Industry and Public Research Grants: Complements for Academic Research?*

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Abstract

This paper investigates empirically the existence of complementarities between public and private funding. We find that for a sample of UK engineering academics that industry funding decreases the marginal utility of public funding by lowering the publication rate increase associated with public grants. However, it reduces the positive effect of funding received from government and charities only for grant values in the top percentile. The paper shows that while both types of funding increase publication rates, private funding increases publications at a lower rate and seems to compromise high-impact research efforts resulting in a decrease in marginal utility from other types of funding. The paper also shows that UK public funding and EU funding act as substitutes, not compromising the marginal utility derived from the other.

Keywords: Research Funding, University-Industry Collaboration, Crowding Out, Scientific Productivity

JEL codes: L31; O3

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1 Introduction

In the past three decades universities and other public research institutions have witnessed a push for greater industrial involvement and commercial relevance in research. Several policies in the US and Europe directly sought to favour research relevant to technological advancement and responsive to the needs of industry. Shrinking public research budgets further resulted in a shift towards private sponsorship in most OECD countries (OECD 2010). This shift has often been criticised for compromising the independence of academic research but has also been celebrated as a way for academia to tap on new financial sources and ideas by academics and policy makers alike.

The controversial debate surrounding the so called commercialisation of academic research has sparked a large body of empirical literature that aims at identifying the real consequences of closer collaboration with industry. It has been claimed that industry partners may direct academics towards applied research and limit or delay the public dissemination of research results (Blumenthal et al., 1986, 1996; Cohen et al., 1998). These papers conclude that academics' general duties and research duties in particular are compromised by an increase in time allocated to development, consulting and commercialisation. On the other hand, several studies have argued that industry can provide not only funds but also ideas for research (Mansfield, 1995; Lee, 2000; Siegel et al., 2003; Hottenrott and Lawson, 2012). Researchers may be able to benefit in their academic work from closer links to practitioners. Insights into applied processes and problems of industry may provide the ideas for new ground-breaking research.

However, industry sponsorship cannot be evaluated without considering its effect on productivity effects from other types of funding. Public funding is considered crucial to increasing research output (Stephan 1996, 2012) and it is of interest whether industry sponsorship would compromise its positive effects. If industry partners demand a shift of research topic and secrecy than also public funding placed with such industry sponsored researchers may suffer from these limitations and result in a decrease in research output (Cohen et al, 1998). This is particularly critical as public budgets are shrinking and researchers increasingly need to look at other channels for support of their research. On the other hand, if researchers obtain new ideas through links with industry then also the expected benefits from public funding should increase as both types of funding may increase the productivity of the other leading to positive complementarities (Mansfield, 1995; Zucker et al., 1996, 1998).

While previous work has identified the various forms of interactions between industry and academia (e.g. Agrawal and Henderson, 2002; Cohen et al, 2002) and studied intensively the effect of such interactions on research outcomes (e.g. Blumenthal et al., 1996; Guldbrandsen and Smeby, 2005; Banal-Estanol et al., 2010; Hottenrott and Thorwarth, 2011), the joint effect of industry and public funding and potential substitution or complementary effects have yet to be investigated to put results of prior studies on industry-science links in context.

This study aims to fill this gap in the literature by investigating the joint effect of funding from public and private sponsors on the research productivity of a sample of UK engineering academics. Using data on research income of individual researchers at 15 UK universities we are able to investigate potential complementarities and substitution effects between private and public money and how they affect publication rates of receiving academics. Previous studies have shown that an increased share of research funding coming from industry is associated with lower publication rates (Manjarres-Henriquez et al., 2008; Banal-Estanol et al., 2010; Hottenrott and Thorwarth, 2011;). Our results add to these insights by showing that industry funding decreases the marginal utility of public funding by decreasing the publication rate increase associated to public grants. The paper shows that while both types of funding increase publication and citation rates, private sector funding seems to compromise research efforts such that it can result in a decrease in marginal utility from other types of funding.

The remainder of the paper is organised as follows: Section 2 summarises the literature on research funding and productivity. Section 3 describes the data and sets out the model and section 4 presents the results. In section 5 we conclude.

2 Background

Industry grants have been identified as a major source of funding for academic research in recent years. In the US the so called competitiveness crisis prompted a series of structural changes in the intellectual property regime accompanied by several incentive programs designed specifically to promote collaboration between universities and industry (Lee, 2000).

Similarly in the UK several changes in funding allocation have taken place since the 1970s. Initially core funding was reduced to promote research activities that attract funding from non-governmental sources, and later was increasingly allocated through program driven research grants to indirectly control universities' research agendas (Geuna, 1999). In recent years also core funding is increasingly allocated based on a series of research evaluation measures. The dual funding structure and selective funding policies introduced in the UK and long history of obtaining funding from industry represent a model, by which the changes in other European countries may be emulated.

2.1 Industry grants and research productivity

In many subject areas, including engineering and material science, much of the research would not be possible without the input of industry partners. In a survey of 671 academic scientists and engineers, Lee (2000) reports securing of funds for equipment and research assistants as the principal reason for collaboration with industry, leading to more autonomy and flexibility for academic researchers. Additionally, contacts to industry allow insight into applied research processes providing new ideas for research.

