discussion is Marschak and Andrews (1944). Recent studies include Angrist and Krueger (1998), Card (1998), Griliches and Mairesse (1997), Heckman (1997), Heckman and Vytlacil (1998).

$\underline{R}_{jt}$: Shadow price of other input at time t to school j.

We normalize the price of research output to one. This is without loss of generality since we allow for individual school and time specific shadow input prices. Any variation in the variables of interest is due to changes in the shadow prices and productivity shocks that the school faces. Let log $Z_{jt} = z_{jt} + \underline{z}_{jt}$, two random variables where z_{jt} is observed before input decisions are made and $\underline{z}_{jt}$ is observed after input decisions are made. The means of z_{jt} and $\underline{z}_{jt}$ are both 0 and uncorrelated with each other, W_{jt}, and $\underline{R}_{jt}$. W_{jt} and $\underline{R}_{jt}$ may be correlated.

For any variable V, let V^* denote the choice of V which solves (1). Let v and v^* denote the log of their respective upper case variables Using a log linear approximation to the production function, and abstracting from fixed effects, observed log output will satisfy:

(3) $y_{jt}^* = a\, f_{jt}^* + b\, x_{jt}^* + z_{jt} + \underline{z}_{jt}$

It is convenient to parameterize the correlation between w_{jt} and $\underline{r}_{jt}$ as $\underline{r}_{jt} = \theta w_{jt} + r_{jt}$ where w_{jt} is uncorrelated with r_{jt}.[12] If θ is zero, the two shadow prices are uncorrelated.

Our interest is to estimate the optimal response of a school's research output as its log shadow price of research funding, w_{jt}, falls, holding the other independent log shadow price, r_{jt}, constant. The change in output due to a marginal change in w_{jt} is captured by:

(4) $\partial y_{jt}^* / \partial w_{jt} = a\, \{\partial f_{jt}^* / \partial w_{jt} + \theta \partial f_{jt}^* / \partial \underline{r}_{jt}\} + b\, \{\partial x_{jt}^* / \partial w_{jt} + \theta \partial x_{jt}^* / \partial \underline{r}_{jt}\}$

Using (4), if w_{jt} is increased by $\Delta w_{jt} = \{\partial f_{jt}^* / \partial w_{jt} + \theta \partial f_{jt}^* / \partial \underline{r}_{jt}\}^{-1}$, the increase in log research funding is:

(5) $\Delta f_{jt}^* = 1$

and our object of interest, the increase in log output is:

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[11] Card (1998), Heckman (1997), Marschak and Andrews (1944).

$$(6)\ \Delta y_{jt}^* = a + b\,\{\partial x_{jt}^* / \partial w_{jt} + \theta \partial x_{jt}^* / \partial \underline{r}_{jt}\}\{\partial f_{jt}^* / \partial w_{jt} + \theta \partial f_{jt}^* / \partial \underline{r}_{jt}\}^{-1}$$

(6) is the formula for the percentage change in research output induced by increasing w_{jt} by Δw_{jt} such that the school is also induced to buy an additional unit of f_{jt}. There are two effects in (6). The first term on the right hand side of (6) is the effect on research output due to a 1% increase in research funding induced by Δw_{jt}. The second term on the right hand side of (6) is the effect on research output due to the change in other input induced by Δw_{jt}. This last term allows for a cross price elasticity effect as well as an own price elasticity effect which is induced by the correlation between the input prices.

To evaluate (6) further, we posit the following input demand system:

$$(7)\ f_{jt}^* = \alpha_w w_{jt} + \alpha_x \underline{r}_{jt} + \alpha_z z_{jt} = (\alpha_w + \theta\,\alpha_x)\, w_{jt} + \alpha_x r_{jt} + \alpha_z z_{jt} = \alpha_f w_{jt} + \alpha_x r_{jt} + \alpha_z z_{jt}$$

$$(8)\ x_{jt}^* = \beta_w w_{jt} + \beta_x \underline{r}_{jt} + \beta_z z_{jt} = (\beta_w + \theta\beta_x)\, w_{jt} + \beta_x r_{jt} + \beta_z z_{jt} = \beta_f w_{jt} + \beta_x r_{jt} + \beta_z z_{jt}$$

Thus, Δy_{jt}^* becomes:

$$(9)\ \Delta y^* = a + b\,\beta_f\,\alpha_f^{-1}$$

Using (7) and (8) to solve out w_{jt}:

$$(10)\ x_{jt}^* = \beta_f\,\alpha_f^{-1} f_{jt}^* + (\alpha_f \beta_x - \alpha_x \beta_f)\,\alpha_f^{-1} r_{jt} + (\alpha_f \beta_z - \alpha_z \beta_f)\,\alpha_f^{-1} z_{jt}$$

And, so, (3) may be rewritten as:

$$(11)\quad y_{jt}^* = \lambda f_{jt}^* + v_{jt} \text{ where}$$

$$\lambda = \Delta y^* = a + b\,\beta_f\,\alpha_f^{-1} \text{ and}$$

$$v_{jt} = b\,(\alpha_f \beta_x - \alpha_x \beta_f)\,\alpha_f^{-1} r_{jt} + b\,(\alpha_f (b^{-1} + \beta_z) - \alpha_z \beta_f)\,\alpha_f^{-1} z_{jt} + \underline{z}_{jt}$$

The plim of the OLS estimator of λ in (11), λ_{OLS}, is:

$$(12)\ \text{plim}\ \lambda_{OLS} = \text{plim}\ (\Sigma_{jt} f_{jt}^* y_{jt})(\Sigma_{jt} f_{jt}^* f_{jt}^*)^{-1}$$

[12] It is important to allow for correlated shadow prices because Connolly (1997) finds a positive relationship between internal and external funding and Payne (1998) finds a positive relationship between private donations and government grants.

$= a + b\, \beta_f\, \alpha_f^{\,-1} + \text{cov}(\, f_{jt}^{\,*}\, , v_{jt}\,)[\text{var}(\, f_{jt}^{\,*}\,)]^{-1}$

$= a + b\, \beta_f\, \alpha_f^{\,-1} + b\{(\alpha_f\, \beta_x - \alpha_x\, \beta_f)\alpha_x\, \text{var}(r_{jt}) + (\alpha_f\, (b^{-1}+\beta_z) - \alpha_z\, \beta_f)\, \alpha_z\, \text{var}(z_{jt})\}[\alpha_f\, \text{var}(\, f_{jt}^{\,*}\,)]^{-1}$

λ_{OLS} is an inconsistent estimator of a or Δy^*.

Consider a vector Q_{jt} which is correlated with w_{jt}, and uncorrelated with r_{jt}, $\underline{z}_{jt}$ or z_{jt}. As a consequence, Q_{jt} is correlated with $f_{jt}^{\,*}$ and uncorrelated with v_{jt} in (11). Let Q_{jt} be an instrument for $f_{jt}^{\,*}$. Since Q_{jt} satisfies the standard properties of an instrument in (11), the plim of the instrumental variable estimator for λ, λ_{IV}, is:

(13) $\text{plim}\ \lambda_{IV} = a + b\, \beta_f\, \alpha_f^{\,-1} = \Delta y^*$

Thus, (13) implies that λ_{IV} estimates:

> C. λ_{IV} estimates the change in log output when school buys an additional unit of log funding due to a change in the shadow price of funding.

Equation (13) applies even when productivity shocks are partially observed before input decisions are made, i.e. $\text{var}(z_{jt}) \neq 0$ and when the input shadow prices are correlated, i.e. $\theta \neq 0$.[13] That is, we allow the instrument to be correlated with the other input shadow price. Using (12) and (13), the relationship between λ_{IV} and λ_{OLS} is:

(14) $\Delta\lambda = \text{plim}\ \lambda_{IV} - \text{plim}\ \lambda_{OLS}$

$= b\{(\, \alpha_x\, \beta_f\, - \alpha_f\, \beta_x\,)\, \alpha_x\, \text{var}(r_{jt}) + (\alpha_z\, \beta_f\, - \alpha_f\, (b^{-1} + \beta_z))\, \alpha_z\, \text{var}(z_{jt})\}[\alpha_f\, \text{var}(\, f_{jt}^{\,*}\,)]^{-1}$

It is difficult to interpret the determinants of the sign of $\Delta\lambda$. Consider the special case where θ equal 0, there is no correlation between the shadow prices of inputs, and $\text{var}(z_{jt}) \approx 0$, the pre-observed productivity shocks are small. $\Delta\lambda$ then becomes:

(15) $\Delta\lambda = b\{(\, \alpha_x\, \beta_f\, - \alpha_f\, \beta_x\,)\, \alpha_x\, \text{var}(r_{jt})\}[\alpha_f\, \text{var}(\, f_{jt}^{\,*}\,)]^{-1}$

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[13] Olley and Pakes (1996) also consider the case of partially observed productivity shocks without time varying shadow input prices.

In this case, $\beta_f = \beta_w$ and $\alpha_f = \alpha_w$. Convexity of the profit function implies ($\alpha_x \beta_f - \alpha_f \beta_x$) and α_f are both negative. Thus, the sign of $\Delta\lambda$ depends on the sign of α_x, the cross price elasticity for input f_{jt}. The sign of α_x is the same as the sign of β_f , the cross price elasticity for input x_{jt}. If α_x (β_f) is positive, the substitution effect dominates the output effect due to an increase in r_{jt} (w_{jt}) and $\Delta\lambda$ is positive.[14] The reverse is true when α_x (β_f) is negative. The profit function also implies β_f has the same sign as α_x. So when $\Delta\lambda > 0$, $a >$ plim $\lambda_{IV} >$ plim λ_{OLS}. Then, λ_{IV} provides a lower bound estimate of a, the marginal product of federal funding. On the other hand, when $\Delta\lambda < 0$, $a <$ plim $\lambda_{IV} <$ plim λ_{OLS} and λ_{IV} provides an upper bound measure of a.

