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RESEARCH PAPER

Research funding and academic output: evidence from the Agricultural University of Athens

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This paper uses detailed data on funding information and research output from the Agricultural University of Athens to examine how each type of funding source is related to the quantity and quality of academic research output. Of special interest are private, Greek government and European Union sources of funding. We find that after controlling for unobserved heterogeneity from each research laboratory, all types of research funding are similarly related to both the count of publications and citations. Further, we find that research laboratories that have filed for at least one patent application produce more publications and citations to their work, indicating that laboratories that are close to industry are also engaged actively in research.

Introduction

Innovation has long been the key driver of agricultural productivity (Johnson, 1997). Technological advances have drastically increased the rate of agricultural production and, as a result, social welfare.[1] The return to research and development (R&D) is one of the most heavily studied topics in the agricultural economics literature. The overwhelming majority of this literature has found that the returns are substantially positive [see Alston *et al*. (2000) for a meta-analysis].

The role of universities in agricultural innovation has not gone unnoticed (Foltz *et al.,* 2000) as they have played a significant role in the sector's R&D (Jaffe, 1989; Adams, 1990; Mansfield, 1991). More recent case studies have also found a positive impact of university research on regional innovation activity (Acosta *et al*., 2009; Carree *et al*., 2012). However, the involvement of universities in public–private partnerships may entail risks. The university's mission is to educate students by providing them with scientific knowledge and skills, as well as to advance the frontiers of science. Skeptics have argued that the latter may be jeopardized when the private sector finances university research (Washburn, 2005; Blumenthal *et al*., 1996).

We add to the above debate by exploring how each type of research funding is associated with academic output in the largest agricultural university in Greece, the Agricultural University of Athens (AUA). Of particular interest is comparison between public and private sector funding as we examine evidence from its 40 research laboratories. We estimate the relationship between type of research funding and research output by measuring by publications and citations. An additional novelty of the dataset is that we look at three types of public funding – government

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funding, European funding handled by Greek agencies, and direct European Union (EU) funding (mostly through the Framework programs). To our knowledge, only Grimpe (2012), looking at Germany, has distinguished between research supported by a national government and research supported by the EU. In our case, we examine an extra source of public support for research – EU money handled by Greek agencies.

Universities may distort their research agenda if faculty focus on entrepreneurial activities instead of scientific-oriented ones (Dasgupta and David, 1994). Scholars have approached this topic by examining the propensity of faculty to patent and publish. While publishing in scientific journals is an indication of research output, patenting may be more related to business-oriented activities of faculty (Thursby *et al.*, 2007). We also examine the patent application profiles of the research laboratories.

We find that, on average, public and private funding have similar effects on research productivity. This finding lends no support to the critics of corporate funding who argue that such funding will hamper academic research. The only exception is funding straight from the Greek government. Here we find a negative relationship with research output. We also find that research laboratories that have filed at least one patent application produce, on average, more publications, receive more citations to their work, and attract more research funding, indicating that commercialization has no negative association with university research. Our paper generally relates to the literature concerned with a decline in university scientific research attributed to public–private partnerships.[2] Specifically, scholars are concerned that universities are sacrificing research output for industry funding (Blumenthal *et al.*, 1996; Campbell *et al.*, 2002; Rai and Eisenberg, 2003) and commercialization activities (Dasgupta and David, 1994; Kennedy, 2000), such as patenting and licensing.

Other studies have examined ideal types of research grant structure in the context of agricultural research (Tisdell, 1997). This paper also relates to the literature that examines the role of universities in agricultural or agricultural-related innovation. This literature generally finds that universities contribute positively to innovation and overall agricultural productivity (Foltz *et al.,* 2003). In a case study, Weber and Xia (2011) discover that universities have played a critical role in advancing nanobiotechnology. While these studies, and those that will be discussed in the next section, have focused on countries which already have experience in public–private partnerships, there is considerably less research in inexperienced countries. Greece belongs in the latter group as it has little experience in technology transfer activities as a number of European Commission reports have shown (EC, 2008a, 2008b).

Our institution was ranked 102nd in the field of agricultural sciences in 2015 out of approximately 300 universities (National Taiwan University, 2015). This ranking is based on publications, citations and the overall impact of the university's research output. Therefore, AUA can be classified as a typical research-oriented agricultural university and our findings are directly relevant to such institutions operating in immature technology transfer environments. In other words, the substantially lower number of patents filed, lower funding, increased dependence on European research funds and fluctuations in national R&D can produce qualitatively different results from those produced in a more developed technology transfer environment.

Context and theory

Since their inception, public–private partnerships have met with criticism. The major concern is corporate research funding. Critics have argued that such funding can endanger one of the core missions of the university, the creation of new basic knowledge. While such knowledge is difficult to appropriate, it is necessary for advancing the frontiers of science (Press and Washburn, 2000; Washburn, 2005). The reasoning is simple: while university researchers have a primary objective to publish and receive recognition for their work by their peers, private sponsors that fund academic research seek scientific output that will be readily available and easy to appropriate (Gibbons *et al*., 1994). On the other side of the coin, policy makers frequently encourage corporations to fund academic research in an effort to make academic research more relevant to society's problems (Mowery and Ziedonis, 2002). For these reasons, substantial effort has been poured into examining whether public–private partnerships in general, and corporate funding in particular, lower the quality of academic research.

Empirical evidence is mixed. Geuna (1997) finds that dependence on industry funding by UK universities can result in reduced academic output. However, Banal-Estanol *et al.* (2015), studying UK engineer academics, find a significant positive relationship between industry funding and publication output when industry funding is small. Manjarrés-Henríquez *et al.* (2009) reach a similar conclusion when examining two Spanish universities. With respect to German universities, Hottenrott and Thorwarth (2011) discover that industry funding leads to reduced quantity and quality of research output. Hottenrott and Lawson (2013) refine this finding at the research laboratory level and show that there is significant variation by type of industry sponsor. From a theoretical standpoint, scholars often argue that while corporate sponsors may demand more applied research from university researchers, this will not necessarily result in lower quality research (Kramer, 2008). The reasoning is that, although academia is excellent at producing basic research, it needs the stimulation of real-life problems to turn research into scientific breakthroughs (Wright *et al*., 2014).

This paper is especially concerned with the relationship between corporate sponsors and academic researchers. We focus on a comparison between government and corporate funding. There is still substantial room for new insight in both the theoretical and the empirical literature. The critics of corporate research funding anticipate either a negative relationship between corporate research funding and academic output or, at the very least, a smaller positive relationship than in the case of government funding and academic output. However, if we were to show that there is no statistical difference between public and private sector funding, then our findings would not support these critics.

