Fishing for Complementarities: Research Grants and Research Productivity

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Abstract

We investigate complementarities between different sources of research funding with regard to academic productivity in terms of publications and citations. We argue that the joint effect of public and private funding depends not only on the funding source but also on the individual differences in researcher ability and preferences with regard to their taste for science and commercialisation. The empirical analysis, based on a sample of UK engineering academics, suggests that for traditional types with a strong taste for science industry funding decreases the marginal utility of public funding by lowering the publication rate increases associated with public grants. For commercial types, on the contrary, the combined influence of both types of research funding is positive for the number of proceedings, and suggests some complementarities for research.

Jelcodes:O30,I23

1 Introduction

Recent research on the concurrence of different types of funding shows that academic publications acknowledge an average of two to three funding agents per paper (Wang et al., 2012). Researchers thus receive grants from multiple sources which facilitate resource-intensive research, but also present the challenge of attribution of research efforts and human resources to each project. Importantly, given the significant effects of industry involvement on research outcomes (Banal-Estanol et al., 2015; Hottenrott and Thorwarth, 2011; Rentocchini et al. 2014), it is of interest whether industry sponsorship accelerates or compromises the positive effect of public research funding. In other words, studying the effects of public funding on research output may require taking other funding channels into account.

Besides the increasing use of external research grants from public funding agents, research sponsorship from the private sector has been identified as an important source of research income, especially by policy makers.[1] 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., 1996; Cohen et al., 1998; Czarnitzki et al. 2011). These papers conclude that academics' general duties and research activities in particular may be compromised by an increase in time allocated to industry-sponsored research and development, consulting and commercialisation. If industry partners determine research topics and demand secrecy then public funding placed with such industry sponsored researchers may also suffer from limitations and result in a decrease in research output (Cohen et al., 1998). This is particularly critical in light of a shrinking of institutional core budgets, which increasingly induces researchers to seek out other channels to fund their research.

On the other hand, 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, 2014). Researchers may be able to benefit in their academic work from closer links with industry, as insights into applied processes and problems in industry may provide the ideas for new ground-breaking research (Rosenberg 1998). If researchers obtain new ideas through links with industry then the expected benefits from public funding placed with these researchers should also increase because of positive complementarities (Mansfield, 1995; Zucker and Darby, 1996; Zucker et al., 1998).

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[1] In the UK core funding from the funding councils has decreased since 2005. While it provided 72% of income in 2001, it only provided 67% in 2011 (Source: Higher Education Statistical Agency (HESA), own calculation). These recent developments show that external research grant income from public and private sources has become increasingly important for academic researchers. Also, funding from industry increased between 1996 and 2001 by 48% and remained at its 2001 level until 2007. From the HESA data we also see that industry funding is pro-cyclical. It has declined since the crisis year 2008. During our sample period (2001-2007) industry funding accounted for 10% of total research grant income and for 17%-21% of research grant income in engineering sciences.

The direction of this joint effect may differ by the type of academic and differences in their ability and preferences regarding scientific research. It may also differ by the type of research output. Previous research has studied this heterogeneity amongst academics focussing on differences in their taste for science and commercialisation (Stern, 2004; Roach and Sauermann, 2010). Building on this typology that distinguishes between academics with a "taste for science", "taste for commercialization", taste for both ("hybrids") or taste for neither, this study evaluate the joint effect of multiple types of funding on research performance.

Based on data on research income of 809 individual academics at 15 UK universities we are able to investigate the effect of public and private funding as well as potential complementarities and substitution effects on publication and citation rates of the sponsored academics. Previous studies have shown a positive effect of external funding on publication output, but that larger shares of research funding coming from industry are associated with publication rate decreases (Banal-Estanol et al., 2015; Hottenrott and Thorwarth, 2011; Rentocchini et al. 2014). Also, previous studies have ignored the effects on proceedings as a potentially more immediate outcome of joint research. Our results add to these insights by showing firstly that external research grants are generally associated with higher research output. The paper also shows that only public funding increases publication rates. Industry funding, instead, decreases the marginal utility of public funding by decreasing the publication rate increase associated with public grants. This effect is most pronounced for traditional academics with a high taste for science and is slightly smaller for "hybrid" types. For commercial types, with a strong taste for commercialisation and weak taste for science, we find instead a complementary relationship between public and industry grants on the number of proceedings published. We find no clear results for mean citation counts.

2 Background

2.1 Research funding and research productivity

In many countries in Europe where universities have primarily been financed through block grants, governments have introduced or increased the amount of funding distributed through competitive funding schemes (Stephan, 2012). Additionally, stagnating public research budgets meant that researchers are increasingly encouraged to look for funding elsewhere, e.g. to source funding from industry and other sponsors. External funding has been seen as a mechanism to reward and thus provide incentives for the most able researchers. It allows researchers to secure funding for equipment and research assistance, leading to more autonomy and flexibility. External funding is thus usually accompanied by an increase in research productivity, regardless of the sponsor (Stephan, 2012), and researchers that receive some external funding outperform those who do not acquire external grants (Kelchtermans and Veugelers, 2011).

However, few papers have analysed the concurrence of different types of funding. Wang et al. (2012) analyse named sponsors on academic publications in 10 selected countries. They show for the UK that 43% of academic publications acknowledge external funding and report an average of 2.8 funding agents per paper. They also observe that the UK funding system is particularly diversified, with no one funding agent dominating. In our data we will see that more than 50% of academics receive either competitive public funding or industry funding for at least one year. Of these, 47% receive public grants and industry funding simultaneously at least once. This points to the importance of analysing potential complementary or substitution effects between grants from different funding agents.

