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The relative success of private funders and government funders in funding important science

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Abstract Regression analysis is used to test the effects of funding source (and of various control variables) on the importance of the article, as measured by the number of citations that the article receives. Funding source is measured by the number of private and the number of government grants mentioned in the acknowledgements section. The importance of an article is measured by an "early" count (of citations through October 1992), and a "late" count (of citations through July 2002). Using either measure of article importance, the evidence suggests that private funders are more successful than the government at identifying important research.

Keywords Government funding · Private funding · Citations · Economics of science

JEL Classification D 780 · H 110 · O 310

The key to scientific progress is creative innovation (see: Kuhn, Root-Bernstein, Simonton and many others). The daunting task for those who would encourage science is to know how to support the efforts of the creative genius without wasting resources on the eccentric crackpot. No easy ex ante algorithm for identifying eventual success has been developed. Yet some individuals, and perhaps some institutions, have been more successful at identifying and funding successful research than others. The search for any useful generalizations that may help identify fruitful innovations is one important long-run research program. The research program will seek answers to questions such as whether the great scientist is a person who has interdisciplinary connections (as Koestler suggests), or is a person who has good judgement about which important problems are solvable (as Medewar suggests), or is a person who views science as fun (as Feynman suggests)? Many generalizations of this sort have been suggested, but few have been rigorously tested.

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While we await the arrival of an empirically validated general theory of scientific creativity (or even a well-established compendium of rules-of-thumb), we still must allocate scarce resources to competing researchers and research projects. Although we do not yet fully understand the optimal decision process for allocating scientific resources, we know that some individuals and scientists have been more successful than others at identifying and supporting successful research. The Prussian Ministry of Culture official[1] Althoff was one successful individual identifier (see: Diamond, 1993). On the institutional level, the University of Chicago may be another (if number of Nobel Prizes received by active faculty is a good measure).

While we wait for the long-run research program to bear fruit, an important and useful short-run research program would seek to learn whether the successful funders have anything useful in common. In the present paper, I begin to look at this question by asking the broad question of whether research that is supported by government, or by private funders, is more likely to turn out to be important research. Using citations as my measure of the importance of scientific research, I test whether that importance is related to the source of funding.

The goal of funding science is to provide the most scientific progress per dollar spent. In recent years many critics have expressed doubts about whether the goal is being met. Some say that too many resources are being spent on "big science,"[2] others that unproductive pure science is being over-funded relative to applied science. Besides criticism of the kind of science being funded, there is also a growing dissatisfaction with the current method of allocating funds. Some of the dissatisfaction is directed at the process of peer review often used in government funding decisions. Nobel-prize-winning economist Milton Friedman, for instance, has emphasized the costs of preparing grant proposals and the tendency of "peer review" to stifle innovation (p. 99).[3] Innovation might be stifled under the current system for a couple of reasons. One would be the tendency of peer committees to approve what is safe, thereby reducing the odds that their decisions will be criticized. Another reason why the current system may stifle innovation is that research is funded on the basis of a proposal rather than on the basis of results (see: Tullock; and Squires).

Sometimes as research progresses, the most fruitful path might be to deviate from the proposal. James Watson (p. 24), for instance, might never have discovered the structure of DNA if he had kept to the terms of a postdoctoral fellowship awarded by a Fellowship Board in Washington (probably the NSF, although he does not say). Predicting the course of scientific work in advance is difficult, especially if the work is risky, ambitious and interesting. The scientist who wants to perform such work is then faced with unpalatable alternatives. She can write proposals that are fundable, but routine or she can write proposals that are ambitious, but less likely to be funded. If the scientist writes routine proposals that are funded, then she must choose between doing the routine work that was proposed or else doing ambitious work that is inconsistent with the proposal.

[1] Althoff is sometimes described as the "Prussian minister of education" (e.g., Pauline Reylyea Andeson as quoted in Senn 1994, p. 215). Although Althoff functioned as though that was his role, he was technically one of several officials at the Ministry of Culture just below the level of minister. The ambiguity of his position is well-expressed by Vereeck (1994): "Despite his position, it is no caricature to write that five Ministers of Culture served under Althoff." (p. 72)

[2] Among those who have advocated a greater emphasis on "small science" in funding decisions, are: Charlton, and Andras (2005), McLuckey, (2001), and Sachs (1997).