We are also interested in whether a faculty that continuously seeks entrepreneurial activities under-performs in cutting-edge research. In other words, university researchers might be conducting applied research at the expense of basic research (Henderson *et al*., 1998; Cohen *et al*., 1998; Foltz *et al*., 2007). Concerns about the mix of applied *versus* basic research are not new (Nelson, 1959). For instance, Lach and Schankerman (2008) conclude that academics respond to royalty incentives by conducting more commercially-oriented research, while Thursby *et al.* (2007) consider the research profile of an academic researcher throughout his career and find that licensing income may direct faculty towards applied research.

While a university researcher achieves recognition via the citations to his work (Diamond, 1986), other money-metric incentives may divert him from his initial goals. For this reason, many empirical studies have attempted to examine the relationship between academic research and entrepreneurial activity. They proxy applied research and entrepreneurial endeavors with patents and basic research with academic papers. Overwhelmingly, studies fail to find substitutability effects between patents and papers (Agrawal and Henderson, 2002; Breschi *et al*., 2007; Goldfarb, 2008; Azoulay *et al.,* 2009). This implies that university researchers do not perform the one activity at the expense of the other.

In this paper, we examine this concern in a similar fashion. We ask whether research laboratories with prior patenting experience have more papers and more citations to these papers than laboratories without. We should note that, given our research design, we are not claiming causality, as with most empirical papers examining this question. We merely examine the relationship between these variables. If we find a negative relationship between patents and academic output, this will lend support for the above concern: if we find a positive or no relationship, then our case study will not support the concern. Our data also allow us to examine differences among types of government funding. While this analysis does not fall strictly within the context of public–private partnerships, it is still important in terms of policy.

Our case study is a mix of theory-confirming/infirming and hypothesis-generating case studies (see Lijphart, 1971). A theory-confirming/infirming case study is one which either confirms or infirms prior theoretical hypotheses. A hypothesis-generating case study is one where empirical observations can provide future research with certain hypotheses to be tested. Our empirical results fall into this latter category, and it is interesting to examine their differences from a policy perspective. In particular, a number of European countries have more than one source of public funding. In the simplest case, all European universities can obtain funding either from the EU through the Framework programs (now Horizon 2020) or from their own governments. We argue that two aspects of this funding are relevant to the formulation of theoretical hypotheses. First, the degree of competition can be smaller in national funding than in European funding; and second, the competence of national agencies to manage funding can lead to underutilization of research grant schemes.

In our own case study, the three public funding types under consideration differ with respect to these dimensions. The EU funding is both competitive and efficient; the European funding handled by Greek agencies, while competitive, is often not absorbed by national agencies (Grant *et al*., 2011), and Greek government funding usually awards research grants direct to research teams and universities. The theory-confirming/infirming part of our study may carry weight as it relates to an existing debate regarding the mission of the research university. But even the hypothesis-generating part of our study can still provide future research with hypotheses that can be tested in other European countries.

Data construction

The institution under investigation is the Agricultural University of Athens (AUA). AUA has six departments.[3] Each department has several research laboratories, and each faculty member belongs to a research laboratory. While courses are taught at department level, research takes place at laboratory level. The university has 42 research laboratories. However, for the purposes of this study, we exclude two laboratories with only one faculty member during the period studied.[4] Therefore, for the remainder of the paper we focus on the remaining 40 research laboratories.

There were several steps in the process of collecting our data. As a first step, we collected publication information for each faculty member from www.scopus.com.[5] Scopus was selected for two reasons. First, at the time of data retrieval it had an identification number for each author (Chadegani *et al.*, 2013). Therefore, by retrieving the id numbers, we were able to collect all the papers corresponding to each faculty member.[6] Second, Scopus is the most comprehensive database of scientific publications. In a case study of researchers in medical schools, Kazakis *et al.* (2014) found that Scopus lists all the publications of more than 90% of authors.[7] We should note that we did not distinguish between types of publications, whether those were journal publications or book chapters. While such a distinction can be important in the social sciences, in the types of sciences we consider, most publications are journal publications, which makes the analysis easier in terms of comparison. To double check the accuracy of Scopus in our case, we also randomly examined the publications of 10 faculty members from their websites and from Scopus. We found that at least 87% of publications from their website CVs are listed in Scopus. In many cases, the number in Scopus and on websites was very similar.[8] As a last note, we should stress that by focusing on Scopus, we in effect focus on publications written in English. We discuss later whether the non-consideration of Greek publications has implications for the interpretation of our results.

To account for the importance of each publication, we also collected the total number of citations received in 2013. Citations have been used widely to measure the scientific impact of papers, scholars or even entire research laboratories. This approach dates to Eugene Garfield (1955), who posited that citations to a paper, a journal or a researcher's work can measure the 'impact factor' of each. However, citations are still plagued by a number of disadvantages (see Gläser and Laudel, 2007; Macdonald and Kam, 2010). From the early 1960s, it was evident that not all citations had equal weight. Only a small portion of citations reflect relevance to prior scientific breakthroughs (Price de Sola, 1965). Further, the 'Matthew Effect', coined by Merton (1968), states that researchers who are already famous will get substantial more recognition (citations in our case) than unknown researchers with equal quality research. More recent studies also show that citations to papers carry significant noise (Kostoff, 1998; Makino, 1998). Even with all their drawbacks, however, citations to academic papers are better indicators of scientific impact than patent citations (Roach and Cohen, 2013). We also collected information on retired faculty members active during the study period (2002–13). Overall, we acquired information on 216 faculty members, 51 of which had retired by the end of 2013.

The second step was to retrieve information on research grants. This information was obtained from the records of the AUA research committee. For each research laboratory, we collected information on all research grants, their start and end dates, the amount and the name of the funder. After a cursory review of each funder, these were classified as follows:

- GOV, which is funding from government or a local government authority (for instance municipalities);
- GOVEU, which is funding handled by a government authority (for instance, the general secretariat for research and technology), but co-financed by the European Union. For most of these grants, the EU money accounts for more than 75% of the total budget;

- EU, which is funding that comes directly from the European Union from competitive research programs. The majority of this research money stems from the Framework programs;
- PRIV, which is funding that comes from private sponsors. This category includes projects that private companies fund, in most cases in the form of services; and
- UNCLASS, which is funding that did not match any of the above categories. Most of the projects in this category were funded from donations and the reserves of the AUA research committee. It should be pointed out that this category includes a few projects with small budgets.

These categories, in addition to allowing us to compare public and private funding, also facilitate the comparison of the three major types of public funding.