Finally, if (11) is not log-linear, we argue by analogy that:

> D. λ_{IV} estimates the change in measured outcome when a school buys an additional unit of the measured input due to a change in the shadow price of the measured input.

II Congress and Federal R&D Funding of Universities

To implement the IV estimator, we need instruments that are correlated with the shadow price of federal research funding and uncorrelated with other independent shadow prices and productivity shocks that affect a university. Potentially, alumni representation on congressional appropriations committees is an instrument. In 1995, approximately 14 percent of total federal discretionary spending went towards research funding. As a proportion of total discretionary spending, R&D funding rose from 11.5 percent in 1980 to 13.3 percent in 1998 (NSF (1998)). Discretionary spending provides opportunities for Congress to channel funds to particular schools. Below we discuss the role of the congressional appropriations committees with respect to the federal government budget and our construction of instruments to reflect this role.

[14] Recent IV estimates of the return to schooling typically exceed the OLS estimates (Card (1998)). Our framework provides a new explanation of that finding.

Congress plays several roles in funding research. The most prominent role is that of appropriations (Kleinman (1995)). Both chambers have an appropriation committee responsible for establishing the budget and allocating discretionary funds. Although the appropriations bill must be approved by the entire Congress and signed by the President, members on the appropriations committees have substantial power in establishing the budget.[15] In addition to widespread anecdotal evidence, there is also systematic evidence that individual Congress members do influence budget allocations (e.g. Hird (1991), and Rich (1989)).

The appropriations bills fund government agencies and may also "earmark" money to be used for a special purpose. Since 1983, earmarking has played a significant role in allocating funds to universities. Currently, more than five percent of research funding to universities is through earmarked funds; in 1998, Congress passed spending measures that included more than $495 million earmarked projects (Chronicle of Higher Education (1998)). Earmarking provides additional opportunities for members of the appropriations committees to fund specific schools.

If members have emotional and political ties to their alma maters, we expect schools with alumni representation on the committees to receive disproportionately more funds than when there is no alumni representation. In other words, when an alumni member is appointed to an appropriations committee, the shadow price of federal research funding falls. The timing of a member's appointment on the appropriations committee is not determined by attributes of the member's alma mater. That is, the fall in the shadow price of funding induced by a member's appointment is not caused by changes in other shadow prices or productivity shocks that the

[15] In practice, the President submits a proposed budget to Congress. The House appropriations committee reviews and changes the proposed budget and then submits it for review by the Senate appropriations committee. The Senate committee plays a role similar to that of an appeals board. Once both chambers approve the budget it is then presented to the President for his approval.

school faces. Thus, alumni representation on the appropriations committee is arguably a valid instrument for federal research funding to a school.

To that end, we collected data on congressional membership on the appropriations committee for both chambers of Congress for the period 1970 to 1996. Except for the occurrence of a death or resignation, both committees may change members every two years.[16] For each member that served on the appropriations committee during this period, we identified the state the member represents, the political party affiliation of the member, the member's position on the committee, and the undergraduate alma maters of the member. With respect to the member's position on the committee, there are three possible positions, majority and minority chair person and general member. The majority chair is assigned to a member affiliated with the political party that controls the chamber of Congress for which the members serve; the minority chair is assigned to a member affiliated with the political party not in control.

With the congressional data, we created six measures, three for each chamber of Congress. All of the measures indicate for a given institution whether there are members who received an undergraduate degree from the university studied. The first two measures are dummy variables to indicate whether the member is the majority or minority chair of the appropriations committee. The third measure indicates the number of general members on the committee. For a school, the number of general members on the committee ranges from 0 to 3; the average over the universities studied is less than .5 for both chambers.

Because we include year and university fixed effects in all specifications, the above six measures, when used to explain government funding, will have explanatory power only when

[16] There are elections for both chambers every two years. In the House, all members must be elected or re-elected every two years. In the Senate, one-third of the members are elected or re-elected every two years since a given member holds office for six years.

there is a change in one of the six measures for a school in the sample under analysis. In other words, the average level of representation in a school is not exploited in the analysis.

There are 71 research or doctoral universities that experience at least one change in representation over the period 1972-1994. The average length in which a school experiences no change in any of the six congressional dummy variables we use is 7.2 years. Put another way, ignoring year effects, our predicted funding for a school keeps the same value for an average of 7.2 years. They change an average of 3.73 times per school over the period studied.

Results from regressing annual federal research expenditures on the congressional variables for the period 1973-1994 are presented in Table 1. The data are discussed in detail in the next section. There are 71 research or doctoral institutions and an average of 17.5 years of data for each school. There is a two year lag between research funding and the congressional variables. The last two columns of Table 1 indicate for each measure the number of changes and the number of schools with a change for each measure.

Overall, the F-tests show the congressional variables, as a group, have significant explanatory power in all regressions. Results are weaker for the log of expenditures. Across specifications, the most consistent and significant results are the estimates of having alumni as general members of the House appropriations committee. In the levels specification, the general member on the House committee increases expenditures by about $2.5 million per year. In logs, evaluated at the mean, it increases expenditures by 5.1% or $2.9 million. Since there are more general members on the house appropriations committee than other kinds of members, a lower bound estimate of the annual value of having alumni representation on the congressional appropriation committees is $2.5 million.[17]

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[17] This value ignores the cost to the school of obtaining these extra funds.

III Other Data

The other key data sources are: CASPAR data on federal funding and institutional characteristics, Institute for Scientific Information data on articles published and citations to articles published, and Chi Research data on patents issued to universities.

Funded by the National Science Foundation (NSF), CASPAR is a compendium of data sources on higher educational institutions.[18] Data from this source are at the institutional and academic discipline level and are available on a yearly basis from as far back as 1972. The schools are classified under the Carnegie (1994) classification scheme. We have selected those schools for which the classification is research or doctoral university.[19] This selection covers 222 institutions. For the period under analysis, there are 71 universities with changes in their alumni representation on the congressional appropriations committee.

Table 2 reports the distribution of schools by Carnegie code and ownership status (private or public) for the entire sample (columns 1 and 2) and for the schools analyzed in this paper (columns 3 and 4). The majority of the schools are classified as Research I schools, which are those considered to be the most research intensive. Of the schools studied in this paper, 62 percent of the schools are Research I. With respect to the distribution between public and private schools, over 60 percent of the schools are public universities. Table A1 in the Appendix provides a list of the schools and the number of years for which CASPAR data exists.

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[18] An overview of the data can be found at their web site, "www.caspar.nsf.gov".

[19] Research universities are defined as those that offer a full range of baccalaureate programs, are committed to graduate education through the doctorate, and give high priority to research, awarding at least 50 doctoral degrees each year. Doctoral schools differ from Research schools in that they do not meet minimum requirements with respect to federal support and they may award fewer doctorate degrees. The Research and Doctoral schools are further divided into classes I and II. Research I differs from Research II in that Research I schools receive more than $40 million annually in federal support. Doctoral I differs from Doctoral II in that Doctoral I schools must offer at least 40 doctoral degrees in at least five disciplines; Doctoral II schools must award 20 or more doctorate degrees in at least one discipline or more than 10 degrees in at least three disciplines.

The data we gathered from CASPAR for this study cover the following measures at the institutional level for the period between 1972 and 1994: federal research expenditures, federal obligations for research in science and engineering, federal contracts, number of faculty, and faculty salary. The number of faculty and faculty salary data are missing for all schools for 1974, 1984, 1987, and 1989. With respect to number of faculty, for the analyses we undertake using this measure we have estimated the missing faculty data by taking the average of the data for the year prior and year subsequent to the missing year.

Table 3 reports the means, standard error, minimum, and maximum of the key measures from the CASPAR data set. Columns 1 through 4 report the summary measures for all data on the research and doctoral universities; columns 5 through 8 report the summary measures for the universities studied. All dollars are reported in real dollars with 1993 as the base year. Overall, the measures for the universities studied are higher than the measures for all universities. For example, the average total R&D expenditures from the federal government and other sources for the universities studied is $89 million; the average for all universities is $53 million.[20] Average annual federal R&D expenditures for the universities studied is $56 million and ranges between $36,000 and $426 million. Federal R&D expenditures represent, on average, 62 percent of total R&D expenditures. The average expenditure per faculty is $56,000 with a minimum of less than $1,000 and a maximum of $414,000. Average total faculty salary is $49 million, ranging from $11 to $211 million. Average salary per faculty is $49,944 and ranges from $34,518 to $80,968.

Data on articles published and citations to articles are provided by the Institute for Scientific Information. For each year from 1981 to 1994, we use data at the institutional level

[20] Total R&D expenditures is the sum of expenditures from the federal government, state and local government, private industry, the university, and other miscellaneous sources.

for papers published during that year for all disciplines.[21] The articles published are measured from a set of approximately 4,800 journals. These data are reported only for the most prolific universities. There are 35 universities that have congressional representation and data on articles published. Over 90 percent of the schools are Research I universities with more public than private universities. Table 4 reports the summary measures for the articles published and citations to articles published per year. The average number of articles published per school-year is 1,761 with an average per faculty member of 1.5.