2.2 Industry funding and research productivity

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). Similar incentive schemes were implemented in Europe and elsewhere. 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. Further, 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, for example finding potential co-authors and ideas for their research agenda. In addition, 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 with firms. This did not only apply to industry-sponsored projects, also research projects sponsored by public agents were influenced by problems from industry. Thus, industry sponsorship may also increase the marginal benefits associated with public grants, through the provision of additional grants and contact with real-world problems.

However, 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 topics and the choice of dissemination channels (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. (1996) argue that industry may direct researchers towards applied research and limit or delay the release of publications. Blumenthal et al. (2006) and Czarnitzki et al. (2011) find evidence of publication delay and secrecy associated with industry funding. Such evidence points towards a potential negative effect of industry involvement on publication rates which could further result in a negative effect on marginal benefits associated with simultaneously-received public funding.

Empirical evidence on the topic is mixed. Banal-Estanol et al. (2015) and Rentocchini et al. (2014) show a curvilinear effect of the share of industry funding on publication output which may be indicative of a complementary effect of public and private funding up to a certain threshold. Other recent studies instead show a consistent negative correlation between the share of industry grants and publication rates (Hottenrott and Thorwarth, 2011). Hottenrott and Lawson (2014) find researchers that report industry as a source for research ideas to publish less than their peers who source research ideas from elsewhere. Their findings suggest that ideas coming from industry do not translate into more or better quality publications. Thus, the potential negative effect of industry funding may simply be offset through public grants instead of creating true complementarities.

3 Theoretical Framework

The effects of research funding on research productivity as well as the interaction between different types of grants may not exclusively depend on the funding source, but also on the academics who receive these grants. Previous research has studied heterogeneity amongst academics and their "taste" for research. In particular, the term "taste for science" has been coined to describe preferences related to the intrinsic desire to produce and diffuse basic scientific knowledge without considering monetary returns (Stern, 2004; Lacetera and Zirulia, 2008). Roach and Sauermann (2010) consider academic freedom, peer recognition and collaboration as value creators for academics with a "taste for science" (TFS). Pecuniary incentives are assumed to be of minor importance to these traditional academics, while academics with a "taste for commercialisation" (TFC) may seek to actively commercialise their scientific knowledge. Academics with a TFC may draw fewer rewards from diffusing their insights using traditional scientific means like publications, but rather seek patent protection for their inventions. It has been argued that between these two opposites we may find "hybrid" types (hybrids). These "hybrids" have attracted considerable attention lately (Owen-Smith, 2003; Thursby et al., 2007; Sauermann et al., 2010; Lam, 2011) because of their potential to act as intermediaries between science and industry helping to valorise additional social and economic returns from publicly funded research. Following Sauermann and Roach (2012), we can classify academics according to their tastes across the two-dimensional space as illustrated in Figure 1.

In our setting, which looks at engineering academics, we can classify engineers as high in TFS if they publish at least one science-oriented paper[2] during the observation period and high in TFC if they apply for at least one patent during the observation period.

Traditional scientists with a high TFS may be more interested in basic research and if they engage in applied research, it may be without pursuing commercial opportunities. Academics have repeatedly been shown to possess a "taste" for science when deriving satisfaction from "puzzle solving" (Stephan, 1996, 2012; Stern, 2004; Sauermann and Roach, 2014). Such academics may source their utility primarily from publications in peer reviewed journals as publications in peer-reviewed journals in turn provide substantial benefits in terms of career, salary and internal and external recognition (Dasgupta and David, 1994; Stephan, 1996, 2012). In line with previous research, we expect that, controlling for pre-grant research performance, public grants have a positive effect on the productivity of these academics in terms of publications. The effect on publications may be especially strong if grants promote basic research and encourage research collaboration. Likewise, if peer-recognition is a major source of reward for these researchers, they may have incentives to publish their results and do so with highest possible visibility.

Facing time-constraints academics have to choose how much time to devote to each sponsor. It seems reasonable to assume that 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. If traditional scientists receive industry grants in addition to their public grants, their publication output may be reduced due to several reasons. Contractual arrangements with the sponsor may require delaying or withholding results from publication in scientific journals (Blumenthal et al., 1996; Cohen et al., 1998; Czarnitzki et al. 2011). Earlier research has also found that funding from industry is less targeted at the production of scientific publications and basic research than unrestricted funding from public sponsors (Blumenthal et al., 1996). Funding from industry could thus be considered restricted funding that may potentially adversely affect an academic's publication behaviour (Cohen et al., 1998). Moreover, academics 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 industry funding, resulting in a substitution between different grants and a negative effect of industry funding on the marginal benefits associated with public grants.

Moreover, industry-sponsored projects may be related to, but still substantially different from a traditional academic's other research projects in terms of materials used, methodologies applied or

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[2] Narin (1976) classified basic and applied type journals based on cross-citation matrices between journals. He distinguishes between four categories where 1 is the most applied and 4 the most basic. We consider a paper to be science-oriented if it falls in categories 3 or 4. See section 5.3 for details.

procedures necessary to obtain usable results. When more time is allocated to industry-sponsored research and development, or to consulting, in addition to administrative and teaching duties, traditional research may be compromised. For traditional academics with a high TFS, we would therefore expect a) a negative effect of industry grants on research productivity and b) industry grants to (partially) compromise the output gains related to public grants.