The final step was to collect all patents taken out by faculty members. We performed a search of all 216 names using the European patent office online service, Espacenet.[9] Espacenet contains information on patents and patent applications for more than 90 countries. We manually searched for each name on the AUA database. In cases where we found a match, we further cross-checked to see if the inventor had disclosed a Greek address and whether the technology field of the patent was similar to his/her area of specialization. After this exhaustive matching, we found that 29% of AUA faculty had filed patent applications.

Our final sample consists of a balanced panel of 40 research laboratories, observed every year between 2002 and 2013. For each laboratory-year observation, we have information on the number of scientific papers published per year *t* per research laboratory *i* (*Publications*) and the number of citations of the *Publications* by laboratory *i* at year *t* that have accrued up to 2013 (*Cites*). Additionally, we have information on the amount of funding by each type of sponsor for every laboratory-year observation, as well as the number of patent applications filed by each research laboratory.

Summary statistics

Table 1 shows the summary statistics for the variables of interest. The average number of *Publications* per year per research laboratory is 8.13 while the number of *Citations* is 95.6. Patent applications per year are naturally small – 0.06 patent applications per application year per research laboratory. The next five variables show amount of research money by type of sponsor. The year is defined as the award year of the research grant. The funding from the European Union either directly (EU), or indirectly through the Greek government (GOVEU), accounts for the majority of the total research funding. Indicatively, per year they amount to 111,000 euros, when the total inflow of research money (adding all five types) is approximately 157,000 euros. In other words, EU and GOVEU account, on average, for 70% of total research funding. GOV accounts for 12.5%, indicating that all public sponsors collectively account for 82.5% of the research funding. PRIV accounts for 15.3% of the total funding.[10]

A comparison with US universities shows that the federal government accounts for approximately 60% of academic research funding, and state and local governments for approximately 7% (National Science Board, 2012), totaling 67% of public support. Grimpe (2012), examining university research funding in Germany, finds

Table 1. Summary statistics of variables of interest.

Variable	Obs	Mean	Std. Dev.	Min	Max
Publications	480	8.13	6.35	0	37
Cites	480	95.36	118.53	0	696
Patent applications	480	0.06	0.31	0	3
EU (by award year)	480	47670.31	146442.10	0	1,226,534
GOV (by award year)	480	15140.14	67103.23	0	875,000
GOVEU (by award year)	480	51195.64	158071.20	0	1,535,014
PRIV (by award year)	480	20991.95	61417.59	0	500,000
UNCLA (by award year)	480	1328.32	13864.72	0	205,600
EU	480	43777.46	92116.60	0	801,901
GOV	480	13589.52	37728.56	0	403,753
GOVEU	480	40694.49	79071.66	0	613,508
PRIV	480	19247.67	36347.96	0	206,490
UNCLA	480	949.15	8261.65	0	102,800

Note: The funding variables that are by award year have been assigned the money of each grant in the year the grant was awarded. The last five variables have evenly distributed the money of each grant over the years the grant was active.

that 66% of research funding stems from public support. The comparisons suggest the share of public support in Greece is higher, indicating perhaps the inability and unwillingness of other sponsors, such as industry and non-profit organizations, to fund university research.

Figure 1 shows total publications per year. Overall, we observe a steady upward trend in the number of publications. Before 2005, the number of publications was below 320, while after 2005, it was closer to 400 publications. Figure 2 shows research funds by type of sponsor 'smoothed out' per year. The most noteworthy finding is that GOVEU increased rapidly after 2010 (the start of the economic crisis

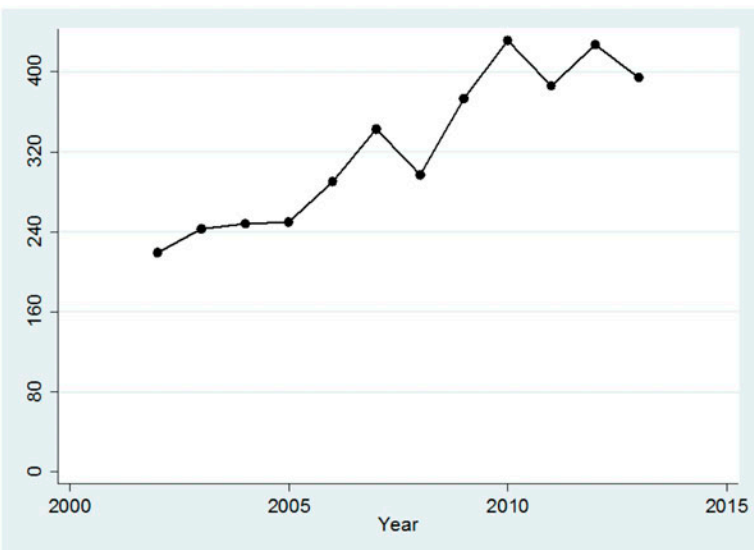

Figure 1. Total publications per year.

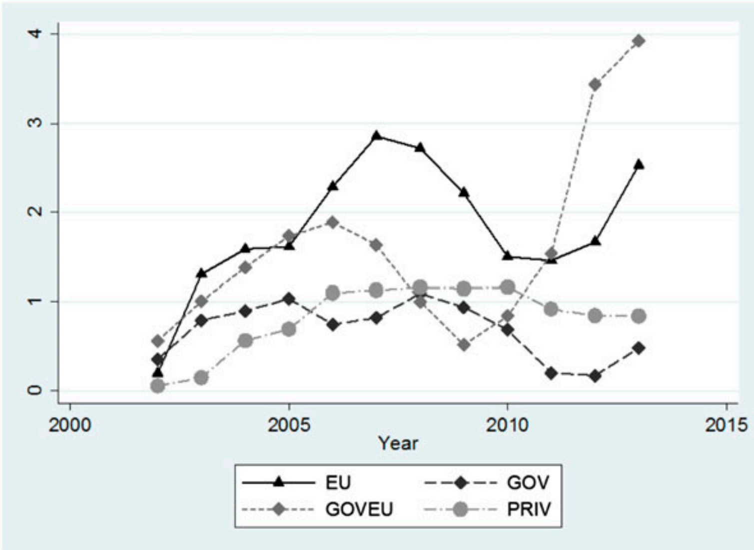

Figure 2. Total research funding by sponsor.

in Greece). This dramatic increase of GOVEU in the final years of the sample was impressive and is attributed to large-scale competitive research projects awarded to research groups of AUA in collaboration with other universities and private companies. The EU increased rapidly over the period 2002–07 from 0.4 to 2.8 million euros. However, in the period 2007–13, grants declined significantly until 2010 and then were relatively stable at about 2 million euros annually. The GOV funding category was stable up to 2008, when it started declining slowly until 2012. At the same time, private funding (PRIV), after a significant increase in the period 2002–06, has been more or less stable, showing that the private sector in Greece requires university expertise regardless of the economic climate.