The citations per article are the total number of citations to articles published in a particular year, accumulated to 1994, divided by the number of articles published in that year. Thus, the number of citations per article in earlier years will be higher on average than the number of citations per article near the end of the sample period; the year fixed effects should control for this difference. Within sample, the average number of citations per article is 14.3.

Data on patents cover the period 1975 to 1994 and are provided by Chi Research, Inc. The data report for 58 of the universities with congressional representation the number of patents issued to the university on an annual basis.[22] The average number of patents issued per school-year is 5.8, ranging from 0 to 128 patents per year. This measure of output has two significant problems. First, prior to the enactment of the Bayh-Dole Act of 1980 by Congress, patents could

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[21] For some of the article and citation counts the name of the school represents the school system and not a particular campus. To address this issue we did the following: if the system for which the school is attributed has only one major research university then the full value of the measure is attributed to that university. If, however, there is more than one major research university affiliated with the system, then we use the rankings of the National Research Council to weight the measures across the research universities in the system. This occurred with two systems, however, only one system is used in our analysis, the University of Alabama.

[22] For some of the patent the name of the school represents the school system and not a particular campus. As with the articles data, we followed the same methods to address this issue (see previous footnote). For the patent data, the problem occurred with ten systems; only five systems are used in our analysis: University of Alabama, University of California, University of Maryland, University of Texas, and University of Wisconsin.

not be issued to universities for federally funding research. In practice, this often encouraged scientists to have two lines of parallel research, one that was federally funded and one that was not, thereby allowing for patents to be issued for the non-federally funded research. With the enactment of the Bayh-Dole Act, federally funded research is now eligible for patents. To correct this potential problem in our analysis, we have analyzed the data for the entire period as well as restrict the analysis to the period subsequent to 1980.

The second problem concerns the incentives set up by the universities with respect to the distribution of benefits resulting from patents issued to the university. Historically, universities were not generous in rewarding its scientists for university owned patents. So scientists had an incentive to establish entities separate from the university and seek the issuance of patents outside of the university. The measure of patents issued to a university is underreported more severely at those universities with low distributions of benefits. Many universities have changed the distribution agreements to encourage scientists to seek patents through the university. We have been unable to identify those universities that undertook this change.

Panels A through F of Figure 3 report the four output measures and number of faculty per year. Articles published have increased over the period studied with a slight dip in the early 1980s. Patents appear to reflect, in part, the two issues raised above with respect to the restrictions on federally funded research and the distribution policies of universities. The average number of patents issued is fairly flat until the early 1980s and then they gradually increase.

IV Results

In all our outcome regressions, we include school and year effects. We will present results by OLS and IV. As explained in Section I, a change in the shadow price of federal funding affects other inputs. Without other exogenous measures to explain the other inputs, including them in the regression is inappropriate.

Our empirical framework assumes that all changes in the shadow price of federally funded research of the same magnitude, independent of its source, will result in the same changes in outcomes. If the funded grants are heterogeneous, this assumption may not be valid. For example, assume all grants funded by federal granting agencies are the same ex-ante. Due to the noisy screening process, some rejected grant applications may be of the same expected quality as those funded. Congressional representation means a qualified application from the represented school has a lower probability of being rejected. All funded grants, regardless of congressional intervention, produce the same expected outcomes. In this case, our instrumental variable estimator estimates the average outcome due to a fall in the shadow price of funding.

At the other extreme, assume funded grants are not alike ex-ante. The first grant to be funded is of higher expected quality than the last grant to be funded. Congressional representation may induce a lower standard for a grant application to receive funding. In this case, our instrumental variable estimator provides a lower bound estimate of the average outcome due to a fall in the shadow price of federal funding.

To be conservative, we will use the first interpretation of our estimator, that it provides an estimate of the average outcome due to a fall in the shadow price of funding. If funded grants are ex-ante heterogeneous, our estimator underestimates the average outcome.

Because the appropriate functional form for (11) is not known apriori, we report results using four linear specifications: levels, level with a control for faculty size, levels per faculty and logs.[23] If a particular functional form is inadequate, higher order funding will be incorporated in the error term of that regression. These higher order terms will be correlated with our instruments since our instruments change the shadow price of research funding. As such, the IV estimator would be inconsistent. We use an over-identification (over-id) test as a means to determine which empirical specification approximates the true specification. The over-id test tests the exogeneity of the instruments in the second stage regression. A high p-value suggests the instruments belong in the first stage regression but not the second stage regression, permitting us to estimate the effect of a change in the shadow price of funding on output. Thus, we will use a high p-value as an indication of the appropriate specification.

When interpreting the qualitative differences in estimates obtained by λ_{OLS} versus λ_{IV}, we assume that var(z_{jt}) and θ are both approximately zero. Otherwise, the differences do not have simple interpretations.

In principle, the specification of lag structures should be an important concern in this paper because of the lags between funding measures and research outcomes such as publication and patent counts. In practice, because our predicted funding measure, attributable to changes in congressional representation, changes so infrequently, different lag structures have little effect on our IV estimates. We report the lag lengths that generate the smallest standard errors.

A. Effect of Federal Funding on Faculty Salary

The first outcome measure we consider is faculty salary. Professors have to expend resources to obtain federal research funding and, thus, it is important to study their pecuniary benefit from doing so.[24] The number of faculty who receive some form of federal funding at universities is on the order of 50 percent (NSF (1998)). Federal research funding may increase salaries directly if federal grants award stipends as well as indirectly if universities reward faculty members who bring in more grants.

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[23] We assume faculty size is exogenous.

In these regressions, we have 71 schools and an average of 17.4 years of data for each school. We lag federal expenditures by one year and the instruments by three years. Tables 5 and 6 report the results from the levels and log specifications for OLS and IV, respectively. The first stage regressions are reported in Table 1. For all specifications, the IV estimate of λ is larger than the OLS estimate. The over-id test is not significant only in column 2, the specification that includes the number of faculty as a separate regressor.

In column 2, the IV estimate on expenditures is about twice the OLS estimate suggesting the cross elasticity of demand is positive. As the shadow price of research funding increases, demand for it falls causing a direct negative impact on salaries. Faculty members mitigate this effect by seeking more of the other inputs. The IV estimate on expenditures suggests a one million dollar increase in federal funding will increase total salaries by more than $150,000. On average, professors capture 15% of the federal funds they bring into the university. Due to caps on research stipends, large grants are likely to have lower pecuniary returns than smaller grants.

The IV estimate of the coefficient on the number of faculty suggests the marginal faculty member earns $61,740, an amount higher than the average faculty salary of $50,000 reported in Table 3. In terms of its effect on total salaries, the marginal faculty member is closer to a senior professor approaching retirement than a potential new assistant professor.

B. Effect of Funding on Articles Published

Tables 7 and 8 report the OLS and IV results when the number of articles published is used as the outcome measure. This is a traditional measure of research output that universities and the funding agencies care about. The analysis of this output measure covers 35 universities and 490 observations, representing 14 years of data for each university. For all specifications,

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[24] Siow (1998) considers the general problem of incentives in academia.

we lag government expenditures by one year and the instruments by three years. The results from the first stage regressions are reported in Table B1 in the Appendix.

Columns 3 and 4 are the two specifications for which the over-id test is satisfied. In column 4, the specification reports the regression of the number of articles per faculty member on the federal expenditures per faculty member. The OLS estimate suggests an additional 7.9 articles are published for each additional $1 million in federal funding whereas the IV estimate suggests an additional 12 articles are published. In Column 3, under a log specification the results suggest a one percent increase in federal funding will increase articles published by .043 percent under the OLS specification and .199 percent under the IV specification.

On the whole, the results in Table 8 suggest the effect of federal funding on articles published is higher than the OLS results. When producing articles, universities substitute toward other inputs if the shadow price of federal funds increase. If we use the specification in column 4, the IV coefficient of 12 implies an elasticity number of articles to funding of 0.38 which is within twice the standard error of the log estimate.

C. Effect of Federal Funding on Citations to Articles Published

In this section, we use citations per article as the outcome variable. It provides a measure of the quality of the articles published. As discussed in the data section, citations per article are the total number of citations to an article published, accumulated to 1994. We use year fixed effects to control for the difference in the number of years covered in the citation counts.

Tables 9 and 10 report the coefficients on federal expenditures for the citations outcome measure. Unlike the other outcome measures, the coefficient on federal funding is negative for the levels specifications. The coefficients across all specifications are statistically significant. The over-id test is not rejected in any of the specifications; it is strongest, however, for columns

3 and 4. Taking the logs specification first (column 3), the IV estimates that the elasticity of citations with respect to funding is .273. This estimate, along with the point estimate with respect to the number of articles published, suggest that both the quantity and quality of research improves as the shadow price of federal research funding falls.

The specification in column 4 uses the per faculty measures in the regression. The number of citations per article falls when a school obtains more research funding by -.08. It suggests that on average the number of citations to an article falls by something much less than one, which given the average number of citations per article is roughly 15, suggests a negligible effect. These results, combined with the results under the log specification, suggest the tentative conclusion that when the shadow price of federal funding falls, a school produces more articles without significant quality change.