[3] Friedman reiterated his 1981 argument in 1994. Laband, et al's (1994) response to Friedman presented evidence that articles in economics that had received NSF support, received more citations than those that did not receive NSF support.

Scientists besides Friedman have criticized peer review for different reasons. Nuclear physicist Leo Szilard, for instance, has noted that under a system of peer review the best scientists end up spending much of their time reviewing the work of others rather than doing their own work (pp. 100–101). Still others have criticized peer review because disagreement among peers is so great that ". . . whether or not a proposal is funded depends in a large proportion of cases upon which reviewers happen to be selected for it." (Cole, Cole, and Simon, p. 881)

Whether big science is more fruitful than little science and pure science more fruitful than applied science and whether a prize system might be better than the current proposal system, are all promising topics for research in the field of economics of science. But here I propose a different, though related question: are some institutions better than others at selecting important research to fund? If some institutions consistently do a better job of picking the winners, then science would be advanced if more resources were devoted to the successful institutions.

On my topic, economists have studied the decision-making process of governments (e.g., in the public choice literature started by Buchanan and Tullock) and the decision-making process of the non-profit sector (e.g., Weisbrod). But they have rarely applied these theories to funding decisions in science.[4]

1. Hypotheses on relative efficiency

Governmental organizations vary from the efficient to the totally corrupt. Non-profit organizations vary from the efficient to the totally corrupt. Here, I hypothesize that, in general, non-profit organizations will be more efficient at providing a service than will the government. This is not because the people working for non-profits are any better than those working for government. Rather, it is because there are important differences in the incentive structure of non-profits and government.

1. A private donor may support a few organizations at relatively high levels, while her taxes are divided into small amounts that go to support a great many government bureaus. It is less costly for the donor to monitor the activities of a few organizations than many bureaus.
2. It is easier for the donor to act on information in the non-profit sector than it is for the taxpayer to act on information in the government sector. This is for two reasons:
   (a) In the government sector, the taxpayer must usually select from a limited number of package-deals. Usually the voter votes for a package (or party platform) that includes government activities that the voter is against, either on principle or because they are being inefficiently carried out.
   (b) In the non-profit sector there are very frequently many organizations providing similar services. The greater number of organizations competing for donor money results in greater efficiency of operations. It also increases the likelihood that a donor will find an organization whose program of activities matches her own preferences.

The importance of incentives in government decision-making under uncertainty has been studied by economists before. Sam Peltzman did a cost-benefit study of whether the benefits of the FDA in preventing drugs like thalidomide were greater than the costs as measured by

[4] Although a couple of noneconomists, Martino (1992) and Kealey (1996), have made use of economic analysis to extensively examine the case of government funding.

the delayed approval of useful and life-saving drugs. He found that the costs of delaying the good drugs were many times higher than the benefits of stopping the bad drugs. This does not imply that those working for the FDA are stupid or incompetent, or uncaring. What it does imply is that they know that their careers will be over if they approve thalidomide, whereas, generally, they will not be held so accountable for the delay of a useful drug. (Although there may be exceptions to this as with the case of the vocal AIDs lobby.) Just as there are high risks for the FDA in approving a drug before it has been thoroughly tested, there may be risks for a government agency in funding scientific ideas before they have been admitted to the mainstream.[5]

We do not hold all the mistaken equally accountable for all of their mistakes. If someone makes a mistake that everyone else in their position is making, then the presumption is that they could not have known better, given the current state of knowledge. If someone makes a novel mistake, then they are out on a limb by themselves, much more likely to be held accountable for their actions (see: Scharfstein and Stein).