More than just providing an attractive source of additional research funding to supplement the department's core resources, external sponsorship involves contractual agreements and research guidance that may potentially affect academic research. Specifically, the objectives of different sponsors may influence the choice of research topic and choice of dissemination channels. Several papers have indeed argued that funding influences the behaviour of researchers, in terms of selection of research topics, methodology and finally research orientation (Slaughter and Leslie, 1997; Cohen et al., 1998; Benner and Sandström, 2000) and industry sponsors may have a particular interest in influencing research and dissemination channels to recover their investments. Accordingly, Blumenthal et al. (1986, 1996, 2006) and Cohen et al. (1998) argue that industry may direct researchers towards applied research and limit or delay the release of publications. Gulbrandsen and Smeby (2005) indeed observe that university researchers in Norway who attracted industry funding are more likely to describe their research as "applied" compared to researchers without industry funding, while Blumenthal et al. (2006) and Czarnitzki et al. (2011) find evidence of publication delay and secrecy. Other recent studies confirm the negative effect of industry grants on publication rates (Hottenrott and Thorwarth, 2011). Instead, industry sponsorship may favour the appropriation of research results through patenting as shown by Hottenrott and Thorwarth (2011) for science and engineering faculty in Germany and Lawson (2012) for UK engineering researchers.

2.2 Complementary role of public grants

The hypothesised negative effect of industry sponsorship on publications may also distort the positive effect of public funding. Public grants have repeatedly been found to positively affect research productivity (Benavente et al., 2012; Chudnovsky et al., 2008; Hottenrott and Thorwarth, 2011; Jacob and Lefgren, 2011; Kelchtermans and Veugelers, 2011), but this effect may be weakened if complementary funding is sourced from industry. Shifts in research topic, time constraints and increased secrecy would then not only have a negative impact on publications but also reduce the positive effect of other, science-oriented funding.

Others have argued that industry funding could also have a positive effect on research performance. Slaughter and Rhoades (2004) argue that university researchers may be motivated to interact with private companies for reasons other than access to additional research funding, like finding potential co-authors and ideas for their research agenda. Also, Lee (2000) identified the acquisition of research ideas as one of the main motives for researchers to pursue joint research with industry. Mansfield (1995) reported that a substantial number of university research projects were initiated through consulting activities within firms. This did not only apply to industry-sponsored projects, also research projects sponsored by public agents were influenced by problems from industry. Theoretical work by Banal-Estanol and Macho-Stadler (2010) and Thursby et al. (2007) argued further that basic research might be reinforced by technology transfer objectives resulting in an increase in basic research efforts. In this line, Manjarres-Henriquez et al. (2008) and Banal-Estanol et al. (2010) show a curvilinear effect of the share of industry funding which may be indicative of a complementary effect of public and private funding up to a certain threshold. However, in a recent paper Hottenrott and Lawson (2012) find researchers that report industry as a source for research ideas to publish less than their peers that source research ideas from elsewhere. Their findings suggest that ideas coming from industry do not translate into more or better quality publications. Thus, public funding might merely off-set the negative effect of industry grants.

Overall, the previous literature suggests a decrease in publications and publication quality for researchers that receive the majority of their funding from industry. It also shows that researchers with low levels of industry funding publish more than their peers that receive no such grants, which indicates a complementary effect of public funding at least up to a threshold. In this line, this paper analyses the joint effect of public and industry sponsorship using the amount of research income from each sponsor and their product as predictors to evaluate the existence of any complementary effects.

2.3 Substitution between public grants

Researchers source funding from a variety of public sources and there is evidence that some public sponsors promote research more effectively than others (Azoulay et al., 2011). Azoulay et al. (2011) study the impact of funding from two different public sponsors with different grant design and agenda. They find that funding from the Howard Hughes Medical Institute's (HHMI), a sponsor that allows for more scientific freedom perform significantly better than a group of similar researchers funded by the National Institutes of Health (NIH). Just as US academic life scientists rely on NIH funding for their research, UK engineers rely on EPSRC research council funding. With the increasing competitiveness of these grants more researchers are turning towards the European Commission Framework Programmes for research sponsorship. While both sponsors have specific research lines they promote, EU grants are organised in specific funding periods and around specific research actions, mostly involving researchers from several countries. The main difference lies in the administrative burden associated with EU grants (Grimple, 2012). Further, Grimpe (2012) found for a sample of German academics that while industry and research council grants go to the most able academics, EU grants are not strongly correlated with research publications. Grimpe (2012) further analysis the effect of different types of funding on the receipt of EU grants and shows that EU grants are not acquired complementary to any other research funding but perhaps only being pursued when other funding channels are not available.

We could therefore expect that also in terms of their effect on publication outcomes industry grants may complement UK or EU grants differently. Further, we may expect potential substitution effects between UK and EU grants in terms of their effect on publications.

3 Empirical Model and data

3.1 Empirical Model

We base our model of research funding complementarity on the notion of utility maximisation of the academic. An academic exerts different research efforts aimed at producing measurable research outputs with the goal of maximising her utility. We assume that the academic derives her utility primarily from publication output. Researchers in science have repeatedly been shown to possess a “taste” for science and derive satisfaction from "puzzle solving" (Stephan, 1996, 2012; Stern, 2004; Sauermann and Roach, 2013). Publications in peer-reviewed journals also provide substantial benefits in terms of career, salary and internal and external recognition (Dasgupta and David, 1994; Stephan, 1996, 2012).

We consider funding from at least two types of funding agents as inputs to the utility function. External resources are crucial for scientific production (Stephan, 1996, 2012) and the number of publications is increasing with funding received from external sponsors. However, while publication numbers are assumed to be non-decreasing regardless the source of funding, this does not rule out a trade-off between different types of resources. Facing time-constraints the academic has to choose how much time to devote to each sponsor to maximize her utility. In our set-up the different types of grants are not frictionless adjustable as they are subject to different adjustment costs and are accompanied by different expectations of the sponsors.

Our main hypotheses for this paper are based on the idea that funding from industry is less targeted at the production of scientific publications and basic research than unrestricted funding from public sponsors. Funding from industry is thus considered restricted funding that may potentially adversely affect a researcher's publication behaviour. The direct involvement of industry sponsors into the research process as well as the supervision of contract research and the exchange of results may limit the disclosure of research results or lead to publications that are less basic than researchers that receive funding from public sponsors. Moreover, researchers may encounter conflicting incentives and guidelines in their research when receiving funding from more than one agent. Public funding aimed at free dissemination may be contradicted with applied funding, resulting in a substitution between different grants. Alternatively, contacts with an applied sponsor may help generate new ideas for research and the different grants could instead be complements in a researcher's production function.