D. The Effect of Federal Funding on Patents

Patents are another measure of research output. Patentable research consists mainly of applied research in the sciences. A university also conducts non-patentable research such as basic research in the sciences, social sciences and humanities disciplines. Since non-patentable research also receives federal research support, our estimates of the impact of total federal research support on patent counts underestimate the efficacy of federal funds in producing patents.

Tables 11 and 12 report the results under the OLS and IV specifications. As discussed earlier, the patent measure contains many zeros. Following Bound et al. (1984) and Pakes and Griliches (1984) in their work on patent counts in for profit firms, we do two things in our log linear specification. First, we assign the log value for zero as zero and, second, we create a dummy variable equal to one if the number of patents is zero. We also report the results under the same three levels specification as used with the other types of research outcomes. In all specifications, we lag the government funding measure by three years. In addition, we lag the congressional measures by six years. Given the process for getting a patent is lengthy we use a specification to reflect this length. We tried other lag lengths and obtained similar results.

In all specifications, the IV estimates are positive and larger than the OLS estimates. In all four cases, the over-id test is not rejected. The levels estimates suggests that a $1 million increase in federal funding would increase the number of patents by .44. The IV coefficient in Column 4, using the per faculty specification, is lower than the coefficient reported in Column 1, suggesting an increase of .34 patent for every additional $1 million in federal funding.

Column 3 reports the results under the modified log specification. The IV coefficient is 1.37 and statistically significant. A one percent increase in federal funding will increase patents by more than 1 percent. Using the same functional form, estimated elasticities of the number of patents issued with respect to research expenditure range from .37 to .61 (Bound et al., Pakes and Griliches).[25] Since the shadow price of federal research funding to society is approximately $1, the returns, as measured by patent counts, to federal research funding of universities are comparable to the returns to research expenditure in the private sector.[26]

Because of the problem of zeros in the patent data, Tables 13 and 14 analyze the data under a fixed effects Tobit specification.[27] The coefficients in the Tobit IV specification are more positive than those in Table 12. Using the per faculty specification, the coefficient is .506

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[25] Two differences should be noted. First, the specifications differ insofar as the period analyzed and controls used for heterogeneity. Second, our results control for other inputs through the use of the IV specification. In fact our results suggest that their estimates underestimate the true impact.

[26] The social cost of federal funds exceeds $1 because the university has to expend resources to obtain those funds. On the other hand, since not all federal funds are applied to producing patents, this effect will underestimate the returns.

suggesting an additional $2 million in funding will increase the number of patents issued by one. Overall, the results across all of the tables in which patents are used as an outcome measure suggests an increase in federal funding positively impacts the production of patents.

F. Robustness Issues

In addition to the regressions reported above there are many other regressions we could and have run. We will discuss some of these other regressions below. In general, however, we have found the results to be quite robust.

One question is what would happen if we used total R&D expenditures as our measure of funding instead of federal R&D expenditures. The primary reason we did not use total expenditures is that we have focused on the effect of federal funding on research output. Given, however, that federal expenditures represent a large portion of total expenditures, we would not expect there to be much difference in the results. And, in fact, the coefficients are very similar if this measure is used. The standard errors, however, tend to increase.

Another question is what happens if we use other measures for federal funding. We have tried two different measures. The first is federal R&D obligations to Science and Engineering. Federal obligations to science and engineering are committed dollars (e.g. awarded grants) for research in science and engineering. On average the dollars committed are slightly higher than the expenditures measure. Presumably the discrepancy between these two measures is from the method used to report the two measures since expenditures represent actual dollars spent in that year and obligations represent dollars committed which may be spent over a period of years. With this measure, the results are similar to those that use federal R&D expenditures.

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[27] We follow Amemiya (1979) to compute the variance-covariance matrix in a two equation model where one endogenous variable is completely observed and the other truncated. Honore (1994) provides another method computing these errors under more relaxed assumptions concerning the distribution of the data.

The second measure is the funds received under federal contracts. Federal contracts represent the dollars received for work performed for the federal government. On average, the dollars received from contracts is higher than those received for research. Federal contracts are different from the federal R&D expenditures in that under a contract a researcher is expected to produce very specific work whereas with a research grant the researcher has latitude over her research projects.

Tables 15 and 16 report the results for our four output measures using federal contracts as our federal funding measure. For the articles, citations, and patents we use the per faculty specification and for the salaries we use the specification that includes the number of faculty as an exogenous regressor. With the exception of the citations measure, the coefficients on the federal contracts measure are positive and significant under both the OLS and IV specifications. The F-tests on the instruments in the first stage regressions are similar to those reported for the regressions using federal R&D expenditures. The coefficients for all of the outputs tend to be smaller than those reported using the federal R&D expenditures as the federal funding measure. This suggests that research output benefits more from federal research grants than from federal contracts, a not too surprising result.

A final issue concerns the potential aggregation of data and whether annual measures are the proper unit of measurement for the effect of funding on research output. We ran the regressions for data that were aggregated over a two-year period. As discussed earlier, since congressional representation changes infrequently, the results are very similar to those reported earlier.

V Conclusion

There are many micro panel studies that have improved our understanding of the effect of R&D expenditures on outcomes in profit seeking firms.[28] Two related and unresolved problems in this literature are endogeneity and omitted variable bias. Griliches and Mairesse (1997) have concluded: "The challenge is to find (instrumental variables) that have genuine information about factors which affect firms differentially as they choose their input levels". Our paper is an attempt in that direction.

Federal R&D funding to universities has risen substantially. Our results show that this funding has large measurable short run effects on universities. Universities are not passive institutions. They use less federal funds and substitute towards other inputs when the shadow price of these funds rises. As a first approximation, when the shadow price of federal research funds falls, universities produce more research without a significant change in its quality. When we use patent counts as our outcome measure, our results suggest that the return to federal R&D funding of universities is quantitatively comparable to R&D expenditure in the private sector.

[28] E.g. Griliches and Mairesse (1984), Hall (1993), Mairesse and Hall (1996), Bound et. al. (1984), Pakes and Griliches (1984) and Pakes (1985). A good summary may be found in Griliches (1998).