I know of only six studies that present hard statistical evidence on the issue of the relative efficiency of non-profits and government. Five of these studies focus on some aspect of health care; the sixth on higher education. There are probably a couple of reasons that most of the studies are on health care. One is that all three types of institution (for-profit, non-profit, and government) are active in providing health care. Since all three types are present, health care presents a promising domain for testing the relative efficiency of each type of institution. Another reason for the focus of research on health care is that for many years in the U.S., health care costs have been rising at a substantial rate. This has made research on health care a high priority for those concerned about public policy. We lack the space to provide the details of any of the six studies, but instead will highlight only the relevant conclusions.

The first focused on whether increased competition increased the efficiency of U.S. medical research charities. Susan Feigenbaum (1987) examined the hypothesis that the level of competition among non-profits will affect how much they spend on administrative costs, fund-raising costs, and "pass-through" to the ultimate beneficiaries. Her systematic analysis of the evidence indicates that increased competition reduces administrative costs and increases fund-raising costs[6] and pass-through to the beneficiaries.

Five other studies, three on nursing homes (Frech and Ginsburg, 1981; Bekele and Holtmann, 1987; Borjas, Frech, and Ginsburg, 1983), one on hospitals (Cowing and Holtmann 1983), and one on higher education (Laband and Lentz, 2004), directly compare the efficiency of the three institutional types. Four of these studies agree with one conclusion: that government institutions have higher costs than for-profit firms. Two of the four studies (Bekele and Holtmann; and Cowing and Holtmann) also find evidence that non-profit institutions have higher costs than for-profit firms. The other two studies (Frech and Ginsburg; and Borjas, Frech, and Ginsburg) show mixed results on the relative costs of non-profits. One of these (Borjas, Frech, and Ginsburg), for instance, finds that church-related nursing homes actually have lower costs than for-profit firms. The fifth study of the five that directly compare the efficiency of the three institutional types (Laband and Lentz, 2004), is an outlier in failing

[5] In the United States, every month the late former Senator William Proxmire used to announce a Golden Fleece award which he gave to some egregious example of waste of the taxpayer's money. Frequently these would go to a research project with a frivolous-sounding title. For a government grant-giver, it would be much easier to fund safe projects than to risk public ridicule as the funder of frivolous fleecing.

[6] At first glance, you might consider that an increase in fund-raising costs is a bad thing. But in this literature fund-raising costs are often viewed as a way to increase the donor's information about the quantity and the quality of the services being provided.

to find that government institutions of higher education have higher costs than for-profit institutions. Applying their research design to their data,[7] Laband and Lenz conclude that the only statistically significant result between the three institutional types is that government institutions have higher costs than non-profit institutions.

Although the empirical evidence is mixed, it is at least not strongly inconsistent with the hypothesis sketched earlier, that for-profit firms are the most efficient, non-profit organizations are the next most efficient, and government organizations are the least efficient.

2. Data

Following accepted practice, I use citations as a measure of the scientific importance of an article. The sample consists of the first 53 chemistry articles by North American scientists published in 1985 in the "Reports" section of *Science* (described by the late Harvard paleontologist Stephen Jay Gould as " ... America's leading professional journal ···" (1985, p. 366)). Articles that are published in *Science* are presumably on the tail of the quality distribution. Looking at differences of quality among a high-quality group, amounts to eliminating the easy cases and then asking: among a sample of competent, solid articles, which ones turn out to have the greater scientific importance? And further: do private or government funders, have greater success at picking the research that has the greater scientific importance?

Comments on the works of others were not counted as "articles."[8] Chemistry is selected as the field of study both because it is an important scientific field, and because chemists are better at documenting themselves (through their *Directory of Graduate Research*) than are scientists in some other fields. The criterion for judging an article to fall within the domain of "chemistry" was that one of the co-authors have some affiliation with chemistry. Although it was not the original intent, it turned out that most of the articles that met the "chemistry" criteria were directly related to some aspect of medicine. To count as being by "North American scientists," at least one of the co-authors had to be affiliated with an institution in the United States or Canada.