The production function in its most general form is then given by:

$$P_{it}(\varphi) = f(A_{it-1}, B_{it-1}, X_{it} | \varphi), \quad (1)$$

where A_{it-1} and B_{it-1} denote two different types of funding allocated in *t-1*, where one could be considered more applied (directed) and other more basic (undirected). X_{it} are other explanatory factors like rank, patents or gender. We then include the notion of a positive increase from either type of funding with potential substitution or complementarity effects:

$$P_{it}(\varphi) = \varphi[A_{it-1} + B_{it-1} + A_{it-1}B_{it-1} + X_{it}] + \varepsilon_{it} \quad (2)$$

where φ is the vector of parameters to be estimated and ε is the error term that can also be written as $\varepsilon_{it} = u_{it} + v_i$.

Thus, to estimate the existence and extent of any complementary or substitution effect between different types of funding we interact our funding variables and estimate their added joint effect. In the case of continuous variables in non-linear models the interaction effect is the cross-derivative of the expected marginal change in publications. Any two types of funding are classified as complements if the sign of the cross derivative is positive, i.e. if an increase in industry funding increases the marginal utility of public funding. If instead, an increase in industry funding decreases the utility of public funding they are considered as substitutes. If the cross-derivative is zero then we would observe a purely additive or substitutive relationship between the two types of funding where one could replace the other without compromising its marginal utility.

We estimate count data models as the number of publications are by nature positive and the data is characterised by a large number of zeros. We assume the outcome variables to have a Poisson distribution and estimate it using a negative binomial model that accounts for the skewed nature of the data. We thus employ negative binomial specifications of the form:

$$E(Y_{it}) = \exp\{\beta_1[A_{it-1}] + \beta_2[B_{it-1}] + \beta_3[A_{it-1}B_{it-1}] + \gamma X'_{it} + u_{it} + v_i\} \quad (3)$$

We control for individual heterogeneity (v_i) by specifying the average productivity of the academic before she enters the sample. The pre-sample mean of the dependent variable has been shown to be a consistent estimator of unobserved individual heterogeneity (Blundell et al., 1995, 2002). Individual heterogeneity mainly corresponds to the intrinsic ability of an academic and her motivation, both factors that are not directly observable but may affect scientific productivity. The log of the average number of publications published in a pre-sample period (in the period 1999 to 2001) should capture these individual characteristics and can serve as a fixed effect proxy that addresses the problem of unobserved individual heterogeneity. In cases where the pre-sample value is zero, we include a dummy to capture the "quasi-missing" value. The fixed effect proxy containing pre-sample data on publications also helps address the problem of endogeneity that arises from unobserved heterogeneity across individuals which may explain both, productivity and external funding. We include university and year fixed effects in all regressions and allow for robust standard errors clustered at the individual level.

3.2 Data collection and sample

This paper evaluates the possible complementarities of public and private research sponsorship, using extramural research grant information for UK engineering academics. Extramural grants represent research grants that an academic receives in addition to the university's core funding.

To gain access to grant information for academic researchers, we contacted 40 UK universities with engineering departments[1]. 15 of these universities sent us detailed records containing information on private and public research grants held by their engineering staff during the period 2001 to 2006[2] (see Table A1 for a list of universities). The funding information was matched with name and rank information for all academic staff employed at engineering departments in the UK, as well as their publication records[3]. We supplemented this data with PhD year and subject information for all 885 researchers that worked at the 15 universities during the whole period 2001 to 2006, whether they received funding or not. After exclusion of incomplete records the final data set contains 809 engineering academics. 471 of these researchers (58%) receive some external funding at least once during the seven year observation period.

Research Output

The main variables of interest are research output and its quality, which are measured using researchers' publication records. Publications were obtained from the ISI Web of Science Data base and the Science Citation Index (SCI), which includes journals based on a selection and reviewing process and serves as an indicator for publications of high scientific value. We collected publications from when the researcher first joined the database (were employed by

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[1] The 40 universities were selected based on a list of universities, for which staff and publication data had been collected as part of the ESRC project described in Banal-Estanol et al. (2010).

[2] 6 more universities sent partial information, e.g. industry funding or researcher names were missing. For some of the 15 universities funding is available for earlier years, e.g. for 3 from 1990 onwards, for another 7 from 1996 onwards. The period 2001 to 2006 is the preferred period for this analysis as it covers a larger number of universities and represents the assessment period for the 2008 RAE. The research information can therefore be expected to be fairly standardised across the 15 institutions and adjusted to the requirements of the RAE.

[3] The original data was collected based on staff registers in academic calendars and the name entries used as basis for gathering publications, patents and research council funding information for engineering academics at 40 UK universities for the period 1985 to 2007 (Banal-Estanol et al., 2010).

one of the institutions in the full 40 university sample) up to 2006. Names were matched based on university address, last name and first initial and cleaned manually.[4]

Funding could have a different impact on research quality than it has on research quantity. We measure research quality using the number of citations received before the end of 2012 by articles published in *t*. In other words, for publications published in 2002 we consider a citation window of ten years while for publications published in 2006 we consider a citation window of six years. As the majority of citations are received in the first few years and we have a minimum citation window of six years, this truncation should not affect the results.

To summarize, we measure publication output as the number of publications in *t* (*PUB*) and quality adjusted publication output as the total number of citations received by publications published in *t* as of 2012 (*CIT*). The mean number of publications during the observation period is 2.24 per academic per year and the citation count for these publications is 25.73. 82 researchers (10%) do not publish during the entire six year period and a further 205 academics (25%) publish less than one paper per year.