Overall, PRIV and EU research funds experience a steady upward trend over the sample period. Conversely, the support provided by GOVEU and GOV shows greater variation. This variation is probably supply driven and indicates that while PRIV and EU funding may be less sensitive to economic cycles, GOV and GOVEU are more sensitive. This is intuitive for GOV, but might be less straightforward for GOVEU, given that the majority of money comes from EU. There can be two reasons why this pattern is observed. First, GOVEU funds need a small participation from the Greek government. Without this participation, open calls to researchers cannot be made. Second, as Grant *et al.* (2011) shows, the Greek government faces serious institutional and organizational challenges in absorbing EU money, which can result in abrupt changes in the flows of funds to research institutions.[11]

In addition to the above variables, we further construct four different variables: $Dummy\_EU_{i,t}$ takes the value of 1 if the ith research laboratory was awarded at least one research grant at period t from EU, and zero otherwise. In similar fashion, we construct $Dummy\_GOVEU_{i,t}$, $Dummy\_GOV_{i,t}$ and $Dummy\_PRIV_{i,t}$. Tables 1 and 2 show the frequency in the data from 2002 to 2013 of the occurrences where research laboratories-year pairs were awarded at least one of the aforementioned research

Table 2. Frequency of research grants by type of sponsor (2002–2013).

Variable	Observations	Percentage
$Dummy\_EU_{i,t}$	118	24.6%
$Dummy\_GOV_{i,t}$	83	17.3%
$Dummy\_GOVEU_{i,t}$	143	29.8%
$Dummy\_PRIV_{i,t}$	174	36.3%

Note: Between 2002 and 2013, there are 480 laboratory-year observations. Hence the percentage is calculated as the number of occurrences over 480. $Dummy\_EU_{i,t}$ takes the value of 1 if the *i*th research laboratory was awarded at least one research grant at period *t* and zero otherwise. In similar fashion we construct $Dummy\_GOVEU_{i,t}$, $Dummy\_GOV_{i,t}$ and $Dummy\_PRIV_{i,t}$.

grants. The largest frequency is observed for PRIV, where out of 480 observations, we observe at least one PRIV research grant being awarded for 174 (36.3%) laboratory-year pairs. GOVEU and EU follow in frequency, while GOV has the lowest frequency in the data with 83 occurrences. It should be noted that the frequency of PRIV funds is another indication that the private sector of the agri-food sector is seeking collaboration with Greek universities.

The average EU grant is €127,000, the average GOVEU grant €115,000, the average GOV grant €58,000, and the average PRIV €31,000. It should be pointed out that while the PRIV projects have the highest frequency, they also have the lowest budget. This shows that while the private sector collaborates with the university, it is in projects short in duration and small in budget, which indicates mostly contract-style research. A review of a handful of research contracts from PRIV suggest that AUA is appointed to provide services (such as measurements requiring very expensive laboratory equipment) that cannot be provided from the company's own resources.

Empirical findings – relationship between type of funding and research output

Descriptive analysis

For the remainder of the analysis, we standardize publications, citations and funding by number of faculty for each research laboratory.[12] As funding may take years to become research output, we consider publications with a two-year lag. Similarly, we consider citations to the scientific papers that were published two years after the year in which we observe the funding. Therefore, our effective observed time period becomes 2002–11.

Table 3 shows the correlations between each type of funding, publication and citation output. Results show that while for EU, GOVEU and PRIV funding there is a weak positive relationship with publication output, there is significant noise. The

Table 3. Pairwise correlations across variables of interest.

	Publications	Citations	EU	GOV	GOVRTD	PRIV
Publications	1					
Citations	0.5357*	1				
EU	0.2961*	0.2656*	1			
GOV	–0.0539	0.0133	0.1995*	1		
GOVEU	0.0769	0.1448*	0.0316	–0.0019	1	
PRIV	0.3407*	0.0859*	0.1823*	0.1229*	0.1107*	1

*displays significance at the 10% level.

correlation coefficients are 0.33, 0.14 and 0.28, significantly different from zero. However, the relationship between GOV funding and publications does not appear to have a sizeable relationship with a correlation of –0.04, which is not statistically different from zero. A similar picture emerges where instead of considering publications per number of faculty for each research laboratory, we consider number of citations per number of faculty for each research laboratory. The correlation coefficients between EU, GOVEU and citations are 0.26 and 0.19, with each being statistically significant. While the correlation between PRIV and citations is positive, it is very small (0.02) and statistically insignificant. This result indicates that, while there is a weak positive relationship between PRIV and publication output, this relationship is not robust and decreases significantly when we examine its impact via citations instead of examining the quantity of scientific output. As before, there is virtually no relationship between GOV and citations.

The above results show that while there are positive associations between three types of funding and research output, such associations are characterized by significant noise and, in the case of PRIV, are not statistically significant when examining citations. Until now, we have focused on amount of funding. Next, we investigate the existence of each of these four types of funding and how these may be associated with research output. As before, for the cases of publications and citations, we consider a two-year lag. Table 4 compares the average number of publications and citations by distinguishing whether there was at least one research grant (of each of the four types) at the laboratory. In the cases of EU, GOVEU and PRIV we observe that both publications and citations are higher when there is at least one research grant in the laboratory two years in advance. Differences are either marginally insignificant at the 10% level or statistically significant. In the case of GOV, laboratories awarded such a grant two years in advance do not have different research output different from that of laboratories not awarded such a grant.

These comparisons show that while research funding can have a small, positive and noisy relationship with research output for the cases of EU, GOVEU and PRIV, the relationship is stronger when considering the presence of such types of grants in research laboratories. EU and GOVEU are most likely competitive research grants and therefore a grant implies an external recognition that the research laboratory is

Table 4. Comparison of publications and citations by funding type.

	$Dummy\_EU_{i,t}$=0	$Dummy\_EU_{i,t}$=1	*t*-test (comparing averages)
$Pubs_{i,t+2}$	1.39	1.6	1.6
$Cites_{i,t+2}$	13.9	20.7	**3.03**
	$Dummy\_GOV_{i,t}$=0	$Dummy\_GOV_{i,t}$=1	
$Pubs_{i,t+2}$	1.49	1.26	1.58
$Cites_{i,t+2}$	15.72	15.26	0.84
	$Dummy\_GOVEU_{i,t}$=0	$Dummy\_GOVEU_{i,t}$=1	
$Pubs_{i,t+2}$	1.37	1.6	**1.8**
$Cites_{i,t+2}$	11.56	24.3	**5.52**
	$Dummy\_PRIV_{i,t}$=0	$Dummy\_PRIV_{i,t}$=1	
$Pubs_{i,t+2}$	1.35	1.63	**2.23**
$Cites_{i,t+2}$	14.4	17.8	1.54

Note: Each number in the first two columns represents the mean number of either the $Pubs_{i,t+2}$ or $Cites_{i,t+2}$. The *t*-statistics are derived from a *t*-test comparing means of independent samples. Bolded *t*-statistics denote that the two averages are statistically different at the 10% significance level.

engaged in research with the outcome being increased publications and citations. While PRIV funding may be less competition, it is based on market need for specialized laboratory work. Finally, GOV projects are mainly non-competitive (assigned to certain research groups by the government) and may not necessarily promote research output (publications and citations).