"Early" citations to the articles were obtained from the Institute for Scientific Information's *Science Citation Index* (*SCI*) database from 1985 through Oct. 1992 (inclusive). "Late" citations to the articles were obtained from the official citation counts for each article provided in the Institute for Scientific Information's Web of Science[9] as of July 2002. Thus the "late" count measures the total citations received by the article from 1985 through July 2002 (inclusive). Following the procedure of Laband et al. (1994), I use the acknowledgement section of each article as the source from which to record the number of grants that the research

[7] Using 1996 data that pre-dates the meteoric rise of the for-profit University of Phoenix, they compare the costs of 176 for-profit institutions with 1,450 government institutions, and 1,316 non-profit institutions. One challenge of the analysis is that the few for-profit institutions are producing a very different mix of outputs than the other institutions—specializing in undergraduate degree production, but, unlike the other institutional types, producing few grants and few graduate degrees. Another challenge of the analysis is how to interpret the 'grants' concept. The university administrator might agree with the authors in considering grants an output. But arguably an economist evaluating the efficiency of alternative institutional types might consider grants to be a cost component, with measures of research being the relevant output.

[8] Besides their substantive differences, comments differ from articles in that comments appear at the end of the Reports section and they lack abstracts.

[9] The official counts in the Web of Science are subject to some limitations discussed in the appendix of Diamond 2004.

Table 1 Descriptive statistics

Variable	Mean	Stand. dev.	Min.	Max.
Early total citations to articles (1985-Oct. 1992, inclusive)	83.60	124.71	3.00	840.00
Late total citations to articles (1985-July 2003, inclusive)	148.58	254.59	6.00	1790.00
Private support (# of private grants)	0.47	0.50	0.00	3.00
Government Support (# of government grants)	1.45	1.05	0.00	4.00
Total publications from 1974 through 1984 (inclusive) by co-author who publishes most	127.02	103.42	11.00	385.00
Proportion of co-authors who are female	0.14	0.19	0.00	0.67
Article is not in the direct area of medicine (=1 if nonmed.)	0.17	0.38	0.00	1.00

Table 2 Number of articles receiving different levels of private and government grants

(Number of articles = 53)		# government grants					
		0	1	2	3	4	Row totals
# Private grants	0	5	15	4	3	1	28
	1	2	7	2	1	2	14
	2	0	4	2	1	3	7
	3	0	1	2	1	0	4
	Column totals	7	27	10	6	3	53

received from private agencies (including corporations), and the number from government agencies (including all levels of government from local to the United Nations). If more than one grant is acknowledged from the same agency, we count these as separate grants. Research not receiving grants of these two types would include research supported by the university, by university centers, or self-supported by the scientist. Such research may have indirectly benefited from government or private investments in research infrastructure.

Descriptive statistics for the article variables used in the regressions appear in Table 1. Table 2 reports the distribution of grants of both types, among the 53 articles. 60% of the articles in the sample were supported by one or more government grant, twice the percent that were supported by one or more private grant. Government grants totaled 77 in the sample, while private grants totaled 40. Of the government grants, a minimum of 36 were from the National Institutes of Health, while seven were from the National Science Foundation. No single private organization was responsible for a high percent of the private grants.

The 215 scientists in the scientist sample consist of each co-author of each article in the article sample. Able, experienced scientists at prestigious universities will, other things equal, produce more highly-cited articles, whether the research is supported by government, private agencies or is unsupported. Hence I try to disentangle the effects of institutional selection procedures from the characteristics of the scientists. To do so, biographical and career data on scientists in the sample were obtained from chemistry's *Directory of Graduate Research* and from other sources. Also useful as a measure of ability is a count of the citations to the life-time output of each scientist. This measure was obtained by counting each scientist's citations in the 1984 *SCI*.

3. Estimation method

Regressions were estimated in order to learn the effects of funding source (and the various control variables) on the importance of the research as measured by the number of citations that the article receives. Where theory provides imprecise guidance, the functional form of the regression was varied in order to learn the robustness of the results. This included using average values (among the co-authors) of the control variables, as an alternative to using the total values. (Since, for instance, it is not a priori clear whether what would matter would be the total years experience of the co-authors, or the average years experience.) It also included estimating both OLS regressions, and maximum likelihood regressions using a Box–Cox transform on the dependent variables.