For both measures we generate pre-sample means (*Pub_Mean* and *Cit_Mean*) for the period 1999 to 2001. These are included in all models to control for the ex-ante scientific quality of the scientist (the unobserved heterogeneity).

Research Funding

The external research income information obtained from the 15 universities (Table A1) includes the name of the principal investigator as well as data on funding agency, award date, grant period and funding amount. Co-investigators could not be considered as not all 15 universities were able to supply this information. We can attribute external income to four different sources: (1) industry and business, (2) UK research councils (mainly EPSRC), (3) UK charities, and (4) the EU[5]. All funding was split across the award period to avoid focussing the entire amount at the start of the grant and to account for the length of the research project. In other words, if the grant lasted two years we split it equally across those

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[4] Publications without address data had to be ignored. However, we expect this missing information to be random and to not affect the data systematically.

[5] Funding was further received from government ministries, regional authorities and overseas sponsors accounting for 11% of total funding. As the nature of these grants could not easily be inferred, they were not considered in this analysis.

two years, if it lasted over three or more years, the first and the last years (which are assumed to not represent full calendar years) received half the share of an intermediate year. This is done in order to account for the on-going benefits and implications of a project.

The majority of researchers in the sample receive funding from more than one type of funding agent during the observation period. 42% of researchers, however, receive no external funding at all. Of those that receive external funding at least once, 58% are sponsored by industry (34% of the total sample). In terms of funding volume, UK research council and charity funding accounts for 60% of all external research income, funding from industry accounts for 18%, followed by EU with 11%.

Funding received in *t-1* is used to capture the impact of resource endowments on scientific productivity in *t*. We differ between funding received from industry (*INDFUND*) and from public agents (*PUBFUND*) which includes UK research council, UK charity and EU funding. Industry funding amounts to approx. £5000 per academic per year, while public funding provides approx. £23000 on average with the majority being sourced from UK research councils and charities (ca. £20000).

To measure complementarity and substitution between different types of grants we multiply our funding variables to estimate interaction effects. In other words, we multiply industry funding and public funding to measure any additional effect of a simultaneous involvement in both types of funded research projects.

In a robustness check we split public funding into UK public funding (*UKFUND*) and EU funding (*EUFUND*) to see if they interact differently with industry sponsorship and to investigate potential complementary effects between different types of public subsidy.

Patents

We include patents as additional control to all regressions. Patent data was obtained from the European Patent Office (EPO) database. We collected those patents that identify the aforementioned researchers as inventors and were filed while they were employed at one of the 15 institutions. Database construction required a manual search in the inventor database to identify those entries where the identity of the academic was certain. This was done by comparing addresses, titles and technology classes for all patents potentially attributable to each researcher. We did not only consider patents filed by the universities themselves, but also those assigned to third parties, e.g. industry or government agencies. Lawson (2013) showed that in engineering more than 50% of inventions are not owned by the university but by private firms, government or individuals. We recorded the filing date of the patent as this represents the closest date to invention. The number of patents filed in *t-1* is used in the regressions. The average number of patents per year is 0.06.

Control Variables

To account for potential age effects and subject area in our data we collected personal information of researchers. PhD information was taken from *Index to Theses*, an online database which lists theses accepted for higher degrees by the universities of the United Kingdom and Ireland. It provides information on PhD institution, year and subject area. For researchers not listed in the database we searched their websites and gathered PhD details from the library catalogues of the PhD awarding university[6]. Of the 809 researchers for which personal information could be collected, 56 do not hold a PhD. As for the remaining 753 researchers, they received their PhDs between 1958 and 2006, with a mean PhD award year of 1984. The degrees come from 58 UK universities and more than 30 different institutions in 16 countries outside the UK.

As controls we include the researcher's academic age (*PHDAGE*) as the difference between the current year and the year of the PhD. We control for gender (*FEMALE*) and include a dummy for those researchers that do not hold a PhD (*NOPHD*). Both account for approximately 7% of the sample each. Subject specialisation (*FIELD*) is based on the subject of the PhD as department division is not consistent across the 15 universities. In our sample 22% of researchers graduated in Electrical and Electronic Engineering, 21% in Civil Engineering, 15% hold a PhD in Chemical Engineering, 15% in Physics and 13% in Mechanical Engineering. Just 8% have a background in Life Sciences. Table 1 reports the descriptive statistics for all our measures.

Year and university dummies are included in all regressions to control for potential institution or time effects. Due to the short panel window separate institution measures are not included as they do not differ significantly across time and any differences should be captured by the fixed effect variables.

[6] This concerned some PhDs awarded in the UK that were not submitted to *Index to Theses* as well as PhDs awarded outside the UK and Ireland.

Funding Profiles

Table 2 additionally reports descriptive statistics by type of funded researcher. Researchers are allowed to move between groups depending on their funding status in *t-1*. We differ between observations where a researcher receives (1) no funding, (2) only private funding, (3) only public funding (UK and EU) and (4) both, private and public funding. The basic descriptive results show that all four groups are significantly different on most of our variables. They also show that researchers receiving funding produce more publications than those who do not, however, only for researchers with some public funding this difference is significant. Further, researchers receiving industry *and* public grants are most productive. In terms of quality adjusted publication numbers again, researchers receiving public sponsorship are significantly more productive than those receiving no grants. Researchers sourcing funding from both types of agents are most productive. These descriptive results support our assumption of a positive production function and also point towards a complementary relationship between public and private grants.

In terms of funding amount, it becomes clear that researchers that source funding from more than one source raise significantly more funding than researchers that rely on just one source. This suggests that as public grants are distributed based on peer review and can be expected to benefit the most able researchers industry may look at public grants to inform their own funding decision and identifying potential partners for research (Perkmann et al., 2013). This group of highly sponsored and diversified researchers is also the group producing the largest number of patents. This is in line with the literature on star scientists (Zucker et al., 1996, 2002) that suggests strong complementarities between high scientific ability, commercialisation and funding success.