Regression analysis

To explore in more detail these relationships with research output, we perform a regression analysis by controlling for the type of funding. The first model considers funding for each type of sponsor. Our model is:

$$\ln(Publications_{i,t+2}+1) = \beta_0+\beta_1\ln(EU_{i,t}) + \beta_2\ln(GOV_{i,t}) + \beta_3\ln(GOVEU_{i,t}) + \beta_4\ln(PRIV_{i,t}) + \beta_5 Laboratory_i + \beta_6 Year_t + \varepsilon_{it}$$

where $Publications_{i,t+2}$ is the number of publications of research laboratory i at year t+2 per number of faculty at laboratory i. $EU_{i,t}$ is the amount of EU funding to laboratory i at year t divided by the number of faculty. $GOV_{i,t}$, $GOVEU_{i,t}$ and $PRIV_{i,t}$ are defined similarly. $Laboratory_i$ are fixed effects for laboratory i and $Year_t$ are year fixed effects (that is, a dummy for each laboratory and each year respectively). We include laboratory fixed effects to account for unobserved heterogeneity within each research laboratory. In other words, these dummies capture all other characteristics, except the funding performance, that may be related to each laboratory separately. To examine the relationship with citations, we re-estimate the regression by replacing $Publications_{i,t+2}$ with $Cites_{i,t+2}$. We should note that while *Publications* and *Citations* are count data, the appropriate estimation would be through a Poisson or negative binomial regression. However, since we divide by the number of faculty to account for the size of each research laboratory, both dependent variables are no longer count data. Hence, we opt for taking the natural logs so that coefficients can readily be interpreted as elasticities.

Table 5 displays the results. The first two columns do not include laboratory fixed effects while columns 3 and 4 do. In the Appendix, we discuss the regression diagnostics. Most of the conditions are satisfied for the models we estimate. The one pronounced exception is the homoskedasticity of residuals and we correct for this by estimating robust standard errors. When we do not include laboratory fixed effects (columns 1 and 2), we observe that increases in EU, GOVEU or PRIV research funds are associated with positive changes in publications and citations, and in at least one of the cases the coefficient is significant. For instance, a 100% increase in EU funding is associated with a 1.52% increase in publications (column 1). Conversely, increases in GOV research funds are associated with negative, though small and statistically-significant, changes in research output.

However, when we include laboratory fixed effects, all the coefficients are statistically insignificant. Therefore, after accounting for unobserved heterogeneity, the association between funding and research output disappears, implying that level of research funding does not seem to influence overall research productivity. Put differently, laboratories that are inherently productive will be productive both in terms of research funding and research output. By including laboratory fixed effects, this productivity attribute is captured in the laboratory dummies, resulting in the relationship between funding and research output being statistically insignificant. In any case,

Table 5. Regression results for level of research funding and research output.

Variables	(1) $\ln(Pubs_{i,t+2}+1)$	(2) $\ln(Cites_{i,t+2}+1)$	(3) $\ln(Pubs_{i,t+2}+1)$	(4) $\ln(Cites_{i,t+2}+1)$
$\ln EU_{i,t}$	0.0152***	0.0470***	0.00170	0.00209
	(0.00539)	(0.0139)	(0.00477)	(0.0120)
$\ln GOV_{i,t}$	–0.0158***	–0.0290**	–0.00452	0.00197
	(0.00530)	(0.0134)	(0.00502)	(0.0114)
$\ln GOVEU_{i,t}$	0.0114*	0.0418***	–0.00256	–0.0113
	(0.00583)	(0.0152)	(0.00478)	(0.0124)
$\ln PRIV_{i,t}$	0.00839	0.0446***	–0.00243	–0.00612
	(0.00563)	(0.0144)	(0.00545)	(0.0154)
Constant	0.567***	1.622***	0.764***	2.429***
	(0.0766)	(0.206)	(0.0653)	(0.181)
Laboratory fixed effects	NO	NO	YES	YES
Year fixed effects	YES	YES	YES	YES
Observations	400	400	400	400
R-squared	0.111	0.330	0.634	0.729

Note: The regressions are estimated via ordinary least squares. Robust standard errors are displayed in parentheses.
*p<0.1; see Appendix C.
**p<0.05.
***p<0.01.

these findings suggest there are no significant differences between public and private research support.

From the regression diagnostics presented in the Appendix, we see that the model specification condition is violated even though the significance is not very strong. Therefore, in this second model we examine the association of the existence, instead of amount, of research funds and research output. In other words, we include dummy variables instead of amounts. The model is:

$$\ln(Publications_{i,t+2}+1) = \beta_0 + \beta_1 DummyEU_{i,t} + \beta_2 DummyGOV_{i,t} + \beta_3 DummyGOVEU_{i,t} + \beta_4 DummyPRIV_{i,t} + \beta_5 Laboratory_i + \beta_6 Year_t + \varepsilon_{it}$$

Table 6 displays the results. The first two columns do not include laboratory fixed effects, while columns 3 and 4 do. When we do not include laboratory fixed effects, *DummyEU* and *DummyPRIV* are associated positively with both publications and citations, with the coefficients in publications being insignificant. The coefficient of *DummyGOVEU* is both positive and statistically significant. Since the regression is in log-linear form, the coefficients should be exponentiated to be interpreted correctly. For instance, a laboratory that obtained at least one GOVEU grant at time t will experience a 14% (Exp(0.134)–1=1.14–1) increase in publications per faculty at time t+2 compared with a research laboratory that was not awarded a GOVEU grant at time t. In the case of GOV, the coefficients are negative and therefore consistent with previous results. These results imply that the mere existence of an EU, GOVEU or PRIV grant is associated with increases in research output. They reinforce our notion that an award of a grant from one of these sponsors indicates the willingness and intention of the research laboratory to engage in research over the following years. This does not hold true for GOV grants, where the majority of this research is non-competitive, resulting in low research output.

Table 6. Regression results for research grant and research output.