The case for “hybrid” types may be different. With their research focus closer to commercial interests, they may be able to recognise and realise commercial opportunities that are aligned to the traditional research that is conducted in the context of publicly funded research projects. Lam (2011) also shows that researchers involved in patenting are indeed primarily motivated by academic goals, including increased reputation and access to new sources of funding. Contact with an industry sponsor may then help generate new ideas for research (Lee, 2000) and the different grants could be complements in the academic’s production function. Hottenrott (2012) further finds that research units that comprise both basic and applied research focus attract more research funding from industry than more focused ones do. Being a highly attractive collaboration partner for firms may thus put “hybrid” types in an advantageous bargaining position that allows them to achieve sponsoring contracts with fewer strings attached. Research output gains from public grants may therefore be compromised to a lesser extent for “hybrid” types compared to traditional academics with high TFS and low TFC. There may be complementarities to be realised within these researchers’ projects financed from public and industry sources. In this context, previous research has repeatedly stressed the concept of ‘dual knowledge’ and the occurrence of patent-paper pairs (Ducor 2000, Murray 2002, Murray and Stern 2007). Academics produce such pairs when they publish their research results in both scientific journals and in patent applications. For “hybrid” academics with high TFS and high TFC there may be complementarities in industry and public grants with regard to research outcomes.

The direct involvement of industry sponsors in the research process as well as the supervision of contract research and the exchange of results may still limit the disclosure of research results or lead to publications that are of lower quality compared to “hybrid” academics that receive funding solely from public sponsors. The expectations regarding the net effect on publications are therefore ambiguous.

For commercial types (TFC) with a relatively low interest in traditional scientific research and/or basic research and dissemination channels, we do not expect public grants to increase their publication performance significantly. Industry grants may thus not have much to compromise. On the contrary, we expect public and industry grants to function as complements when industry-sponsored research results in novel insights and applications that commercial academics want to share with fellow academics. Thus, as for “hybrids”, the research output of commercial types may occur in the form of patent-paper pairs, which implies a complementary relationship between public and industry sponsorship for these academics. The stronger focus on applied research, however, may also mean that commercial types are more likely to be affected by secrecy concerns because of the immediate commercial viability of their research when they receive most of their funding from industry (Perkmann and Walsh, 2009). In terms of the quality of their research, we may expect that the higher visibility due to commercialisation could result in more citations to academic research. At the same time, for commercial types, the lack of basic research may only result in publications that receive few citations.

For each of the quadrants I to III of Figure 1, we can derive expectations on the direct and joint effects of research funding from public and industry sources. In particular, we expect:

I. Traditional types' public research grants will be associated with more ex-post publications and more citations per paper. Industry grants may yield fewer publications and the joint effect may be negative.
II. "Hybrid" types' public research grants will be associated with more ex-post publications and more citations per paper. Industry grants may also be positively related to publication outcomes, but expectations about the joint effect are ambiguous.
III. Commercial types' public research grants will be associated with more ex-post publications and more citations per paper. Industry grants may also be positively related to publication outcomes and we expect the joint effect to be positive.
IV. For researchers with low TFS and low TFC ("others"; quadrant IV of Figure 1) the expected effects of joint public and industry funding are not clear ex-ante. Just as with commercial types industry funding might not have much to compromise as "others" do not engage in basic research. However, neither do we expect complementarities based on more applied, commercial research efforts.

4 Empirical Model

We base our empirical model about the effects of research funding on research productivity on the idea that an academic exerts different research efforts aimed at producing measurable outputs with the goal of maximising her productivity. The academic's "taste" determines her research focus. The productivity effects of research grants from different sources and, in particular, their joint effects depend on the academic's position in the two-dimensional space as illustrated in Figure 1.

We consider funding from at least two types of funding agents as inputs to the research production function.[3] External resources are crucial for scientific production (Stephan, 1996, 2012) and the

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[3] We distinguish public from private sector funding. Public funding may stem from UK research councils (mainly EPSRC), UK charities, UK government and the EU. See section 4.1 for details on the funding information.

number of publications is increasing with funding received from external sponsors (Kelchtermans and Veugelers, 2011). However, while publication numbers are assumed to be non-decreasing with research input, this does not rule out diminishing returns or trade-offs between different types of resources as shown by Manjarres-Henriquez et al. (2009) and Kelchtermans and Veugelers (2011).

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

$$P_{it}(\varphi) = f\left(F_{1_{it-1}}, F_{2_{it-1}}, X_{it} | \varphi\right), \qquad (1)$$

Where P_{it} are publication numbers, $F_{1_{it-1}}$ and $F_{2_{it-1}}$denote two different types of funding allocated in t-1, where one could be considered public, science oriented funding and the other funding from industry. X_{it} are other explanatory factors like age, rank or gender. We then include the notion of a positive increase from either type of funding with potential substitution or complementarity effects:

$$P_{it}(\varphi) = \varphi\left[F_{1_{it-1}} + F_{2_{it-1}} + F_{1_{it-1}} F_{2_{it-1}} + X_{it}\right] + \varepsilon_{it} \qquad (2)$$

where φ is the vector of parameters to be estimated and ε is the error term given as $\varepsilon_{it}=u_{it}+ v_i+\tau_t$, where v_i is the unobserved individual effect, and τ_t is the time fixed effect.

Thus, to estimate the existence and extent of any complementary or substitution effect between different types of funding we interact the two funding variables and estimate their joint effect.

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 negative binomial distribution and use a model that accounts for the skewed nature of the data. As we can expect decreasing marginal returns to funding even if it comes from the same funding source, we also include the quadratic term thus employing a specification of the form:

$$E(P_{it}) = exp\{\beta_0 + \beta_1[F_{1_{it-1}}] + \beta_2[F_{1_{it-1}}]^2 + \beta_3[F_{2_{it-1}}] + \beta_4[F_{2_{it-1}}]^2 +$$
$$\beta_5[F_{1_{it-1}} F_{2_{it-1}}] + \beta_6[F_{1_{it-1}} F_{2_{it-1}}]^2 + \beta_7\left[(F_{1_{it-1}})^2 F_{2_{it-1}}\right] + \beta_8[F_{1_{it-1}}(F_{2_{it-1}})^2] +$$
$$\gamma X'_{it} + \varepsilon_{it}\} \qquad (3)$$