In terms of control variables we make some interesting observations. Significantly fewer female researchers can be found amongst the group of researchers that receive funding from industry alone. Researchers without a PhD are significantly less represented in the groups of funded researchers, suggesting that they are less research but perhaps more teaching driven. Age is significantly higher in the groups of researchers receiving public funding and highest amongst the top performing group. We can further see that different scientific fields attract different types of funding. Researchers in bioscience are significantly more represented in the group that attracts funding from several sources, while researchers in Physics are focussing on one agent. Researches in Mechanical Engineering are more likely to be found amongst funded researchers, while researchers in Chemical Engineering are mostly found amongst those receiving no or only public funding. Electrical and Electronic Engineering faculty are less likely to only source funding from industry, while Civil Engineering researchers are more likely to be found amongst this group.

4 Results

Table 3 reports the results of our model in which we test if these insights remain once we control for scientist and laboratory characteristics. In columns 1 and 2 we regress the number of articles published *t* on funding received during the previous period using a negative binomial model. Standard errors are robust and clustered at the individual level. Columns three and four report results for the citation count.

Regressions in columns one and three report results that counter industry funding with all public funding. The results show that both, the receipt of public funding and the receipt of industry funding have a positive effect on publication outcomes, supporting our production function assumption. The interaction term, however, has a negative sign. We calculate the cross-derivative for the joint effect of public and industry income holding all variables at their mean. The cross-derivative is negative, indicating that while both types of funding positively correlate with publication numbers, their joint effect is negative (substitutive).

To illustrate the interaction effect we can examine the impact of a one-standard-deviation increase in funding on publication output. Assume a researcher receives public grants at their mean level of approx. £23,000 and industry grants at a mean value of approx. £5,000, a one-standard-deviation increase in public grants would increase the publication rate by 10 percent (0.83*(0.126-0.073*0.05)=0.10). For the same researcher a one-standard-deviation increase in industry funding would increase the publication rate by 4% (0.26*(0.184-0.073*0.23)=0.04). Thus, industry grants contribute much less towards publication output than public grants.

We can further illustrate the substitution effect by calculating the citation rate increase associated with public grants at different levels of industry funding. Let us again consider a researcher receiving £23,000 in public funding and £5,000 in industry funding. For this researcher public grants increase the publication rate by a multiplier of 1.0285 (=EXP(0.126*0.23-0.073*0.05*0.23)). If instead the researcher receives the same amount of public grants but £10,000 in industry grants (90th percentile), then public grants would raise the publication rate by a multiplier of 1.0277 (=EXP(0.126*0.23-0.073*0.1*0.23)). Thus, having a higher amount of industry grants reduces the benefit received from public grants.

Looking at marginal effects for different levels of funding, however, it becomes apparent that when holding all other explanatory variables at their mean, the negative effect of the cross-derivative only translates into an effective decrease in publication numbers for high values of non-industry funding in the 98 percentile or high values of industry funding in the 99 percentile. As can be gathered from these results, industry funding has a weaker effect than public funding on publication outcome, and at higher levels of public funding the benefits from industry funding is reduced but does only compromise the positive effect of public funding for top grant receivers.

The results are similar for the average citation count. Both types of funding show positive signs but again the interaction term is negative. The cross-derivative is also negative indicating that the joint effect of industry and non-industry funding is negative.

Again we can look at the citation rate changes for one-standard-deviation increases in funding. A one-standard-deviation increase in public funding increases the citation rate by 22%, while a one-standard-deviation increase in industry funding leads to an increase of only 8%. Further, for a researcher receiving an average amount of industry grants, public grants of £23,000 increase the citation rate by a multiplier of 1.0624, while for a researcher receiving twice as much industry funding, public grants of £23,000 increase the citation rate by 1.0602.

Columns two and four consider funding received from UK public agents, EU, and industry and include their interactions. The results show that all three types of funding are associated with higher publication output and quality. The interactions between public and industry funding are again negative and mostly significant. If we again compute one-standard-deviation increases in funding for citation rates we observe the following: A one-standard-deviation increase in industry funding leads to an increase in citation rates of only 7.9%, while EU funding increases lead to an increase of 15.1% and UK public funding to an increase of 15.6%. This again confirms that industry grants contribute less to publication outcomes. Again we illustrate the substitution effect by calculating the citation rate increase associated with public grants at different levels of industry funding. We find that for a research receiving an average amount of industry funding EU grants of £4000 (the mean) increase the citation rate by 1.0390, while for a research receiving twice as much industry funding the citation rate increases by 1.0388. Similarly, for UK grants at the mean the citation rate increases are reduced from 1.0398 to 1.0386.

The interaction between UK and EU funding is insignificant in the robustness regression. This indicates that an increase in EU funding does not affect the benefit received from UK public funding and the two can be considered additives (substitutive). Moreover, the citation and publication rate increase for UK one-standard deviation increases in public funding is only a little larger than that of EU funding. Thus, UK funding could be exchanged for EU funding without loss in utility, making the two almost perfect substitutes.

The control variables are all consistent across the different specifications. Patents show a positive correlation with publication and citation numbers confirming prior research. Researchers that do not hold a PhD also produce significantly fewer publications than their peers. Productivity and publication quality declines with age. Publication numbers are lower in more applied fields of engineering and lowest in civil engineering. Citation numbers are lowest for civil and mechanical engineering and highest in chemical engineering and physics. Year and university effects are significant.