Tables 3 and 4 report regressions using the same independent variables and the same functional forms. They differ in that the dependent variable in the regressions in Table 3 consists of the number of citations received in about the first eight years after the article's publication, while the dependent variable in the regressions in Table 4 consists of the number of citations received in about the first 19 years after the article's publication.

The rationale for including two time periods is the possibility that one institutional form takes greater risks in picking research, and that the payoff of the risks take longer to be

Table 3 Regression estimates of determinants of "early" citations to articles.

	Regression number and specification			
Variable	1 OLS	2 OLS	3 Box-Cox on Dep. Var.	4 Box-Cox on Dep. Var.
Private support (# of private grants)	34.702* (1.789)	34.248* (1.819)	0.339** (2.250)	0.369** (2.505)
Government support (# of government grants)	−9.074 (−0.531)	−4.580 (−0.271)	−0.00938 (−0.071)	0.0296 (0.223)
Total pubs from 1974 through 1984 (inclusive) by co-author who publishes most	1.518** (2.411)	1.509** (2.392)	0.0119** (2.441)	0.0116** (2.348)
Above squared	−0.00407** (−2.463)	−0.00397** (−2.407)	−0.0000319** (−2.490)	−0.0000301** (−2.330)
Proportion of co-authors who are female	−100.63 (−1.124)	–	−0.368 (−0.530)	–
Article is not in the direct area of medicine (= 1 if nonmed.)	−53.084 (−1.154)	–	−0.627* (−1.756)	–
Constant	9.416 (0.179)	−21.472 (−0.439)	3.149** (7.706)	2.904** (7.580)
Lambda[&]	–	–	0.000	0.000
Number of articles (obs.)	53	53	53	53
Adjusted R-squared	0.075	0.067	0.140	0.118

^The t-statistics are reported in parentheses.

*One star indicates statistical significance at the 10% level for a two-tailed test. Two stars indicate statistical significance at the 5% level for a two-tailed test.

[&]A lambda of zero indicates that the dependent variable is in logarithmic form.

Table 4 Regression estimates of determinants of "late" citations to articles

	Regression number and specification			
Variable	5 OLS	6 OLS	7 Box-Cox on Dep. Var.	8 Box-Cox on Dep. Var.
Private support (# of private grants)	69.424* (1.730)	64.188 (1.660)	0.26991** (2.104)	0.26982** (2.186)
Government support (# of government grants)	−34.708 (−0.9815)	−27.915 (−0.8042)	−0.062686 (−0.5546)	−0.038561 (−0.3480)
Total pubs from 1974 through 1984 (inclusive) by co-author who	3.0932** (2.37 5)	3.1129** (2.403)	0.0077016* (1.850)	0.0076367* (1.847)
publishes most Above squared	−0.0082915** (−2.426)	−0.0082763** (−2.443)	−0.000022318** (−2.043)	−0.000021733** (−2.009)
Proportion of co-authors who are female	−218.80 (−1.181)	–	−0.50588 (−0.8540)	–
Article is not in the direct area of medicine (= 1 if nonmed.)	−58.077 (−0.6102)	–	−0.29643 (−0.9743)	–
Constant	15.355 (0.1410)	−34.316 (−0.3416)	3.5627** (10.24)	3.3984** (10.60)
Lambda[&]	–	–	−0.050	−0.050
Number of articles (obs.)	53	53	53	53
Adjusted R-squared	0.050	0.056	0.0608	0.0695

^The t-statistics are reported in parentheses.
*One star indicates statistical significance at the 10% level for a two-tailed test. Two stars indicate statistical significance at the 5% level for a two-tailed test.
[&]A lambda of zero indicates that the dependent variable is in logarithmic form.

revealed. Most articles that are ever highly-cited, become highly-cited within a few years of publication. But very rarely, there may be a substantial lag before an article becomes highly-cited. One example in economics is Zvi Griliches's 1957 *Econometrica* article on technological change (see: Diamond, 2004).