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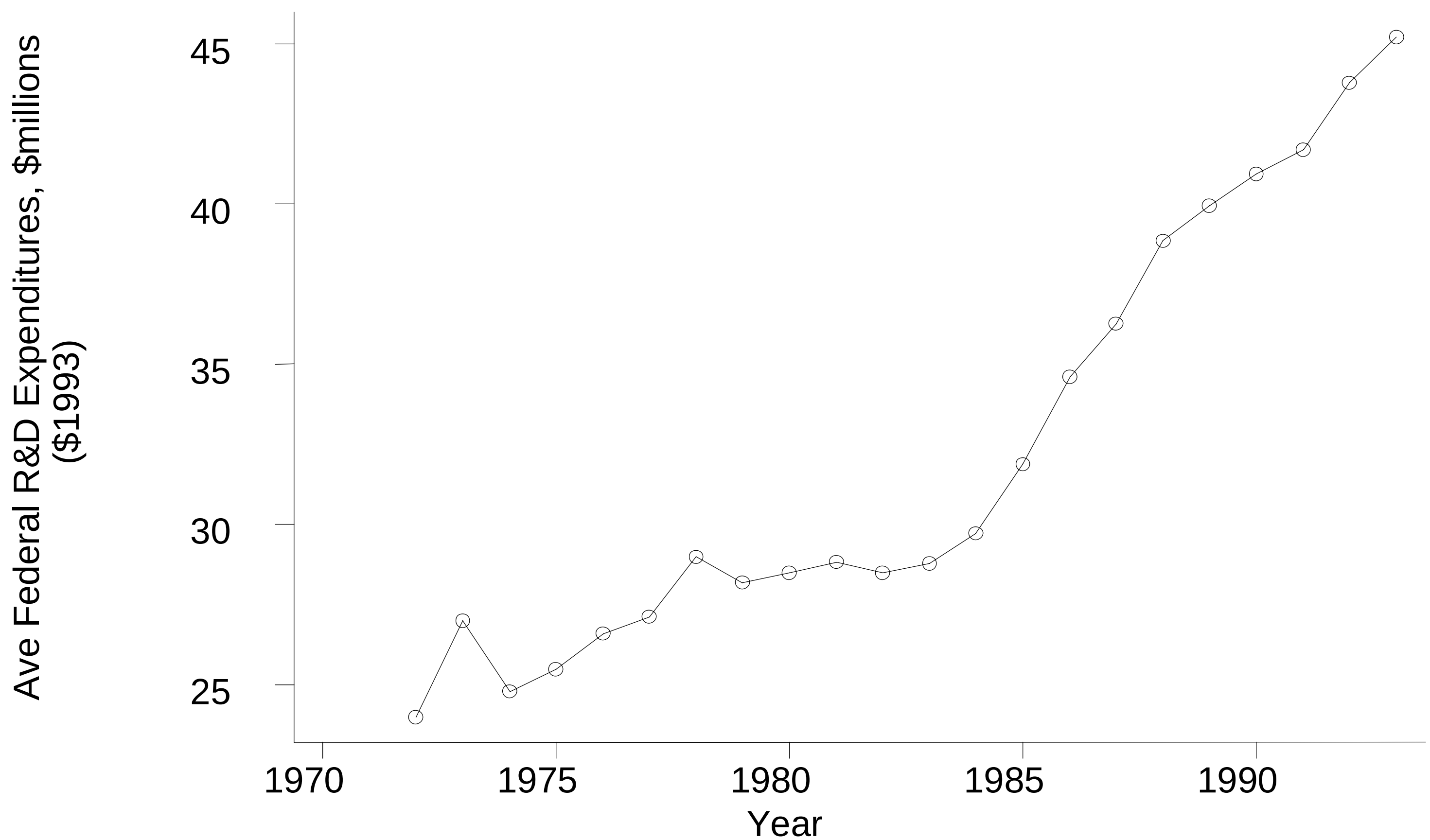
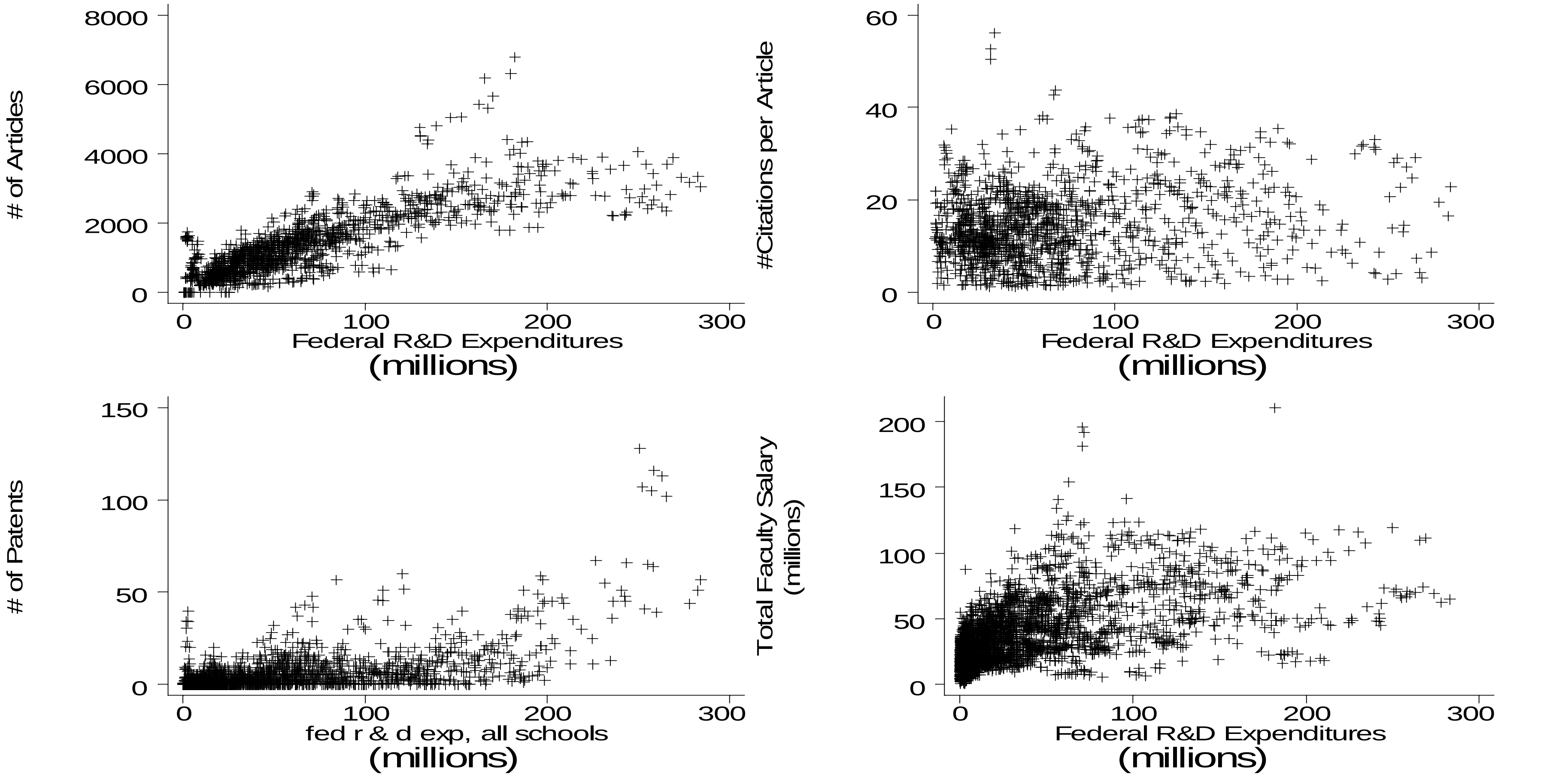
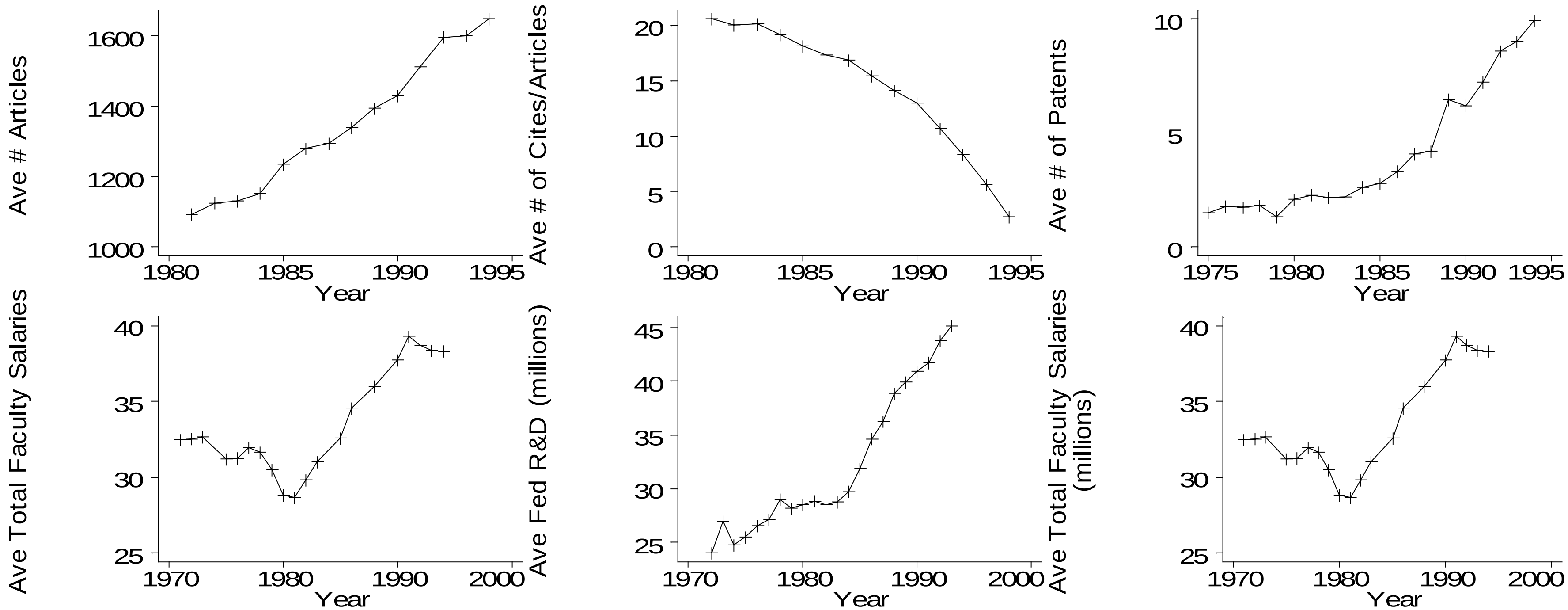

Ave Federal R&D Expenditures, $millions
($1993)
45
40
35
30
25
1970
1975
1980
1985
1990
Year

Figure 1



8000
6000
4000
2000
0
# of Articles
0
100
200
300
Federal R&D Expenditures
(millions)
60
40
20
0
#Citations per Article
0
100
200
300
Federal R&D Expenditures
(millions)
150
100
50
0
# of Patents
0
100
200
300
fed r & d exp, all schools
(millions)
200
150
100
50
0
Total Faculty Salary
(millions)
0
100
200
300
Federal R&D Expenditures
(millions)

Figure 2


Ave # Articles
1000
1200
1400
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Year
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Ave Total Faculty Salaries (millions)
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Figure 3

Table 1: Impact of Congress Members' Alma Maters on Federal Funding

Dependent Variable Fed R&D Expenditures	Levels	Levels	Log	Per Faculty Member	# of Changes	# of Schools w/ Changes
Majority Senate Leader on Appropriations Comm.	-1.884 (6.457)	-1.795 (6.351)	-0.061 (0.076)	0.000 (0.004)	11	6
Minority Senate Leader on Appropriations Comm.	**32.572** (13.240)	**32.980** (13.403)	**-0.092** (0.044)	**0.048** (0.017)	5	3
# of Senate General Members on Appropriations Comm.	0.133 (1.033)	0.274 (1.032)	-0.002 (0.020)	0.001 (0.001)	78	37
Majority House Leader on Appropriations Comm.	**-10.263** (2.933)	**-10.207** (2.909)	-0.027 (0.087)	**-0.007** (0.003)	1	1
Minority House Leader on Appropriations Comm.	**-9.926** (3.851)	**-10.103** (3.893)	**-0.205** (0.085)	**-0.011** (0.004)	3	2
# of House General Members on Appropriations Comm.	**2.584** (0.903)	**2.379** (0.896)	**0.051** (0.021)	0.000 (0.001)	116	51
Number of Faculty		**0.010** (0.005)				
F-test on Instruments (p-value)	8.130 (0.000)	7.710 (0.000)	4.220 (0.000)	3.800 (0.001)		
Lag on Instruments	2years	2years	2years	2years		
School & Year Fixed Effects	yes	Yes	yes	yes		
R-Square	0.955	0.955	0.966	0.943		
Number of Observations	1239	1239	1239	1239		
Number of Schools	71	71	71	71		

Note: White corrected standard errors in parentheses unless otherwise noted. Coefficients in bold are significant less than a p-value of .05. All regressions included school and year fixed effects. The last two columns represent the number of changes on the appropriation committees during the period studied. A change may be from on to off of the committee (and vice versa) or a change in membership type (e.g. from general committee to majority leader).