Variables	(1) $\ln(Pubs_{i,t+2}+1)$	(2) $\ln(Cites_{i,t+2}+1)$	(3) $\ln(Pubs_{i,t+2}+1)$	(4) $\ln(Cites_{i,t+2}+1)$
$Dummy\_EU_{i,t}$	0.0416	0.235*	–0.0272	–0.0231
	(0.0544)	(0.136)	(0.0355)	(0.0895)
$Dummy\_GOV_{i,t}$	–0.108**	–0.187	–0.0603	–0.0511
	(0.0488)	(0.136)	(0.0396)	(0.0962)
$Dummy\_GOVEU_{i,t}$	0.134***	0.360***	0.00838	–0.0152
	(0.0506)	(0.137)	(0.0343)	(0.0877)
$Dummy\_PRIV_{i,t}$	0.0711	0.324***	–0.00925	–0.0129
	(0.0449)	(0.113)	(0.0312)	(0.0748)
Constant	0.699***	2.216***	0.865***	1.735***
	(0.0685)	(0.193)	(0.0538)	(0.120)
Laboratory fixed effects	NO	NO	YES	YES
Year fixed effects	YES	YES	YES	YES
Observations	400	400	400	400
R-squared	0.088	0.293	0.636	0.728

Note: The regressions are estimated via ordinary least squares. Robust standard errors are displayed in parentheses.
*$p<0.1$; see Appendix C.
**$p<0.05$.
***$p<0.01$.

A note with respect to GOV is warranted. Overall, the association of GOV and research output is small to negative compared with other funders when we do not control for laboratory heterogeneity. This result could be partially driven by the fact that GOV funding may lead to publications written in Greek. As we have focused on publications in English, we could have lost a part of GOV's scientific output. Even if this is the case, such Greek publications are not likely to have a significant scientific impact (they are likely to be cited only by Greek-speaking scholars). Therefore, we are not likely to be underestimating the association between GOV and impact of research output.

When we include laboratory fixed effects, the positive and statistically-significant relationships disappear (Table 5). Therefore, the unobserved heterogeneity of each research laboratory explains a large part of the productivity. This finding, as before, implies that laboratories which are inherently productive will publish and be cited, and will also be able to attract extramural funding. To provide robustness of our results, we consider two more additional checks. First, in addition to considering a two-year lag between research output and funding, we examine the sensitivity of our results for a one-year and a three-year lag. Tables A1 and A2 in Appendix A consider the counterparts of Tables 5 and 6. The dependent variables are $\ln(Pubs_{i,t+1}+1)$ and $\ln(Cites_{i,t+1}+1)$ instead of $\ln(Pubs_{i,t+2}+1)$ and $\ln(Cites_{i,t+2}+1)$. Tables B1 and B2 of Appendix B also consider the counterparts of Tables 5 and 6. The dependent variables are $\ln(Pubs_{i,t+3}+1)$ and $\ln(Cites_{i,t+3}+1)$ instead of $\ln(Pubs_{i,t+2}+1)$ and $\ln(Cites_{i,t+2}+1)$. Results in both cases are similar to those presented in the main text.

Role of patent filing propensity

We now examine the relationship between patenting and research productivity. Nine research laboratories filed for at least one patent application.[13] If we exclude research laboratories from the department of agricultural and rural development (AGECON)

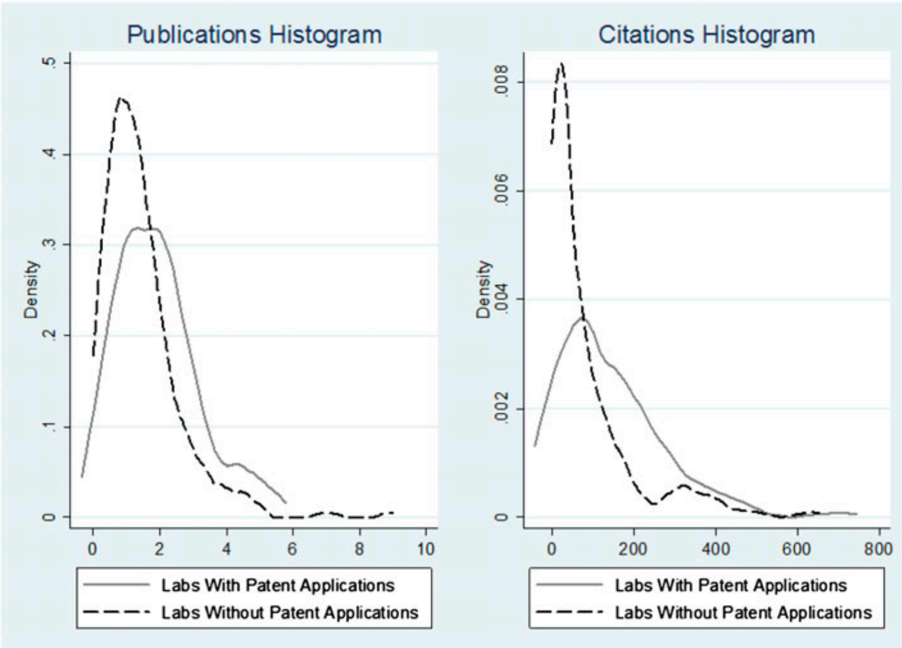

Figure 3. Comparison of publications and citations for laboratories with and without patent applications.

(because they are less likely to have patentable output), this indicates that 25.7% of the remaining laboratories made at least one patent application. Figure 3 shows the difference in publications and citations per faculty for laboratories with at least one patent application and for laboratories without (excluding laboratories from the AGECON department). Laboratories with at least one patent application appear to outperform laboratories without any applications in both metrics. Table 7 looks at differences in research funds in relation to patent output. With the notable exception of GOV, laboratories with at least one patent application receive more funds from all types of research sponsors. The differences are statistically significant (with the exception of EU, which is borderline insignificant).

Table 7. Comparison of laboratories with and without patent applications.

	Laboratories without patent application	Laboratories with at least one patent application	*t*-test (comparing averages)
$Pubs_{i,t+2}$	1.4	1.92	–3.6
$Cites_{i,t+2}$	14.7	23.4	–3.2
$EU_{i,t}$	6358	9833	–1.64
$GOV_{i,t}$	2401	2301	1.06
$GOVEU_{i,t}$	4480	6707	–2.4
$PRIV_{i,t}$	2916	4718	–2.3

Note: Each number in the first two columns represents the mean number of each variable. The *t*-statistics are derived from a *t*-test of comparing means of independent samples. Bolded *t*-statistics denote that the two averages are statistically different at the 10% significance level.