In the case of continuous variables in non-linear models the interaction effect is the cross-derivative of the expected marginal change in publications. For example, the marginal effect of funding $F_{1_{it-1}}$ on our dependent variable P_{it} is derived as the first derivative of (3):

$$\frac{\partial E(P)}{\partial F_1} = (\beta_1 + 2\beta_2 F_1 + \beta_5 F_2 + 2\beta_6 F_1 F_2^2 + 2\beta_7 F_1 F_2 + \beta_8 F_2^2)E(P) \qquad (4)$$

Then, derived from (4) the marginal change of funding $F_{1_{it-1}}$ on the dependent variable P_{it} with respect to the interaction term $F_{2_{it-1}}$ can be written as:

$$\frac{\partial E(P)}{\partial F_1 \partial F_2} = (\beta_5 + 2\beta_6 F_1 F_2 + \beta_7 F_1 + \beta_8 F_2)E(P) + (\beta_1 + 2\beta_2 F_1 + \beta_5 F_2 + 2\beta_6 F_1 F_2^2 + 2\beta_7 F_1 F_2 + \beta_8 F_2^2)(\beta_3 + 2\beta_4 F_2 + \beta_5 F_1 + 2\beta_6 F_2 F_1^2 + +\beta_7 F_1^2 + 2\beta_8 F_2 F_1)E(P) \qquad (5)$$

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 productivity gains of public funding they are considered as substitutes on the outcome variable P_{it}. If the cross-derivative is zero then we would observe a purely additive relationship between the two types of funding where one could replace the other without compromising its marginal utility.

We estimate pooled models, which have the advantage that they relax the strict exogeneity assumption of a fixed effects model. However, they do not control for unobserved individual heterogeneity (v_i). In our case such unobserved effects could be specific skills of each academic that are positively correlated with the right hand side variables such as external funding and a potential endogeneity problem arises. For example, the literature suggests that more able academics have many more opportunities to receive funding as grant awarding bodies screen academics for their ability and sponsor the most productive. If unobserved individual heterogeneity were present, the estimated coefficient of the funding variables would be upwards biased. We can cope with this challenge if pre-sample information of the dependent variable is available. Specifically, Blundell et al. (1995, 2002) suggest a solution which controls for individual heterogeneity by specifying the average productivity of the academic before she enters the sample. The pre-sample mean of the dependent variable is a consistent estimator of the unobserved individual effect if it mainly corresponds to the intrinsic ability of an academic and her motivation, both factors that are not directly observable but may affect scientific productivity. Following Blundell et al. (1995, 2002) we can therefore account for unobserved individual heterogeneity by using pre-sample information of publications and citations. We include the log of the average number of publications published in a pre-sample period (in the period 1998 to 2000). In cases where the pre-sample value is zero, we include a dummy to capture the "quasi-missing" value.

Theory further suggests that research activity is subject to dynamic feedback (Dasgupta and David, 1994) as each academic's performance is driven by cumulative unobserved factors (u_{it}), e.g. learning, which are not controlled for through fixed effects. Blundell et al. (1995) therefore argue that it is important to consider continuous, sample-period dynamics when modelling research outcomes. To proxy for dynamic feedback within the sample period we calculate the stock of publications (and citations) published during the observation period. We assume that knowledge does not depreciate during the short sample period considered here (6 years).

The pre-sample value and the stock variable are included in all estimations. This dual approach helps to address the problem of endogeneity that arises from correlated individual effects and through feedback from the dependent variable.

5 Data

This paper evaluates the possible joint effects of different types of external sponsorship on publications and citations, using data on external public research grants and industry funding for UK engineering academics. External grants represent research funding that an academic receives in addition to the university's core funding.

To gain access to grant information for academics, we contacted UK universities with engineering departments. Fifteen of these universities sent detailed records containing information on private and public research grants received by their engineering staff during the period 2001 to 2007[4]. We manually matched the funding information with name and rank information, as well as with their publication records. We supplemented this data with PhD year and subject information for all 885 academics that worked at the 15 universities at least during the whole period 2001 to 2006 (or 2007), whether they received funding or not. After exclusion of incomplete records, the final data set contains 809 engineering academics. Of these academics, 58% received some external funding at least once during the six-year observation period.

5.1 Descriptive statistics

Research Output

The descriptive statistics for the sample are reported in Table 1. The main variables of interest are research output and its quality, which we measure using academics' publication records as well as proceedings, which are considered as very important in some fields of engineering. Publications and proceedings were obtained from the ISI Web of Science database. We collected publications for all the years 1998 up to 2007, matched names based on last name and first initial and cleaned all database entries manually to assure correct matching to individual academics.

Funding could have a different impact on research quality than it has on research quantity. Therefore, we include a measure for research quality using the average 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

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[4] For some of the 15 universities funding is available for earlier years, e.g. for 3 from 1990 onwards. Funding was available until 2007. The period 2001 to 2007 is the preferred period for this analysis as it covers a larger number of universities and represents the assessment period for the 2008 Research Assessment Exercise (RAE). The research information can therefore be expected to be fairly standardised across the 15 institutions and adjusted to the requirements of the RAE.

citation window of ten years while for publications published in 2007 we consider a citation window of five years. We do not look at citations to proceedings as they are far less likely to occur.

To summarize, we measure publication output as the number of publications in *t* (*PUBLICATIONS*) and quality as the average number of citations received by publications published in *t* as of 2012 (*CITATIONS*). In addition we measure the number of proceedings in *t* (*PROCEEDINGS*). The mean number of publications during the observation period is 2.26 per academic per year and the mean citation count for these publications is 7.99. Further, 8% of the academics in our sample did not publish during the entire six year period and 30% published less than one paper per year. The average number of proceedings per year is 1.06.