5 Conclusions

This paper investigated empirically the existence of complementarities or substitution between public and private funding for scientific performance. The question is particularly critical as public budgets are shrinking and researchers are increasingly looking at other channels for support of their research. Industry collaboration can provide ideas and resources for research that may open up new research lines (Mansfield, 1995). If this is the case then also the expected benefits from public funding could increase, resulting in positive complementarities. On the other hand, several researchers have expressed concerns that industry partners may direct academics towards applied research and limit or delay the dissemination of research results (Blumenthal et al., 1986, 1996; Cohen et al., 1998). If industry partners demand a shift of research topic and secrecy than also public funding placed with such industry sponsored researchers may suffer limitations and the marginal utility of public grants may decrease resulting in a substitution effect.

Using a sample of 809 researchers in engineering and controlling for unobserved heterogeneity, we find that industry funding decreases the marginal utility of public funding by decreasing the publication rate increase associated to public grants. This indicates that researchers are working at full capacity and increases in funding do not translate into increases in research output when multiple sponsors are involved. This negative interaction effect could be found for co-sponsorship from UK funders and EU grants. Further, the benefits of increases in EU and UK funding in terms of publication output are higher than those for industry funding.

The results also showed that EU funding has been able to substitute declines in UK public funding without decreasing the benefits of UK funding. In fact, the benefits of increases in EU and UK funding in terms of publication output are almost identical suggesting that UK public funding could successfully be substituted with EU funding.

The results help to inform the debate on how industry and public funding jointly affect research productivity. They show that it is important to maintain high levels of public funding to ensure the quality of the higher education research sector. Industry is not able to provide support at the same level, as is required for high quality research. Further, some negative complementarities exist and researchers receiving funding from industry in addition to public grants will be less productive than a researcher receiving a similar amount of funding through public sources alone.

This study is a first step to unleash the interactions between different types of funding. We strongly encourage further research as funding environments continue to shift. OECD data has shown that funding from industry is rising and that core and research funding from governments is decreasing (OECD, 2010). The evidence presented here shows that this shift may not be without consequences for the development of the science base, even in applied sciences like engineering. Ours can only be a first attempt and more research is needed to pin down the mechanisms behind the negative effect of industry grants that could be due to non-disclosure clauses or research themes less irrelevant to science. Blumenthal et al. (2006) and Czarnitzki et al. (2011) show evidence of secrecy for researchers benefiting from industry grants that may also affect the release of publications from public grants. Hottenrott and Lawson (2012) further show that ideas from industry may not always lead to better research performance perhaps by simply not being relevant to science (Perkmann and Walsh, 2009).

This paper does not evaluate other benefits that may come from co-sponsorship, and a more comprehensive assessment is necessary to establish if benefits for students, teaching or commercialisation of research or benefits for the sponsoring firm exist that may be of greater policy relevance than publications in scientific journals.

References

Agrawal, A. and Henderson, R. (2002), Putting patents in context: exploring knowledge transfer from MIT. Management Science 48 (1), 44–60.

Azoulay, P., Graff Zivin, J. G., and Manso, G. (2011), Incentives and creativity: Evidence from the academic life science. The Rand Journal of Economics 42, 527-554.

Banal-Estanol, A., Jofre-Bonet, M., and Meissner, C. (2010), The impact of industry collaboration on research: Evidence from engineering academics in the UK. UPF Working Paper no1190, Barcelona, Spain.

Banal-Estanol, A. and Macho-Stadler, I. (2010), Scientific and Commercial Incentives in R&D: Research vs. Development? Journal of Economics and Management Strategy 19 (1), 185–221.

Benavente, J. M., Crespi, G., Figal Garone, L., and Maffioli, A. (2012), The impact of national research funds: A regression discontinuity approach to the Chilean FONDECYT. Research Policy, 41(8), 1461-1475.

Benner, M. and Sandström, U. (2000), Institutionalizing the Triple Helix: Research Funding and Norms in the Academic System, Research Policy 29, 291–301.

Blumenthal, D., Gluck, M., Louis, K.S., Stoto, M.A. and Wise, D. (1986), University-industry Research Relationships in Biotechnology: Implications for the University, Science Magazine, 232 (4756), 1361-1366.

Blumenthal, D., Campbell, E., Anderson, M., Causino, N. and Seashore-Louis, K. (1996), Participation of life-science faculty in research relationships with industry. New England Journal of Medicine, 335, 1734-1739.

Blumenthal, D., Campbell, E.G., Gokhale, M., Yucel, R., Clarridge, B., Hilgartner, S. and Holtzman, N.A. (2006), Data withholding in genetics and other life sciences: Prevalences and practices, Academic Medicine 81(2), 137-145.

Blundell, R., Griffith, R. and van Reenen, J. (1995), Dynamic count data models of technological innovation. Economic Journal 105 (429), 333-344.

Blundell, R., Griffith, R. and van Reenen J. (2002), Individual Effects and Dynamics in Count Data Models, Journal of Econometrics. 108, 113-131.

Carayol, N. and Matt, M. (2006), Individual and collective determinants of academic scientists' productivity, Information Economics and Policy 18, 55–72.

Chudnovsky, D., Lopez, A., Rossi, M. A., and Ubfal, D. (2008). Money for Science? The Impact of Research Grants on Academic Output. Fiscal Studies 29(1), 75-87.

Cohen, W.M., Florida, R., Randazzese, L. and Walsh, J. (1998), Industry and the academy: Uneasy partners in the cause of technical advance, in: R.G. Noll (ed.), Challenges to Research Universities, Washington, DC: Brookings Institution Press.

Cohen, W., Nelson, R. and Walsh, J. (2002), Links and Impacts: The Influence of Public Research on Industrial R&D, Management Science, 48, 1-23.

Czarnitzki, D, Grimpe, C. and Toole, A. (2011), Does Industry Sponsorship Jeopardize Disclosure of Academic Research?, ZEW Discussion Paper 11-009, Mannheim.