Much of the literature also finds little relationship between patenting and publications (e.g. Foltz *et al.*, 2007). Thursby *et al.* (2007) show that an academic career spread between basic and applied research is likely to be more productive than a one-dimensional career. The results in this paper give insights for a country with a less mature technology transfer culture, and should help reduce concern that commercialization of universities may lead to a distortion of university research agenda. The necessary caveat is that our findings are based on the current level of commercialization. They do not extend to potential future increases in commercialization activities by universities. In Greece, debate on university–industry collaboration is intense. Future policy there and in similar countries should ensure that such collaboration yields optimal results both for industry and university.

Conclusion

This paper has examined public–private relationships in the largest agricultural university in Greece. While universities play a critical role in innovation, concerns have been raised that continuing interaction between industry and academia can impede the university's mission. Most research has focused on countries with significant experience in public–private collaboration. Conclusions about the relationship between type of research funding and quantity and quality of research output are mixed. As Greece is a country with less experience, valuable insights can be provided for countries of similar expertise.

We have examined the relationship between research support and scientific output by distinguishing among types of sponsor. Further, we distinguish among public funding that stems from the Greek government, the European Union but handled by Greek agencies, and the European Union directly. This is an important distinction when examining European universities as they all encounter similar sorts of public sponsors. We find that all types of sponsor, with the notable exception of GOV, are positively associated with quantity and quality of research output, though the relationships are not always statistically significant. While the difference between GOV and the other public sponsors could be partially driven by the fact that government funding may lead to publications in Greek (which we do not include in our sample), this difference still indicates that GOV funding is associated with lower impact research output. We propose that the difference between GOV and the other sponsors is most likely attributable to all other grants being competitive. This finding is relevant to the public funding of research in universities across the EU and not just in Greece.

More importantly, our results do not lend support to concerns that private funding may reduce academic research output. Further, once we control for the inherent resources of each research laboratory by including laboratory fixed effects, all relationships turn insignificant. Even though these findings do not claim causality, they do suggest that, at equilibrium, all types of sponsors are associated in a similar fashion with research output after we control for laboratory heterogeneity.

We also considered whether commercially-oriented research laboratories differ from other laboratories. We assume that more commercially-oriented laboratories will file for patent applications. We find that these laboratories are, on average, more productive and receive more research funding from both public competitive sponsors and industry sponsors. These results should also be interpreted cautiously; however, they do not support views that commercially-oriented laboratories in universities are likely to fall behind in academic research. Our results imply that, at equilibrium, the most productive laboratories are also the ones that will successfully pursue entrepreneurial activities.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Notes

1. Two examples are research into wheat varieties in Mexico and rice at the International Rice Research Institute (Wright, 2012).
2. The other major concern of those studying university–industry collaboration is the exclusionary control over academic research findings stemming from industry funding (Washburn, 2005). This concern received considerable attention in the literature after a series of high-profile research grants from multinational corporations to academic institutions (Press and Washburn, 2000; Washburn, 2010). This issue, however, is not the focus of this paper. For evidence from the UK, see Lawson (2013) and from California, see Wright *et al*. (2014).
3. These are Agricultural Economics and Rural Development; Crop Science; Animal Science and Aquaculture; Agricultural Biotechnology; Food Science and Technology; Natural Resources Management and Agricultural Engineering.
4. Results are similar if we include these two laboratories in our analysis.
5. We should also note that an alternative data source would be the Web of Science. Web of Science has a smaller number of journals listed (Chadegani *et al*., 2013) than Scopus as it focuses more on basic research (Goldfarb, 2008). Since we are also interested in the overall impact of the research and have included citations as a variable in the quantitative analysis, Scopus seems overall more appropriate to our research.
6. Whenever the id number was not unique (fewer than 10% of cases), we downloaded all the id numbers and their associated publications for each author.
7. We also excluded duplicate publications. For instance, we took out Greek publications as these were also likely to be published in English. These accounted for approximately 20 publications out of 3000.
8. In detail, we downloaded the CV of each faculty member from their academic webpage and retrieved all their publications. In addition, we retrieved all their publications from their Scopus profiles. As not all CVs were up to date, we made sure to compare the number of publications up to a certain common year. In all cases, the number of publications in Scopus was very close to the number of publications in CVs. On occasion, the Scopus profile counted a few more publications, mainly because Scopus considers chapters in edited volumes to have been peer reviewed (as they have been in most cases). In conclusion, we did not find pronounced differences between the number of papers reported in Scopus and the number reported in the CVs.
9. http://worldwide.espacenet.com/advancedSearch?locale=en_EP.
10. As UNCLASS is a very small portion of total research funding, we exclude it from the rest of the analysis.
11. Harman and Ollif (2004) show that implementation of public funding in Australia also faces similar problems.

12. We also collected information about Ph.D. students, postdocs, teaching and research staff by laboratory. However, these data are not accurate for earlier years in our sample. In any case, regressions where we divide research metrics with the entire number of research staff by laboratory provide qualitatively similar results and are available on request.
13. These are evenly spread across the five departments of AUA, excluding the AGECON department. The most productive laboratories in terms of patent applications are the general chemistry laboratory of the FOOD department and the agricultural engineering laboratory of the NAT department with nine and five applications respectively.

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Appendix A

Table A1. Regression results for funding and research output.

Variables	(1) $\ln(Pubs_{i,t+1}+1)$	(2) $\ln(Cites_{i,t+1}+1)$	(3) $\ln(Pubs_{i,t+1}+1)$	(4) $\ln(Cites_{i,t+1}+1)$
$\ln EU_{i,t}$	0.0134***	0.0544***	–0.00118	0.00396
	(0.00496)	(0.0134)	(0.00418)	(0.0115)
$\ln GOV_{i,t}$	–0.0171***	–0.0437***	–0.00545	–0.0107
	(0.00516)	(0.0146)	(0.00454)	(0.0129)
$\ln GOVEU_{i,t}$	0.0204***	0.0504***	0.00576	–0.00203
	(0.00540)	(0.0145)	(0.00422)	(0.0113)
$\ln PRIV_{i,t}$	0.0131**	0.0451***	0.00647	–0.00493
	(0.00542)	(0.0143)	(0.00526)	(0.0129)
Constant	0.539***	1.684***	0.725***	2.520***
	(0.0836)	(0.225)	(0.0669)	(0.168)
Laboratory fixed effects	NO	NO	YES	YES
Year fixed effects	YES	YES	YES	YES
Observations	440	440	440	440
R-squared	0.152	0.322	0.643	0.733

Note: Regressions are estimated via ordinary least squares. Robust standard errors are displayed in parentheses.
*$p<0.1$. Our sample size is 440 as we examine 40 research laboratories during the 10-year period from 2002 to 2012 and take one-year forward lag of our dependent variable.

Table A2. Regression results for existence of research funds and research output.