For all three measures, we generate three-year pre-sample means (*Pub_Mean*, *Cit_Mean, Proc_Mean*) for the period 1998 to 2000, and a stock variable (*Pub_Stock, Cit_Stock, Proc_Stock*) for the years following 2000. These are included in all models to control for the ex-ante scientific quality of the academic (time-invariant unobserved heterogeneity) and dynamic feedback (time-variant unobserved heterogeneity).[5]

Patents and publications are moderately correlated. We therefore include the lagged number of patents (*PATENT*) in the publication equations as previous research has shown that publications and patent outputs tend to be correlated (Agrawal and Henderson, 2002). We obtain patent data from esp@cenet (the European Patent Office (EPO) web-interface). The web-interface allows searches for patent applications filed with the EPO, the UK Intellectual Property Office (UKIPO), the US patent office (USPTO) and other national patent offices. Database construction required a manual search in the inventor database to identify those entries where the identity of the academic was certain. We did this by comparing addresses, titles and technology classes for all patents potentially attributable to each academic. We did not only consider patents filed by the universities themselves, but also those assigned to third parties, e.g. industry or government agencies. As each invention can lead to multiple patent applications (e.g. at different patent offices), we additionally verified each entry with the International Patent Documentation Center (INPADOC) that contains information grouped around a patent family, enabling us to uniquely identify the original invention and avoid multiple counts. In the remainder of the paper the term patent will refer to patent families grouped around an original priority patent (as defined in INPADOC) and not to individual patents or patent applications. We recorded the filing date of the patent as this represents the closest date to invention. The average number of patents per year is 0.08 and 0.30 amongst those with at least one patent during the observation period.

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[5] Regressions do not suffer from multicollinearity when stock and pre-sample measures are included. The collinearity diagnostics show a vif (variance inflation factor) < 2 for all stock and pre-sample measures.

Research Funding

The research income information obtained from the 15 universities includes the name of the principal investigator as well as data on funding source, award date, grant period and funding amount. We can attribute grant-based income to: (1) industry and business, (2) public funding agents, including UK research councils (mainly EPSRC), UK charities, UK government and EU. The average length of the grants is 3 years for public grants and 2.9 for industry grants. This difference is small but significant. The amount of funding is significantly higher for public grants with an average of more than 150,000 per grant and only 60,000 for industry grants. All funding amounts were 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 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 was done in order to account for the on-going benefits and implications of a project.

We use funding received in *t*-1 to capture the impact of financial resource on scientific productivity in *t*. We firstly look at the overall effect of external funding (*FUNDING*). Then, we differentiate between funding received from industry and from public agents which includes UK research council and UK charity funding, EU funding and government funding.

After excluding some outliers[6] academics receive on average £32,000 per year in external funding. Industry funding amounts to approximately £6,000 per academic per year, while public funding provides approximately £26,000 on average, with the majority being sourced from UK research councils and charities (circa £20,000). If we only consider academics that receive some funding during the observation period, the average amount of external funding per year is £53,000 with approximately £9,000 coming from industry and £40,000 from public sponsors. The majority of academics receive funding from more than one type of funding agent during the observation period. 42% of academics, however, receive no external funding at all. Of those that receive external funding at least once, 60% are sponsored by industry (35% of the total sample). In terms of funding volume, UK research council and charity funding accounts for 65% of all external research income, funding from industry accounts for 17%, followed by EU with 11% and UK government with 8%.

Looking at funding received during one period, we find that 42% of funded academics receive public and industry funding simultaneously at least once. Accordingly find a strong positive correlation

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[6] Outliers were identified using average values of leverage and (normalized) residuals following a linear regression of funding on publication outputs and are excluded using DFFITS (Belsley et al., 1980). We follow Bollen and Jackman (1990) and exclude observations with DFFITS>1, meaning that the observation shifts the estimate by one standard deviation. We repeat the process for all funding variables and in total exclude 14 observation, most of which are EU funding outliers.

between public and industry funding. Publication numbers correlate strongest with research council and industry funding; citations are only weakly correlated with funding; patents are strongest correlated with industry funding.

Control variables

We account for academic rank by including a dummy variable that takes the value one if the academic was a professor in *t*-1 *(PROFESSOR).* Academic rank information was obtained from university websites. Professors may have more resources available than lower ranked academics and may thus benefit more in terms of publication output than junior academics. The rank variable is lagged by one period to allow for publication delays and avoid simultaneity with our outcome measure. *PROFESSOR* is strongly correlated with publication numbers and to a lesser extent with publication quality. Further it is moderately correlated with all our funding measures.

We control for gender (*FEMALE*) as previous literature has found a gender bias in both funding and academic productivity (Stephan, 2012). Women account for 7% of academics in our sample. Table 2 shows that the gender dummy is not highly correlated to any of our main explanatory variables. We only find a negative significant sign for correlation with EU funding.

To account for other individual effects, we collected personal information of academics based on PhD data. PhD information was taken from *Index to Theses*, an online database which lists theses accepted for higher degrees by the universities of the UK and Ireland. It provides information on PhD institution, year and subject area. For academics not listed in the database we searched their websites and gathered PhD details from the library catalogues of the PhD awarding university[7]. Of the 809 academics for which personal information could be collected, 56 do not hold a PhD. As for the remaining 753 academics, 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. Based on the PhD information we include the academic's academic age (*PHD_AGE*) as the difference between the current year and the year of the PhD as a control to account for life-cycle effects. The correlation matrix shows that *PHD_AGE* is moderately correlated with our outcome variables but only weakly with the funding measures. We further include a dummy for those academics that do not hold a PhD (*NO_PHD*), which represents 7% of the sample.

Subject specialisation is based on the subject of the PhD as department division is not consistent across the 15 universities. In our sample 22% of academics graduated in electrical and electronic engineering (*ELECTRICAL*), 21% in civil engineering (*CIVIL*), 15% hold a PhD in chemical engineering (*CHEMICAL*), 15% in physics (*PHYSICS*) and 13% in mechanical engineering

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[7] 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.