Dasgupta, P., David, P. (1994), Towards a new economics of science. Research Policy 3, 487–521.

Geuna, A. (1999), The Economics of knowledge production: Funding and the structure of university research. Cheltenham: Edward Elgar.

Grimpe, C. (2012), Extramural research grants and scientists' funding strategies: Beggars cannot be choosers? Research Policy 41: 1448-1460.

Gulbrandsen, M. and Smeby, J-C. (2005), Industry funding and university professors' research performance. Research Policy 34 (6), 932–950.

Hottenrott, H. and Lawson, C. (2012), Research grants, sources of ideas and the effects on academic research. ZEW Discussion Paper 12-048, Mannheim.

Hottenrott, H. and Thorwarth, S. (2011), Industry Funding of University Research and Scientific Productivity. Kyklos, 64 (4), 534–555.

Jacob, B. A. and Lefgren, L. (2011), The impact of research grant funding on scientific productivity. Journal of Public Economics 95, 1168-1177.

Kelchtermans, S. and Veugelers, R. (2011), The Great Divide in Scientific Productivity: Why the Average Scientist Does Not Exist. Industrial and Corporate Change 20 (1), 295-336.

Lawson, C. (2012), Academic Patenting: The Importance of Industry Support. Journal of Technology Transfer, forthcoming.

Lawson, C. (2013), Academic Inventions outside the University: Investigating Patent Ownership in the UK, University of Turin, mimeo.

Lee, Y.S. (2000), The sustainability of university-industry research collaboration: an empirical assessment. Journal of Technology Transfer 25 (2), 111-133.

Manjarres-Henriquez, L., Gutierrez-Gracia, A., and Vega-Jurado, J. (2008), Coexistence of university-industry relations and academic research: Barrier to or incentive for scientific productivity. Scientometrics 76 (3), 561-563.

Mansfield, E. (1995), Academic research underlying industrial innovations: sources, characteristics, and financing. The Review of Economics and Statistics, 77 (1), 55-65.

OECD (2010). Main Science and Technology Indicators. Paris

Perkmann. M. and Walsh, K. (2009), The two Faces of Collaboration: Impacts of University-Industry Relations on Public Research, Industrial and Corporate Change 18(6), 1033-1065.

Perkmann, M., Tartari, V., McKelvey, M. et al. (2013), Academic engagement and commercialisation: A review of the literature on university–industry relations. Research Policy 42, 423– 442.

Sauermann, H. and Roach, M. (2013), The Price of Silence: Science and Engineering PhDs' Preferences for Publishing in Industrial R&D. Georgia Institute of Technology, Working Paper.

Siegel, D.S., Waldman, D. and Link, A., (2003), Assessing the impact of organizational practices on the relative productivity of university Technology Transfer Offices: An Exploratory Study. Research Policy 32, 27–48.

Slaughter, S. and Leslie, L.L. (1997), Academic Capitalism, Baltimore: Johns Hopkins University Press.

Slaughter, S. and Rhoades, G. (2004), Academic Capitalism and the new Economy: Markets, State, and Higher Education, Baltimore: The Johns Hopkins University Press.

Stephan, P. E. (1996), The Economics of Science. Journal of Economic Literature, 34(3), 1199-1235.

Stephan, P. E. (2012), How economics shapes science. Cambridge, MA: Harvard University Press.

Stern, S. (2004), Do scientists pay to be scientists? Management Science, 50 (6), 835-853.

Thursby, M., Thursby, J. and Mukherjee, S. (2007), Are there Real Effects of Licensing on Academic Research? A Life Cycle View. Journal of Economic Behavior and Organization 63(4), 577-598.

Zucker, L.G. and Darby, M.R. (1996), Star scientists and institutional transformation: patterns of invention and innovation in the formation of the biotechnology industry. Proceedings of the National Academy of Sciences of the United States of America 93 (23), 709–712.

Zucker, L., Darby, M. and Brewer, M (1998), Intellectual capital and the birth of U.S. Biotechnology Enterprises. American Economic Review 88, 290–306.

Zucker, L.G., Darby, M.R. and Armstrong, J.S. (2002), Commercializing knowledge: university science, knowledge capture, and firm performance in biotechnology. Management Science 48 (1), 138–153.

Table 1: Descriptive statistics (4045 observations)

	mean	sd	min	max
Productivity measures				
PUB_{it} (Publication number)	2.24	3.29	0	32
CIT_{it} (Citation number)	34.95	97.58	0	1645
Funding measures(in 100,000 GBP)				
$PUBFUND_{it-1}$	0.23	0.83	0	17.36
$INDFUND_{it-1}$	0.05	0.26	0	7.22
$UKFUND_{it-1}$	0.20	0.80	0	16.54
$EUFUND_{it-1}$	0.04	0.16	0	3.00
Patent measure				
PAT_{it-1}	0.06	0.32	0	8
Individual characteristics				
$FEMALE_i$	0.07	0.25	0	1
$NOPHD_i$	0.07	0.25	0	1
$PHDAGE_i$	18.20	10.40	0	48
$FIELD1_i$=Bioscience and Chemistry	0.08	0.26	0	1
$FIELD2_i$=Physics	0.15	0.36	0	1
$FIELD3_i$=Mechanical Engineering	0.13	0.34	0	1
$FIELD4_i$=Electrical and Electronic Eng.	0.22	0.41	0	1
$FIELD5_i$=Chemical Engineering	0.15	0.36	0	1
$FIELD6_i$=Civil Engineering	0.21	0.40	0	1