Variables	(1) $\ln(Pubs_{i,t+1}+1)$	(2) $\ln(Cites_{i,t+1}+1)$	(3) $\ln(Pubs_{i,t+1}+1)$	(4) $\ln(Cites_{i,t+1}+1)$
$Dummy\_EU_{i,t}$	0.0511	0.173	–0.0350	–0.144*
	(0.0492)	(0.130)	(0.0336)	(0.0834)
$Dummy\_GOV_{i,t}$	–0.0781	–0.243*	–0.0132	–0.0578
	(0.0512)	(0.144)	(0.0411)	(0.108)
$Dummy\_GOVEU_{i,t}$	0.176***	0.516***	0.0328	0.0632
	(0.0468)	(0.127)	(0.0326)	(0.0821)
$Dummy\_PRIV_{i,t}$	0.0980**	0.373***	–0.00173	–0.0643
	(0.0425)	(0.110)	(0.0301)	(0.0746)
Constant	0.875***	2.191***	0.928***	2.429***
	(0.0808)	(0.183)	(0.0639)	(0.149)
Laboratory fixed effects	NO	NO	YES	YES
Year fixed effects	YES	YES	YES	YES
Observations	440	440	440	440
R-squared	0.113	0.282	0.640	0.735

Note: Regressions are estimated via ordinary least squares. Robust standard errors are displayed in parentheses.
*$p<0.1$. Our sample size is 440 as we examine 40 research laboratories during the 10-year period from 2002 to 2012 and take one-year forward lag of our dependent variable.
**$p<0.05$.
***$p<0.01$.

Appendix B

Table B1. Regression results for funding amount and research output.

Variables	(1) $\ln(Pubs_{i,t+3}+1)$	(2) $\ln(Cites_{i,t+3}+1)$	(3) $\ln(Pubs_{i,t+3}+1)$	(4) $\ln(Cites_{i,t+3}+1)$
$\ln EU_{i,t}$	0.0195***	0.0628***	–0.000466	–0.000352
	(0.00558)	(0.0145)	(0.00461)	(0.0123)
$\ln GOV_{i,t}$	–0.0141**	–0.0281*	0.00267	0.0162
	(0.00596)	(0.0147)	(0.00537)	(0.0133)
$\ln GOVEU_{i,t}$	0.00897	0.0284	0.00225	–0.0200
	(0.00649)	(0.0173)	(0.00544)	(0.0142)
$\ln PRIV_{i,t}$	0.00514	0.0192	0.00317	–0.0205
	(0.00619)	(0.0167)	(0.00554)	(0.0161)
Constant	0.728***	1.865***	0.840***	2.623***
	(0.0739)	(0.179)	(0.0649)	(0.161)
Laboratory fixed effects	NO	NO	YES	YES
Year fixed effects	YES	YES	YES	YES
Observations	360	360	360	360
R-squared	0.102	0.323	0.651	0.744

Note: Regressions are estimated via ordinary least squares. Robust standard errors are displayed in parentheses.
*$p<0.1$. Our sample size is 360 as we examine 40 research laboratories during the period 2002–2010 and take a three-year forward lag of our dependent variable.
**$p<0.05$.
***$p<0.01$.

Table B2. Regression results for existence of research funds and research output.

Variables	(1) $\ln(Pubs_{i,t+3}+1)$	(2) $\ln(Cites_{i,t+3}+1)$	(3) $\ln(Pubs_{i,t+3}+1)$	(4) $\ln(Cites_{i,t+3}+1)$
$Dummy\_EU_{i,t}$	0.0549	0.194	–0.0271	–0.0985
	(0.0568)	(0.147)	(0.0369)	(0.0994)
$Dummy\_GOV_{i,t}$	–0.117**	–0.214	–0.0355	–0.00687
	(0.0516)	(0.143)	(0.0378)	(0.106)
$Dummy\_GOVEU_{i,t}$	0.128**	0.459***	–0.00306	–0.0331
	(0.0576)	(0.151)	(0.0374)	(0.0954)
$Dummy\_PRIV_{i,t}$	0.0918*	0.234*	0.0295	–0.0766
	(0.0477)	(0.119)	(0.0351)	(0.0889)
Constant	0.632***	1.962***	0.933***	1.370***
	(0.0704)	(0.215)	(0.0428)	(0.0972)
Laboratory fixed effects	NO	NO	YES	YES
Year fixed effects	YES	YES	YES	YES
Observations	360	360	360	360
R-squared	0.082	0.295	0.652	0.741

Note: Regressions are estimated via ordinary least squares. Robust standard errors are displayed in parentheses.
*p<0.1. Our sample size is 360 as we examine 40 research laboratories during the period 2002–2010 and take a three-year forward lag of our dependent variable.
**p<0.05.
***p<0.01.

Appendix C.

Diagnostics for regressions in Tables 5 and 6

We ran a number of diagnostics to verify that our model specifications and the Ordinary Least Squares estimator were acceptable. Here, we discuss the diagnostics for Tables 5 and 6.

- Outliers: as robustness, we excluded from our estimations the five observations with the most publications. All coefficients retained the same sign, similar significance and (once we control for laboratory fixed effects), results are qualitatively similar.
- Normality of residuals: once we had run each regression, we calculated the residuals and used the Shapiro–Wilk W test for normality. In all cases we cannot reject the null hypothesis that the residuals follow the normal distribution.
- Homoskedasticity of residuals: this condition is violated. For this reason in all our specifications we calculate robust standard errors. In other words, we allow for the diagonal elements in the variance–covariance matrix to vary.
- Multicollinearity: after each regression, we estimate the variance inflation factor (VIF) for each variable. In none of the cases is the VIF large enough to warrant attention. Therefore, the independent variables do not display collinear behavior in our estimations.
- Linearity: here in essence we check whether the independent variables have a linear relationship with the dependent variable. Therefore, in the case of Table 6, non-linearity cannot be tested as the independent variables are dummies. For Table 5, in all cases after regressions we plot the standardized residuals against each independent variable. While there appears to be a weak non-linear relationship, this is not pronounced. Further, if we include squared terms in the regressions, they are not statistically significant. This diagnostic was one

of the reasons we included Table 6 (by converting our independent variables into dummies) to capture other aspects of the sponsorship–output relationship. In any event, comparisons between Tables 5 and 6 do not reveal any pronounced differences.

- Model specification: with this diagnostic, we explore whether our model is specified correctly; in other words, that all the relevant variables have been included. In our case, the first two columns of Table 5 fail such a diagnostic as there are naturally a number of laboratory variables that are relevant and should be included in our model. The statistical test of specification error is weaker when we include the laboratory dummies, but it is still significant at the 10% level (though not at the 1% level). However, in Table 6, tests for specification errors appear to be even weaker. Nonetheless, this issue stems from omitted variables, which we cannot obtain for earlier years in our sample.