Table 2: Distribution of Universities By Carnegie Classification

	All Data		Analyzed Data	
Carnegie Code	Private	Public	Private	Public
Research I	30	58	16	28
Research II	9	37	3	10
Doctoral I	21	28	6	2
Doctoral II	17	32	1	5
Total	77	145	26	45

Table 3: Summary Statistics of Government Funding, Faculty Salary, and Market Endowment

	All Data				Analyzed Data			
	Number of Obs	Mean (Std Err)	Minimum	Maximum	Number of Obs	Mean (Std Err)	Minimum	Maximum
Total R&D Expenditures (millions of dollars)	4839	52.908 (0.978)	0.042	425.868	1606	88.665 (2.103)	0.163	425.868
Federal R&D Expenditures (millions of dollars)	4888	32.927 (0.669)	0.001	284.080	1606	56.001 (1.473)	0.036	284.080
Federal R&D Expenditures Per Faculty Member	4888	0.046 (0.001)	0.000	0.922	1606	0.056 (0.001)	0.000	0.414
Federal R&D Obligations Science & Engineering	4636	37.476 (0.764)	0.005	401.697	1619	63.646 (1.638)	0.051	401.697
Federal Contracts (millions of dollars)	4643	42.170 (0.801)	0.003	489.111	1612	69.170 (1.743)	0.888	489.111
Total Faculty Salary (millions of dollars)	3961	34.400 (0.383)	0.557	211.000	1239	48.602 (0.782)	11.460	210.611
Total Faculty Salary Per Faculty Member	3961	48,220.48 (125.585)	14,514.74	102,520.90	1239	49,944.02 (209.481)	34,517.85	80,967.78
Number of Faculty	5403	671.540 (5.874)	4.000	3,258.000	1690	929.668 (11.477)	147.000	3,258.000

Table 4: Summary Statistics for Articles Published, Citations per Articles, and Patents

	All Data				Analyzed Data			
	Number of Obs	Mean (Std Err)	Minimum	Maximum	Number of Obs	Mean (Std Err)	Minimum	Maximum
# of Articles Published	1462	1,344.746 (24.519)	0.000	6,802.000	490	1,761.410 (51.216)	297.000	6,802.000
# of Articles Published Per Faculty Member	1426	1.778 (0.055)	0.000	23.647	490	1.533 (0.041)	0.409	4.994
# of Citations per Articles Published	1420	14.426 (0.212)	1.235	56.230	490	14.334 (0.355)	1.262	38.630
# of Citations per Articles Published Per Faculty Member	1420	0.025 (0.001)	0.001	0.285	490	0.015 (0.000)	0.001	0.049
# of Patents	3105	3.895 (0.160)	0.000	128.000	1155	5.833 (0.373)	0.000	128.000
# of Patents Per Faculty Member	3105	0.005 (0.000)	0.000	0.229	1155	0.005 (0.000)	0.000	0.130

Table 5: Relationship Between Faculty Salary and Federal Funding, OLS

Dependent Variable: Total Faculty Salary	Levels	Levels	Log	Per Faculty Member
Federal R&D Expenditures	**120076.0**	**76591.0**	**0.034**	**28041.0**
(millions of dollars)	(21813.3)	(8723.0)	(0.013)	(9704.2)
Number of Faculty		**62490.6**		
		(2212.4)		
Lag on Government Funding	1 year	1 year	1 year	1 year
R-Square	0.929	0.986	0.967	0.871
Number of Observations	1239	1239	1239	1239
Number of Schools	71	71	71	71

Table 6: Relationship Between Faculty Salary and Federal Funding, IV

Dependent Variable Total Faculty Salary	Levels	Levels	Log	Per Faculty Member
Fed R&D Expenditures	**193261.0**	**152015.0**	0.041	**132150.0**
(millions of dollars)	(62719.0)	(27257.0)	(0.114)	(22143.5)
Number of Faculty		**61740.4**		
		(2245.6)		
F-test on Instruments	8.130	7.710	4.220	3.800
(p-value)	(0.000)	(0.000)	(0.032)	(0.000)
Over-Identification Test	2.367	0.901	4.117	3.883
(p-value)	(0.038)	(0.480)	(0.001)	(0.002)
Lag on Government Funding	1 year	1 year	1 year	1 year
Lag on Instruments	3 years	3 years	3 years	3 years
R-Square	0.928	0.985	0.967	0.843
Number of Observations	1239	1239	1239	1239
Number of Schools	71	71	71	71

Note: White corrected standard errors in parentheses unless otherwise noted. Coefficients in bold are significant less than a p-value of .05. All regressions included school and year fixed effects.

Table 7: Relationship Between Articles Published and Federal Funding, OLS

Dependent Variable # of Articles Published	Levels	Levels	Log	Per Faculty Member
Fed R&D Expenditures (millions of dollars)	**7.436** (0.540)	**6.903** (0.495)	0.043 (0.025)	**7.933** (0.995)
Number of Faculty		**0.351** (0.161)		
Lag on Government Funding	1 year	1 year	1 year	1 year
R-Square	0.987	0.988	0.994	0.983
Number of Observations	490	490	490	490
Number of Schools	35	35	35	35

Table 8: Relationship Between Articles Published and Federal Funding, IV

Dependent Variable # of Articles Published	Levels	Levels	Log	Per Faculty Member
Fed R&D Expenditures (millions of dollars)	**10.568** (3.870)	**10.261** (3.740)	0**.199** (0.101)	**12.024** (2.438)
Number of Faculty		**0.296** (0.154)		
F-test on Instruments (p-value)	5.750 (0.000)	5.440 (0.000)	7.310 (0.000)	3.220 (0.013)
Over-Identification Test (p-value)	5.122 (0.000)	4.573 (0.001)	0.437 (0.823)	1.468 (0.200)
Lag on Government Funding	1 year	1 year	1 year	1 year
Lag on Instruments	3 years	3 years	3 years	3 years
R-Square	0.986	0.987	0.992	0.980
Number of Observations	490	490	490	490
Number of Schools	35	35	35	35

Note: White corrected standard errors in parentheses unless otherwise noted. Coefficients in bold are significant less than a p-value of .05. All regressions included school and year fixed effects.

Table 9: Relationship Between Citations Per Article Published and Federal Funding, OLS

Dependent Variable: Citations to Articles Published	Levels	Levels	Log	Per Faculty Member
Federal R&D Expenditures (millions of dollars)	**-0.084** (0.009)	**-0.083** (0.009)	**0.055** (0.024)	**-0.068** (0.019)
Number of Faculty		**-0.000** (0.001)		
Lag on Government Funding	1 year	1 year	1 year	1 year
R-Square	0.931	0.931	0.988	0.901
Number of Observations	490	490	490	490
Number of Schools	35	35	35	35

Table 10: Relationship Between Citations Per Articles Published and Federal Funding, IV

Dependent Variable: Citations to Articles Published	Levels	Levels	Log	Per Faculty Member
Federal R&D Expenditures (millions of dollars)	**-0.202** (0.056)	**-0.200** (0.057)	**0.273** (0.126)	**-0.084** (0.049)
Number of Faculty		.002 (0.001)		
F-test on Instruments (p-value)	5.750 (0.000)	5.440 (0.000)	7.310 (0.000)	3.220 (0.013)
Over-Identification Test (p-value)	1.675 (0.140)	1.683 (0.138)	0.386 (0.858)	0.321 (0.900)
Lag on Government Funding	1 year	1 year	1 year	1 year
Lag on Instruments	3 years	3 years	3 years	3 years
R-Square	0.905	0.906	0.986	0.901
Number of Observations	490	490	490	490
Number of Schools	35	35	35	35

Note: White corrected standard errors in parentheses unless otherwise noted. Coefficients in bold are significant less than a p-value of .05. All regressions included school and year fixed effects.

Table 11: Relationship Between Patents and Federal Funding, OLS

Dependent Variable: # of Patents Received	Levels	Levels	Log	Per Faculty Member
Federal R&D Expenditures	**0.227**	**0.223**	0.036	**0.159**
(millions of dollars)	(0.021)	(0.021)	(0.056)	(0.019)
Number of Faculty		**0.004**		
		(0.003)		
Dummy = 1 if Patent =0			**-0.536**	
			(0.049)	
Lag on Government Funding	3 years	3 years	3 years	3 years
R-Square	0.809	0.810	0.802	0.818
Number of Observations	1155	1155	1155	1155
Number of Schools	58	58	58	58

Table 12: Relationship Between Patents and Federal Funding, IV

Dependent Variable # of Patents Received	Levels	Levels	Log	Per Faculty Member
Federal R&D Expenditures	**0.436**	**0.428**	**1.366**	**0.342**
(millions of dollars)	(0.075)	(0.075)	(0.438)	(0.075)
Number of Faculty		0.001		
		(0.003)		
Dummy = 1 if Patent =0			**-0.413**	
			(0.069)	
F-test on Instruments	10.590	9.610	7.250	6.180
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)
Over-Identification Test	0.708	0.706	1.445	1.014
(p-value)	(0.618)	(0.619)	(0.206)	(0.408)
Lag on Government Funding	3 years	3 years	3 years	3 years
Lag on Instruments	6 years	6 years	6 years	6 years
R-Square	0.773	0.756	0.723	0.782
Number of Observations	1155	1155	1155	1155
Number of Schools	58	58	58	58

Note: White corrected standard errors in parentheses unless otherwise noted. Coefficients in bold are significant less than a p-value of .05. All regressions included school and year fixed effects.