(*MECHANICAL*). Just 8% have a background in life sciences (*BIO*). The correlation table shows some important differences by scientific field. Physics and chemical engineering are strongest correlated with our outcome measures. Physics is also positively correlated with funding, while civil engineering correlates negatively with all types of funding and the outcome measures.

Year and university dummies are included in all regressions to control for potential institution or time fixed effects. Due to the short panel window institution specific measures (e.g. size, income) are not included as they do not differ significantly across time and any differences should be captured by the university fixed effect.[8]

5.2 Analysis of funding profiles

Table 2 reports descriptive statistics by type of funded academic. Academics are allowed to move between groups depending on their funding status in *t*-1. We differ between observations where an academic receives (1) no public or industry funding, (2) only industry funding, (3) only public funding and (4) both, industry 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 academics with some public funding this difference is significant. Further, academics receiving industry *and* public grants are most productive. This observation also holds when looking at average citation numbers or at proceedings. The group of highly sponsored and diversified academics is also the group producing the largest number of patents. This is in line with the literature on star scientists (Zucker and Darby, 1996; Zucker et al., 2002) that suggests strong complementarities between high scientific ability, commercialisation and funding success. The descriptive results thus support our assumption of a positive production function and point towards a complementary relationship between public and private sector grants for all research outputs.

In terms of funding amount, it becomes clear that academics that source funding from more than one source raise significantly more funding than academics 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 academics, industry may look at public grants to inform their own funding decision and to identify potential partners for research (Perkmann et al., 2013).

In terms of control variables, we make some interesting observations. Significantly fewer female academics can be found amongst the group of academics that receive funding from industry alone. Academics without a PhD are significantly less represented in the groups of funded academics,

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[8] Mobility of academics across institutions is limited in our sample period. We observe as few as nine individuals who move from one institution to another.

suggesting that they are less research but perhaps more teaching oriented. Age is significantly higher in the groups of academics receiving public funding and highest amongst the top performing group that also includes the highest share of professors. We can further see that different scientific fields attract different types of funding. Academics in bioscience are significantly more represented in the group that attracts funding from several sources, while academics in physics are focussing on one agent at a time. Researches in mechanical engineering are more likely to be found amongst funded academics, while academics in chemical engineering are mostly found amongst those receiving no or only public funding. Electrical and electronic engineering faculty are less likely to solely source funding from industry, while civil engineering academics are more likely to be found amongst this group.

5.3 Analysis of "Taste" profiles

Table 3 reports descriptive statistics by the taste for science and commercialisation of academics. We do not allow academics to change between groups but evaluate them based on their overall sample period profile. We base our TFS measure on the journal classification developed by Narin (1976) that distinguishes between basic and applied type journals.[9] Based on cross-citation matrices between journals, it distinguishes between four categories where 1 is the most applied and 4 the most basic ((1) applied technology, (2) engineering and technological science, (3) targeted basic research, and (4) basic scientific research). We consider academics to have a high taste for science if they published at least one article in a basic research oriented journal (3 or 4) during the observation and pre-observation period. This being a sample of engineering academics there is a bias towards applied research and basic research publications are not as common as in other fields of research and we therefore adopt a broad definition of 'basic'. Our TFC measure is based on patent applications filed by the respective academic. If the focal academic applied for at least one patent during the observation and pre-observation periods he or she is considered to have a taste for commercialisation. In our sample 29.5% can be considered traditional academics (quadrant I), 9.5% are commercial types (quadrant III) and 18% can be considered "hybrids" (they both patent and publish basic research articles, quadrant II).

In Table 3 we show how the input and output measures of our estimations differ by the type of academic. The descriptive statistics show that "hybrid" academics, those with a high taste for both science and commercialisation publish most articles and receive most citations. They also have the highest amount of research income from both industry and public sources. All the other groups perform less well in terms of both publications and citations and receive significantly less funding. The group of "others", who show no strong taste for science or commercialisation, still outperform

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[9] We use the 2005 version of the classification updated by Kimberley Hamilton for the National Science Foundation (NSF).

commercial types in terms of outcomes and funding. They also publish more proceedings than scientific or commercial types. This suggests that ‘others’ represent a group of academics that may not have the time or funding to develop their research into inventions or into scientific papers. In terms of patent numbers, we find that hybrids file significant more patents than purely commercial types.

There are some differences regarding our control variables. Significantly more professors can be found amongst the group of “hybrid” academics. Academics with a high TFC are also significantly older than traditional scientists or those that are least research active (“others”). Academics without a PhD are significantly more represented in the group of “others”, suggesting that they are less research but perhaps more teaching oriented. Female academics are also more likely to be amongst those with low TFS, either as “commercial types” or “others”.

6 Results

6.1 Baseline results

6.1 Results with funding interactions

We secondly estimate the effect of different types of funding and their interactions on publication outcomes. For a correct interpretation of the interaction variable, we calculate the cross-derivative for the joint effect of public and industry income holding all variables at their mean (following eq. (5)). Table 4 shows the marginal effects of the key funding variables at the mean. The cross-derivative of the interaction term is negative and significant for publication counts, indicating that while public funding positively correlates with publication numbers, the joint effect of industry and public funding is negative, offsetting part of the positive productivity effect of public grants. A similar negative interaction effect is found for proceedings but not for citations.