Table 2: Means by funding structure

Funding	No funding	Public=0; Industry>0	Public>0; Industry=0	Public>0; Industry>0	Anova F-Test
Observations	2487	284	857	417	Sig.
Researcher IDs	652	137	314	168	
Productivity measures					
PUB_{it}	1.73	1.91	2.83***	4.27***	***
CIT_{it}	25.73	21.63	47.91***	72.31***	***
Funding measures (in 100,000 GBP)					
$PUBFUND_{it-1}$	0.00	0.00	0.60***	1.03***	***
$INDFUND_{it-1}$	0.00	0.22***	0.00	0.38***	***
$UKFUND_{it-1}$	0.00	0.00	0.50***	0.90***	***
$EUFUND_{it-1}$	0.00	0.00	0.11***	0.13***	***
Patent measure					
PAT_{it-1}	0.05	0.05	0.06	0.14***	***
Individual characteristics					
$FEMALE_i$	0.07	0.03***	0.08	0.06	**
$NOPHD_i$	0.09	0.06*	0.02***	0.03***	***
$PHDAGE_i$	17.79	17.37	18.66**	20.28***	***
$FIELD1_i$=Bioscience	0.07	0.04**	0.08	0.11***	***
$FIELD2_i$=Physics	0.14	0.18**	0.18***	0.15	***
$FIELD3_i$=Mechanical Engineering	0.12	0.18***	0.14**	0.17***	***
$FIELD4_i$=Electrical and Electronic	0.22	0.17**	0.21	0.23	n.s.
$FIELD5_i$=Chemical Engineering	0.16	0.10***	0.15	0.11***	***
$FIELD6_i$=Civil Engineering	0.20	0.27***	0.21	0.20	**

Mean comparison test compares observations with funding to observations with no funding (column 1).
Analysis of variance compares the four groups of researchers.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3: Estimation results

VARIABLES	(1) PUB NBREG	(2) PUB NBREG	(3) CIT NBREG	(4) CIT NBREG
$PubFund_{it-1}$	0.126***		0.272***	
	(0.043)		(0.075)	
$UKFund_{it-1}$		0.099***		0.201***
		(0.038)		(0.075)
$EUFund_{it-1}$		0.434***		0.963***
		(0.116)		(0.269)
$IndFund_{it-1}$	0.184**	0.202**	0.357**	0.340*
	(0.087)	(0.092)	(0.147)	(0.180)
$IndFund_{it-1}$ *$PubFund_{it-1}$	-0.073*		-0.178**	
	(0.043)		(0.070)	
$IndFund_{it-1}$ *$UKFund_{it-1}$		-0.055		-0.113*
		(0.040)		(0.065)
$IndFund_{it-1}$ *$EUFund_{it-1}$		-0.217**		-0.346*
		(0.090)		(0.192)
$UKFund_{it-1}$ *$EUFund_{it-1}$		-0.013		-0.095
		(0.080)		(0.095)
PAT_{it-1}	0.236***	0.226***	0.282***	0.257***
	(0.067)	(0.067)	(0.083)	(0.076)
$NOPHD_i$	-0.663***	-0.654***	-0.854***	-0.849***
	(0.182)	(0.184)	(0.270)	(0.270)
$PHDAGE_{it}$	-0.009***	-0.009***	-0.009*	-0.010**
	(0.003)	(0.003)	(0.005)	(0.005)
$FEMALE_i$	0.082	0.089	0.113	0.115
	(0.150)	(0.150)	(0.132)	(0.132)
FIELD1i=Bioscience and $Chemistry_i$	0.318***	0.321***	0.773***	0.760***
	(0.109)	(0.109)	(0.176)	(0.172)
FIELD2i=$Physics_i$	0.469***	0.471***	0.953***	0.952***
	(0.103)	(0.103)	(0.161)	(0.162)
FIELD3i=Mechanical $Engineering_i$	0.182*	0.183*	0.235	0.232
	(0.101)	(0.101)	(0.157)	(0.158)
FIELD4i=Electrical and Electronic Eng. $_i$	0.203**	0.198**	0.558***	0.517***
	(0.088)	(0.088)	(0.150)	(0.150)
FIELD5i=Chemical $Engineering_i$	0.495***	0.506***	0.908***	0.918***
	(0.099)	(0.098)	(0.136)	(0.136)
FIELD6i=Civil $Engineering_i$ (Reference)				
ln[Pub_Mean]/ln[Cit_Mean]	0.596***	0.591***	0.430***	0.416***
	(0.039)	(0.039)	(0.044)	(0.044)
[Pub_Mean=0]/[Cit_Mean=0]	-0.438***	-0.444***	-0.105	-0.133
	(0.102)	(0.103)	(0.153)	(0.154)
Constant	-0.118	-0.112	1.185***	1.242***
	(0.186)	(0.188)	(0.290)	(0.293)
Joint sign. of university dummies $\chi2$ (14)	102.00***	102.37***	120.43***	118.50***
Joint sign. of subject dummies $\chi2$ (5)	35.63***	37.22***	63.36***	64.43***
Joint sign. of year dummies $\chi2$ (4)	48.96***	48.17***	5.26	4.53
Log-likelihood	-7051.422	-7045.833	-14251.709	-14246.185
Lnalpha	-0.668***	-0.681***	1.337***	1.333***
Cluster	809	809	809	809
Observations	4045	4045	4045	4045

Coefficients are reported. Robust standard errors in parentheses; clustered by individual. *** p<0.01, ** p<0.05, * p<0.1

Appendix

Table A1: List of Universities

University Name	Academics	Observations
Brunel University	48	240
University of Cambridge	123	615
City University	23	112
University of Durham	21	95
University of Essex	26	130
Lancaster University	10	50
University of Leicester	29	144
Loughborough University	123	612
Queen Mary University	31	153
University of Reading	22	110
University of Sheffield	100	493
University of Edinburgh	54	266
University of Glasgow	63	313
University of Strathclyde	97	482
University of Swansea	46	230
Total	**809***	**4045**

*Academics can change university within the sample. Therefore numbers do not add up to 809.