Table 13: Relationship Between Patents and Federal Funding, Tobit

Dependent Variable: # of Patents Received	Levels	Levels	Per Faculty Member
Federal R&D Expenditures (millions of dollars)	**0.215** (0.020)	**0.210** (0.020)	**0.164** (0.016)
Number of Faculty		0.002 (0.002)	
Lag on Government Funding	3 years	3 years	3 years
Number of Observations	1155	1155	1195
Number of Schools	58	58	58

Table 14: Relationship Between Patents and Federal Funding, IV Tobit

Dependent Variable # of Patents Received	Levels	Levels	Per Faculty Member
Federal R&D Expenditures (millions of dollars)	0.659 (0.449)	0.642 (0.462)	**0.506** (0.120)
Number of Faculty		-0.003 (2.90)	
Lag on Government Funding	3 years	3 years	3 years
Lag on Instruments	6 years	6 years	6 years
Number of Observations	1155	1155	1155
Number of Schools	58	58	58

Note: Standard errors in parentheses unless otherwise noted. Coefficients in bold are significant less than a p-value of .05. All regressions included school and year fixed effects.

Table 15: Relationship Between Research Output and Federal Contracts, OLS

Dependent Variable Per Faculty Specification	Articles	Citations	Patents	Salaries
Federal Contracts (millions of dollars)	**5.485** (0.651)	**-0.036** (0.012)	**0.069** (0.013)	**32908.0** (6867.0)
Lag on Government Funding	1 year	1 year	3 years	1 year
Specification	Per Faculty	Per Faculty	Per Faculty	# of Faculty Included
R-Square	0.983	0.899	0.812	0.986
Number of Observations	490	490	1188	1373
Number of Schools	35	35	60	71

Table 16: Relationship Between Research Output and Federal Contracts, IV

Dependent Variable Per Faculty Specification	Articles	Citations	Patents	Salaries
Federal Contracts (millions of dollars)	**6.591** (1.225)	**-0.042** (0.026)	**0.151** (0.033)	**57232.0** (14390.9)
F-test on Instruments (p-value)	3.280 (0.012)	3.280 (0.012)	5.530 (0.000)	5.530 (0.000)
Over-Identification Test (p-value)	0.916 (0.471)	0.418 (0.837)	1.139 (0.338)	2.653 (0.022)
Lag on Government Funding	1 year	1 year	3 years	1 year
Lag on Instruments	3 years	3 years	6 years	3 years
Specification	Per Faculty	Per Faculty	Per Faculty	# of Faculty Included
R-Square	0.983	0.899	0.789	0.978
Number of Observations	490	490	1189	1373
Number of Schools	35	35	60	71

Note: Standard errors in parentheses unless otherwise noted. Coefficients in bold are significant less than a p-value of .05. All regressions included school and year fixed effects.

Table A1: Research and Academic Institutions Analyzed

State	University	Congress Rep	Salary # years	Articles # years	Patent # years
Alabama	University of Alabama	3	18	11	17
Arizona	Arizona State University	3	19	11	17
	University of Arizona	2	19	0	17
California	San Diego State University	2	19	0	0
	Stanford University	3	17	11	17
	University of California-Berkeley	2	17	11	17
	University of California-Los Angeles	3	17	11	17
Colorado	University of Denver	2	19	0	17
	University of Colorado	1	19	0	17
Connecticut	Yale University	3	17	11	17
D.C.	American University	1	19	0	0
	Catholic University of America	2	19	0	17
	George Washington University	2	19	0	17
	Georgetown University	3	17	11	17
	Howard University	2	18	0	17
Florida	Florida State University	3	19	11	17
	University of Florida	3	19	11	17
Georgia	Emory University	1	18	0	17
	University of Georgia	3	19	11	17
Hawaii	University of Hawaii at Manoa	2	18	11	0
Iowa	Iowa State University	2	19	11	0
Idaho	University of Idaho	1	19	0	0
Illinois	Northwestern University	3	19	11	17
	University of Chicago	2	16	0	17
Indiana	University of Notre Dame	2	19	0	17
	Purdue University	3	19	11	17
Kansas	Kansas State University	2	19	0	17
Kentucky	University of Kentucky	3	19	11	17
Louisiana	Tulane University	2	19	0	17
Massachusetts	Boston College	2	19	0	17
	Harvard University	3	18	11	17
	Massachusetts Institute of Technology	3	19	11	17
Maryland	University of Maryland at College Park	3	19	11	17
Michigan	Michigan State University	2	19	0	17
	University of Michigan	1	19	0	17
Minnesota	University of Minnesota	1	19	0	0
Mississippi	Mississippi State University	2	19	0	17
	University of Mississippi	2	19	0	17
North Carolina	Duke University	1	10	0	17
	University of North Carolina at Chapel Hill	2	19	11	0
North Dakota	North Dakota State University	2	19	0	17
Nebraska	University of Nebraska at Lincoln	2	19	11	0
New Hampshire	University of New Hampshire	2	19	0	17

Note: Congress Rep indicates for which output measures the membership on the committee changes during the period analyzed. 1= Salary Only; 2=Salary and Patents Only; 3= Salary, Patent & Articles
The other measures indicates the number of years which we analyze.

Table A1: Continued

State	University	Congress Rep	Salary # years	Articles # years	Patent # years
New Jersey	Princeton University	3	19	11	17
New Mexico	University of New Mexico	3	19	11	17
New York	Columbia University	3	19	11	17
	Fordham University	1	19	0	0
	New York University	3	19	11	0
	Cornell University	3	19	11	17
	Syracuse University	3	19	11	17
Ohio	Cleveland State University	1	19	0	17
Oklahoma	Oklahoma State University	2	19	0	17
	University of Oklahoma	1	19	0	0
Oregon	Oregon State University	2	19	0	17
	University of Oregon	2	19	0	17
Pennsylvania	Pennsylvania State University	3	19	11	17
	University of Pittsburgh	2	19	0	17
South Carolina	University of South Carolina	1	19	0	17
Tennessee	Middle Tennessee State University	1	2	0	0
	Vanderbilt University	3	19	11	17
Texas	Southern Methodist University	2	19	0	17
	University of Houston	2	19	0	17
	University of Texas at Austin	3	19	11	17
	Baylor University	2	19	0	17
Utah	University of Utah	2	19	11	17
	Utah State University	3	19	11	17
Virginia	Virginia Polytechnic Institute	3	19	11	17
	College of William and Mary	2	19	0	0
Vermont	University of Vermont	3	19	11	17
Washington	University of Washington	3	19	11	17
Wisconsin	University of Wisconsin-Madison	3	19	11	17

Note: Congress Rep indicates for which output measures the membership on the committee changes during the period analyzed. 1= Salary Only; 2=Salary and Patents Only; 3= Salary, Patent & Articles The other measures indicates the number of years which we analyze.

Table A2: Research and Academic Institutions **Not** Analyzed

State	University	Congress Rep	Salary # years	Articles # years	Patent # years
Alaska	University of AK Fairbanks	1	16	0	0
Alabama	University of Alabama at Birmingham	1	19	11	17
	University of Alabama in Huntsville	0	19	11	0
	Auburn University	0	19	0	17
Arkansas	University of Arkansas, Main Campus	0	19	0	0
Arizona	Northern Arizona University	0	19	0	0
California	University of San Diego	0	2	0	0
	California Institute of Technology	0	19	11	17
	United States International University	0	1	0	1
	Claremont Graduate School	0	18	0	0
	Loma Linda University	0	12	0	11
	Pepperdine University	0	0	0	16
	University of California-Davis	0	17	11	17
	University of California-Irvine	0	17	11	17
	University of California-Riverside	0	17	11	17
	University of California-San Diego	0	17	11	17
	University of California-San Francisco	0	17	11	17
	University of California-Santa Barbara	0	17	11	17
	University of California-Santa Cruz	0	17	11	17
	University of San Francisco	0	15	0	0
	University of Southern California	1	18	10	16
	University of the Pacific	0	19	0	0
Colorado	Colorado School of Mines	0	19	0	0
	University of Northern Colorado	0	5	0	0
	Colorado State University	0	18	11	17
Connecticut	University of Connecticut	0	19	11	117
Delaware	University of Delaware	0	19	11	17
Florida	Florida Institute of Technology	0	19	0	0
	Florida Atlantic University	0	18	0	17
	Nova Southeastern University	0	19	0	0
	University of Miami	0	19	11	17
	University of South Florida	0	19	0	17
	University of Central Florida	0	18	0	17
	Florida International University	0	2	0	17
Georgia	Clark Atlanta University	0	18	0	0
	Georgia State University	0	19	0	17
	Georgia Institute of Technology	0	19	11	17
Iowa	University of Iowa	1	19	11	17
Idaho	Idaho State University	0	19	0	0
Illinois	De Paul University	0	19	0	0
	Illinois Institute of Technology	0	19	0	0
	Illinois State University	0	19	0	17
	Loyola University of Chicago	0	19	11	17
	Northern Illinois University	0	18	0	17
	Southern Illinois University-Carbondale	0	19	0	17
	University of Illinois at Urbana-Champaign	0	19	11	17
	University of Illinois at Chicago	0	19	11	17