The control variables are consistent across the different specifications. Patents show a positive correlation with publication, proceeding and citation numbers though the effects are insignificant in columns 1 and 2. Professors publish significantly more and of higher quality than junior academics, perhaps due to their experience and better access to resources. We do not find a significant difference between the publication rates of men and women. Academics that do not hold a PhD also produce significantly fewer publications, and receive fewer citations than their peers, but they are equally as productive in terms of proceedings. This indicats that they may focus primarily on teaching and may not be able to develop their initial conference papers into scientific articles. Productivity and publication quality decline with age. Publication and average citation numbers are lower in more applied fields of engineering and lowest in civil and mechanical engineering. Proceeding numbers are highest in Electrical and Electronic Engineering where they do in fact account for more than 40% of academic research output. University fixed effects and year effects are jointly significant in the case of publications and citations, but not for proceedings. Our pre-sample mean and the dynamic feedback variables are both positive and significant pointing at the importance of controlling for individual unobserved effects.

6.2 Results by "Taste" type

Table 4 shows the marginal effects of the funding variables and their interactions by researcher type. As with the baseline case, we find a positive effect of public grants for all types, except the "traditional" type. This is somewhat surprising as we would have suspected a greater effect, however, perhaps this group of academics publishes regardless of funding incentives and perhaps relies less on external funding for their research. Industry funding is positive for traditional scientists and "others". For median to high values of industry funding, however, the effect turns negative. The most interesting result is the difference in the interaction effect of public and industry grants between types of academics. For traditional scientists the marginal interaction effect is -3.429. For "hybrids" it is notably smaller (-0.800) suggesting that the publication output of "hybrids" is less compromised by industry sponsored research than that of traditional scientists. For commercial types the interaction effect is insignificant pointing towards no direct relationship between the two types of funding. For "others" the interaction effect is again negative.

We find a strong positive complementary effect of public and private funding on the number of proceedings published by commercial types. For traditional and hybrid types the negative interaction effect is also found for proceedings. Further, we find no evidence of complementarity or substitution between public and industry funding on the average number of citations for any of the types.

Figure 2 illustrates the effect of industry funding on the marginal effect of public funding on publication numbers for all four types. From the downwards sloping lines, we see the substitutive relationship in the quadrant of traditional types. The negative predicted number of publications also shows that for high amounts of industry funding any increase in public funding will result in fewer publications. "Hybrids" show a similar pattern to the one of traditional scientists, but the substitutive effect is less pronounced and higher amounts of funding will still result in an increase in publications albeit at a decreasing rate. For commercial types, however, we find an increase in research productivity in terms of quantity of publications where high amounts of research funding are obtained from both sources. The remaining group of "Others" follows a pattern similar to that of hybrid scientists, though less pronounced. Figure 3 shows the marginal effect on proceeding numbers. Again it illustrates the substitutive relationship for traditional scientists that is less pronounced for "Hybrids". Commercial types instead show a complementary relationship between public and industry funding on the number of proceedings which only disappears for those that receive high amounts of both industry and public funding. For "Others" the flat slopes indicate a simple additional effect with no complementarity or substitution.

The control variables also expose some interesting differences across types of academics. Professors publish significantly more in all groups accept "commercial". Professors in all groups except for "commercial" also have higher mean citation counts and proceedings. While we did not find a significant difference between the publication rates of men and women in the baseline regressions in Table 4, we now find that "hybrid" women publish more than men, while "traditional types" publish fewer proceedings. Academics that do not hold a PhD also produce significantly fewer publications, receive fewer citations than their peers in all groups of academics, but are no different in terms of numbers of proceedings. Performance declines with age, but primarily for those with low "TFC".

7 Conclusions

This paper empirically investigated the existence of complementarities between public and private grant-based research funding on scientific performance. Our results suggest that the direction of this effect depends on the type of academic and on the type of scientific output. Using a typology that distinguishes between academics with a "taste for science", "taste for commercialization", this study examined a sample of academics in engineering regarding the joint effects of public and private sector grants. Controlling for unobserved heterogeneity, we find that industry funding decreases the marginal effect of public grants on publication outcomes for "traditional academics" with a high taste for science, but a low taste for commercialisation. The joint effect was considerably smaller, but still negative, for "hybrids". These results point to the conclusion that academics with a high "taste for science" may find it more difficult to recognise and realise potential complementarities between their publicly funded work and industry-sponsored projects. It may also imply that basic research undertaken by traditional scientists is least compatible with industry led projects.

Conversely, for "commercial types" with a high taste for commercialisation and a low taste for science, we find that industry grants stimulate proceedings output. These insights suggest that "commercial types" do realise complementarities between projects from public and industry sponsors, and that this not only spurs commercial output, but also increases conference paper numbers. However, the same complementarities cannot be realised for more scientific work, for which they may lack capability.

The results are less clear for mean citation output. While "commercial scientists" (and to a lesser extent "hybrids") publish fewer and less impactful articles, "traditional types" achieve a quality increase as a result of private co-sponsorship. The joint effects are, however, insignificant, and therefore suggest that overall quality of research output is little affected by external funding.

These results help to inform the debate on how industry and public funding jointly affect research productivity. In terms of policy implications we can conclude that co-sponsorship may affect different types of academics differently. It seems important to provide public grants to fund all academics as this will allow them to focus their research efforts without the distraction of work for other sponsors.

For all types public sponsorship increases research outcome in terms of publications and proceedings. Moreover, those that have been unable to realise their potential (the "Others") benefit most from public funding in terms of citation number increases. It is therefore important to sponsor not just established scientists but to enable others to reach their potential. Private sector grants may also be very valuable to those academics who are capable of combining publicly financed research with industry projects. For these academics the complementarities between grants open up additional research, as indicated in an increase in proceedings papers for commercial types, that may not have been achieved without multiple sources of funding.