In both tables, "private support" is equal to the number of different private grants that are acknowledged by the co-authors of the paper. Similarly, "government support" in those regressions is equal to the number of different government grants that are acknowledged by the co-authors of the paper.

In all of the regressions reported in Tables 3 and 4, the independent variables for the "number of private grants," and the "number of government grants" are interpreted as continuous variables. Both OLS and Box-Cox regressions are estimated in Tables 3 and 4. The general form of the OLS regressions estimated in Tables 3 and 4, is:

$$Y = X\beta + \varepsilon \qquad (1)$$

where Y is a (53×1) vector of the observations of the dependent variable and, X is a (53×4) or (53×6) matrix of the observations of the independent variables, depending on whether the gender and non-medicine control variables were included. ε is a vector of random disturbances that is assumed to be distributed i.i.d.

In the absence of theory determining the precise functional form, I also estimated maximum likelihood regressions using the classical Box-Cox transform on the dependent variable. The general form of the Box-Cox regressions in Tables 3 and 4, is:

$$\frac{Y^{\lambda} - 1}{\lambda} = X\beta + \varepsilon \tag{2}$$

where the parameter λ is estimated through a maximum likelihood process. As before, Y is a (53×1) vector of the observations of the dependent variable, and X is a (53×4) or (53×6) matrix of the observations of the independent variables, depending on whether the gender and non-medicine control variables were included. ε is a vector of random disturbances that is assumed to be i.i.d.

In the regressions reported in Table 5, the independent variables for the "number of private grants," and the "number of government grants" are interpreted, perhaps more appropriately, as discrete variables. In the data set, the number of private grants ranges from 0 to 3 and

Table 5 Regression estimates using discrete versions of the grants variables

	Regression number and specification			
	Dep. Var. = Cites through 1992		Dep. Var. = Cites through 2002	
Variable	9 OLS	10 Box-Cox on Dep. Var.	11 OLS	12 Box-Cox on Dep. Var.
One private grant	87.059** (2.072)	0.74633** (2.384)	201.57** (2.391)	0.71691** (2.446)
More than one private grant	82.491* (1.743)	0.93447** (2.650)	158.79 (1.672)	0.82909** (2.511)
One government grant	49.118 (0.9351)	0.49777 (1.272)	116.13 (1.102)	0.41862 (1.143)
Two government grants	−2.8048 (−0.04545)	0.27079 (0.5890)	−24.451 (−0.1975)	−0.065032 (−0.1511)
More than two government grants	30.116 (0.4681)	0.37523 (0.7830)	9.5999 (0.07439)	0.17777 (0.3962)
Total pubs 1974–1984 by co-author who publishes most	1.4906** (2.345)	0.011845** (2.501)	3.1368** (2.460)	0.0089571** (2.020)
Above squared	−0.0035823** (−2.151)	−0.000028073** (−2.263)	−0.0075001** (−2.245)	−0.000022436* (−1.931)
Constant	−80.072 (−1.237)	2.3013** (4.772)	−192.50 (−1.482)	2.9846** (6.609)
Lambda[&]	–	−0.010	–	−0.030
Number of articles (obs.)	53	53	53	53
Adjusted R-squared	0.0768	0.1461	0.1086	0.1296

^The t-statistics are reported in parentheses.
*One star indicates statistical significance at the 10% level for a two-tailed test. Two stars indicate statistical significance at the 5% level for a two-tailed test.
[&]A lambda of zero indicates that the dependent variable is in logarithmic form.

the number of government grants ranges from 0 to 4. (More detailed information on the distribution of the number of grants is provided in Table 2.) Since so few articles received three private grants, that category is combined in the estimation into a "two or more" category. Similarly, since so few articles received four government grants, that category is combined in the estimation into a "three or more" category. The omitted category for private grants is the "zero grants" category. Likewise, the omitted category for government grants is the "zero grants" category. OLS and Box-Cox regressions were estimated for the discrete case, using estimation equations similar to equations (1) and (2) above. In these regressions, the gender and nonmedicine control variables were omitted, because of previous lack of robust significance, and in order to save space.