Table A2: Continued

State	University	Congress Rep	Salary # years	Articles # years	Patent # years
Indiana	Ball State University	0	19	0	17
	Indiana State University	1	19	0	0
	Indiana University	1	19	0	0
Kansas	Wichita State University	0	19	0	17
	University of Kansas	0	19	11	17
Kentucky	University of Louisville	0	19	0	17
Louisiana	Louisiana Tech University	0	19	0	0
	University of New Orleans	0	9	0	17
	University of Southwestern Louisiana	0	14	0	17
	Louisiana State University	1	1	0	0
Massachusetts	Boston University	1	17	11	17
	Brandeis University	0	19	11	17
	Clark University	0	19	0	17
	University of Massachusetts Lowell	0	18	0	0
	Northeastern University	0	16	0	17
	Tufts University	0	19	11	17
	University of Massachusetts at Amherst	0	14	0	0
	Worcester Polytechnic Institute	0	19	0	17
Maryland	Johns Hopkins University	0	19	11	17
	University of Maryland Baltimore County	0	16	0	0
Maine	University of Maine	0	19	0	0
Michigan	Andrews University	0	11	0	0
	Michigan Technological University	0	19	0	17
	University of Detroit Mercy	0	19	0	0
	Wayne State University	0	16	11	17
	Western Michigan University	0	19	0	0
Missouri	University of Missouri, Columbia	0	18	0	0
	University of Missouri, Rolla	0	18	0	0
	University of Missouri, Kansas City	0	18	0	0
	University of Missouri, St Louis	0	18	0	0
	Washington University	0	19	11	17
	St Louis University	0	19	0	17
Mississippi	University of Southern Mississippi	0	22	0	20
Montana	Montana State University	0	19	0	17
	University of Montana	0	19	0	17
North Carolina	North Carolina State University at Raleigh	0	18	11	17
	University of North Carolina at Greensboro	0	19	0	0
	Wake Forest University	0	19	11	17
North Dakota	University of North Dakota	0	19	0	17
New Hampshire	Dartmouth College	0	19	11	17
New Jersey	New Jersey Institute Technology	0	18	0	17
	Seton Hall University	0	18	0	0
	Stevens Institute of Technology	0	19	0	17
	Rutgers the State Univ of NJ	0	18	11	17

Table A2: Continued

State	University	Congress Rep	Salary # years	Articles # years	Patent # years
New Mexico	New Mexico State University	0	19	11	17
Nevada	University of Nevada-Reno	0	19	0	0
New York	Adelphi University	0	18	0	0
	Clarkson University	0	19	0	17
	Hofstra University	0	19	0	17
	Polytechnic University	0	18	0	0
	Rensselaer Polytechnic Institute	0	19	0	17
	Rockefeller University	0	13	6	12
	St John's University	0	19	0	0
	SUNY at Albany	0	19	0	0
	SUNY at Binghamton	0	19	0	0
	University of Rochester	0	18	11	17
	Yeshiva University	0	18	0	0
	Teachers College, Columbia University	0	16	0	0
	CUNY Graduate School and University	0	16	0	0
	Pace University	0	0	0	17
	SUNY at Buffalo	0	19	0	0
	SUNY at Stony Brook	0	18	0	0
Ohio	University of Akron	0	14	0	13
	Case Western Reserve University	0	19	11	17
	University of Toledo	0	19	0	17
	Bowling Green State University	0	18	0	17
	Kent State University	0	19	0	17
	Miami University	0	19	0	0
	Ohio State University	0	19	11	17
	Ohio University	0	19	0	17
	University of Cincinnati	0	18	11	17
	Wright State University	0	19	0	17
Oklahoma	University of Tulsa	0	19	0	0
Oregon	Portland State University	0	18	0	0
Pennsylvania	Carnegie Mellon University	0	19	11	17
	Drexel University	0	19	0	17
	Duquesne University	0	18	0	17
	Lehigh University	0	19	11	17
	Temple University	0	19	0	17
	Indiana University of PA	0	2	0	0
	University of Pennsylvania	0	18	11	17
Rhode Island	Brown University	0	19	11	17
	University of Rhode Island	0	19	0	17
South Carolina	Clemson University	0	19	0	17
South Dakota	University of South Dakota	0	19	0	0
Tennessee	University of Memphis	0	19	0	0
	Tennessee State University	0	17	0	0
	University of Tennessee at Knoxville	0	6	0	0

Table A2: Continued

State	University	Congress Rep	Salary # years	Articles # years	Patent # years
Texas	East Texas State University	0	11	0	0
	University of North TX	0	19	0	17
	Rice University	0	19	11	17
	Texas Christian University	0	19	0	0
	Texas Southern University	0	17	0	0
	Texas Tech University	0	19	0	17
	Texas Woman's University	0	19	0	0
	University of Texas at Arlington	0	19	0	17
	University of Texas at Dallas	0	14	11	0
Virginia	Old Dominion University	0	19	0	17
	Virginia Commonwealth University	0	19	11	17
	University of Virginia	1	19	11	17
	George Mason University	0	18	0	17
Washington	Washington State University	0	19	11	17
Wisconsin	Marquette University	0	19	0	17
	University of Wisconsin-Milwaukee	0	19	0	0
West Virginia	West Virginia University	0	19	11	17
Wyoming	University of Wyoming	0	19	0	17

Note: Congress Rep indicates whether there was representation on the appropriations committee over the entire sample period.

Table B1: First Stage Regressions for Articles and Citations

Dependent Variable Fed R&D Expenditures	Levels	Levels	Log	Per Faculty Member	# of Changes	# of Schools w/ Changes
Majority Senate Leader on Appropriations Comm.	0.883 (11.847)	0.986 (11.707)	**0.074** (0.029)	0.005 (0.010)	3	2
Minority Senate Leader on Appropriations Comm.	14.572 (11.913)	17.296 (11.979)	-0.031 (0.044)	**0.045** (0.014)	3	**2**
# of Senate General Members on Appropriations Comm.	-1.939 (1.801)	-1.661 (1.766)	-0.041 (0.022)	-0.001 (0.002)	30	19
# of House General Members on Appropriations Comm.	**5.351** (1.241)	**5.131** (1.252)	**-0.057** (0.022)	0.002 (0.001)	39	23
Number of Faculty		**0.018** (0.006)				
F-test on Instruments (p-value)	5.750 (0.000)	5.440 (0.000)	7.310 (0.000)	3.22 (0.0126)		
Lag on Instruments	2 years	2 years	2 years	2 years		
R-Square	0.976	0.977	0.974	0.971		
Number of Observations	490	490	490	490		
Number of Schools	35	35	35	35		

Note: Standard errors in parentheses unless otherwise noted. Coefficients in bold are significant less than a p-value of .05. All regressions included school and year fixed effects. The last two columns represent the number of changes on the appropriation committees during the period studied. A change may be from on to off of the committee (and vice versa) or a change in membership type (e.g. from general committee to majority leader).

Table B2: First Stage Regressions for Patents

Dependent Variable Fed R&D Expenditures	Levels	Levels	Log	Per Faculty Member	# of Changes	# of Schools w/ Changes
Majority Senate Leader on Appropriations Comm.	**21.117** (7.700)	**22.306** (7.601)	**0.114** (0.040)	**0.029** (0.009)	9	5
Minority Senate Leader on Appropriations Comm.	8.906 (10.612)	10.009 (10.699)	-0.054 (0.039)	0.019 (0.014)	5	3
# of Senate General Members on Appropriations Comm.	0.743 (1.042)	0.665 (1.034)	0.010 (0.021)	0.001 (0.001)	63	28
Majority House Leader on Appropriations Comm.	**-11.360** (2.685)	**-10.577** (2.589)	-0.075 (0.077)	**-0.007** (0.003)	1	1
Minority House Leader on Appropriations Comm.	**-13.252** (3.097)	**-13.133** (3.029)	**-0.314** (0.080)	**-0.011** (0.003)	1	1
# of House General Members on Appropriations Comm.	**2.176** (0.817)	**1.770** (0.833)	**0.055** (0.018)	0.001 (0.001)	103	46
Number of Faculty		**0.017** (0.004)				
Dummy = 1 if Patent =0			**-0.085** (0.025)			
F-test on Instruments (p-value)	10.590 (0.000)	9.610 (0.000)	7.250 (0.000)	6.180 (0.000)		
Lag on Instruments	3 years	3 years	3 years	3 years		
R-Square	0.964	0.964	0.968	0.949		
Number of Observations	1155	1155	1155	1155		
Number of Schools	58	60	60	60		

Note: Standard errors in parentheses unless otherwise noted. Coefficients in bold are significant less than a p-value of .05. All regressions included school and year fixed effects. The last two columns represent the number of changes on the appropriation committees during the period studied. A change may be from on to off of the committee (and vice versa) or a change in membership type (e.g. from general committee to majority leader).