4. Estimation results

Various control variables were explored, including total citations received by all co-authors in 1984, average citations received by co-authors in 1984, number of co-authors, the proportion of co-authors who were female, and whether the article involved substantial applications to medicine (most did). The only control variable that evidenced robust statistical significance was the variable for the number of articles published by the co-author with the most publications. The importance of this variable seems to indicate that an article is as strong as its strongest co-author (the opposite of the truism that a chain is only as strong as its weakest link). Alternatively, it could be interpreted as compatible with what Robert Merton has called the "Matthew Effect" in science, that those who are already well-known, ceteris paribus, will receive more attention than those who are less well-known. The square of the high-publisher variable is negative (and statistically significant) indicating that there are diminishing returns to the effect of the high publisher on the importance of the article.

Regressions 1, 3, 5 and 7 in Tables 3 and 4 included the "non-medical" dummy variable and the proportion of co-authors who are female, the latter testing the gender discrimination hypothesis. Regressions 1, 2, 5 and 6 were estimated using a simple OLS specification while regressions 3, 4, 7 and 8 were estimated making the Box-Cox transformation on the dependent variable in order to impose fewer restrictions on the theoretically underdetermined functional form. Regressions 9–12 in Table 5 differ from those in Tables 3 and 4, in that the key grant variables are interpreted as discrete. Regressions 9 and 10 are OLS regressions, while 11 and 12 use the Box-Cox transform, estimated using maximum likelihood. In all of the six regressions using Box-Cox transformations, λ either equaled zero or approximately equaled zero, indicating that the optimal transformation on the dependent variable turned out either to equal, or to approximately equal, the natural log of the number of citations to the article.

One robust result of all 12 regressions is that no version of the government grants variable is ever statistically significant for a two-tailed test at either the .05 or even the .10 level of statistical significance. In contrast, all versions of the private grants variable, estimated in the Box-Cox regressions, turn out to be both positive and statistically significant for a two-tailed test at the .05 level of statistical significance. The Box-Cox regressions are arguably more informative than the OLS regressions because they impose fewer restrictions on the functional form. In the OLS regressions, all versions of the private grants variable have positive signs, and the estimates are often, but not always, statistically significant at either the .05 or the .10 level for a two-tailed test.

In summary, a robust feature of the Box-Cox regressions is that the number of private grants received is always a positive and statistically significant predictor of whether the article will turn out to be highly cited in either the short-run, or the long-run. Conversely, the null hypothesis that the coefficient is zero for the number of government grants, cannot be rejected at the most common conventional levels of statistical significance.

5. Conclusions and future work

The regressions in Tables 2 and 3 indicate that the "number of private grants received" is a positive predictor of the importance of research, both in the short-run and in the longer run, as measured by the number of citations received by an article. The "number of government grants received" does not appear to be a positive predictor of the number of citations received by the article, in either the short-run, or the long-run. The most straightforward interpretation is that private funders are more successful than the government at identifying important research.

One possible objection to the current study is that I assume that privately funded and government funded researchers, have no systematic differences in their likelihood of submitting their research to *Science*. Although this seems to be a plausible assumption, in the future it might be useful to test the robustness of the current study, by randomly selecting a set of proposals funded by the government, and a set of proposals funded privately. The proposals would then be tracked over time to observe those that result in journal articles, the quality of the journals in which the articles are published, and the number of citations that the articles receive. The current study could also be improved, though at significant cost in time and effort, by obtaining information, not just on the number of grants received, but also on the dollar value of grants.

The research begun here should result in a better understanding of how successful various funding institutions have been in selecting important research. Such understanding should be useful to better understand the behavior of these institutions. But it also should be relevant to policy considerations, especially related to whether marginal dollars should be allocated to one institution rather than another. Additional questions for research should also be raised as a result of this research. If one institution is more successful, it will be natural to ask what it is about the decision process of the institution that leads to its success. Such research will be intimately related to questions of the economic, social and personal characteristics that encourage success in science.

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