This study is a first step to unleash the interactions between different types of external funding for different types of academics. We concentrated on the field of engineering, which is traditionally associated with applied research and industry relations. We therefore strongly encourage further research taking into account other disciplines as funding environments continue to shift. 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 clearly needed to pin down the mechanisms behind the effect of industry grants that can be so different on different types of academics. Negative effects for traditional scientists, for example, could be due to non-disclosure clauses or research topics less relevant to science. Blumenthal et al. (2006) and Czarnitzki et al. (2011) show evidence of secrecy clauses for academics with industry grants that may also affect the release of publications from public grants. Hottenrott and Lawson (2014) further suggest that ideas from industry may not always lead to better research performance, perhaps by simply not being relevant to science (see Perkmann and Walsh, 2009). With the comparability of our results in mind, we suggest further research on the dynamics underlying the sponsoring-research outcome relationship in both qualitative and quantitative approaches. In particular, the debate on research funding would benefit from investigating if and how funding relationships affect not only short-term scientific outcomes but also the shaping of scientific careers. Academics may specialise in certain types of grants and sponsors, and hence the type of research output they pursue.

This paper also shows that a group of academics exists with a taste for neither science nor commercialisation, which is less involved in research. We provide some weak evidence that these academics can draw benefits from contracts with industry, primarily due to their inability to access competitive public funding. As these academics may focus primarily on teaching, the consequences of their links to industry for students could be of importance.

Finally, it is important to stress that this study does not evaluate other benefits that may come from co-sponsorship. A more comprehensive assessment is therefore needed to establish any benefits for students, teaching or commercialisation of research as well as benefits for the sponsoring firms, which would contribute to the social returns from science and may therefore be of greater policy relevance than publications in scientific journals.

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Figures

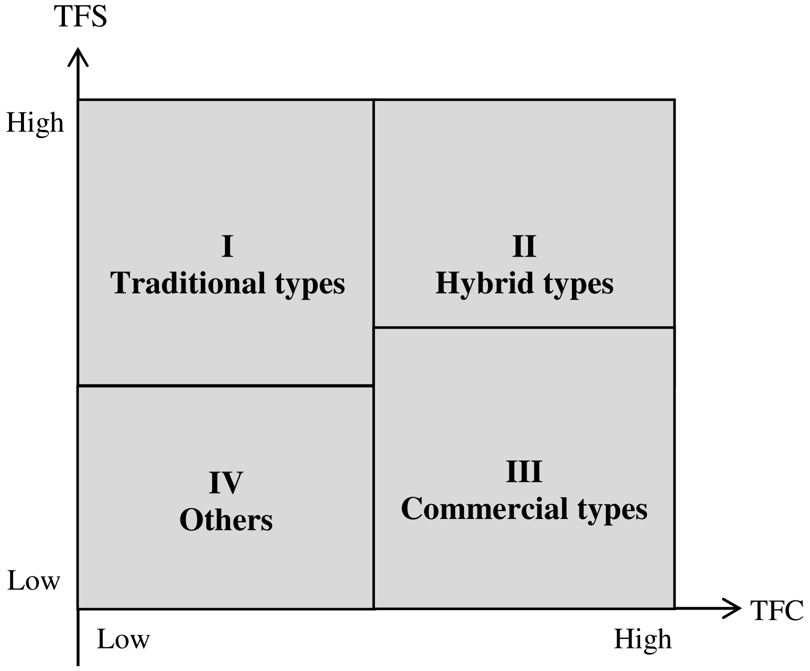

Figure 1: Classification of academics by their “Taste for Science” (TFS) and “Taste for Commercialization” (TFC)

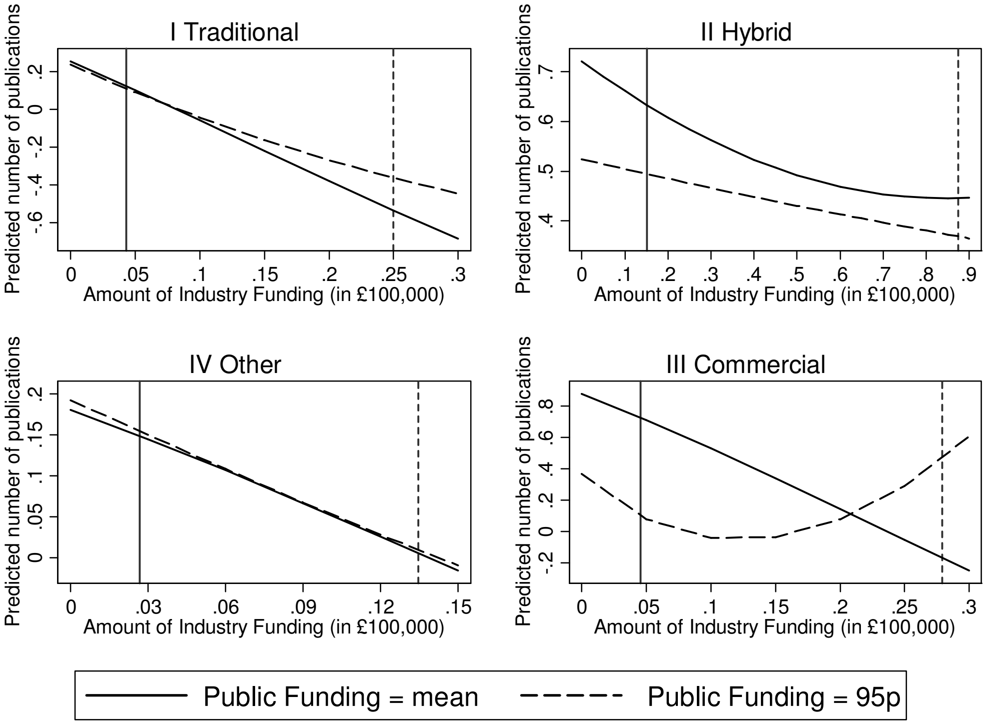

Figure 2: Effect of industry funding on the marginal effect of public funding on publication numbers (by type of academic)

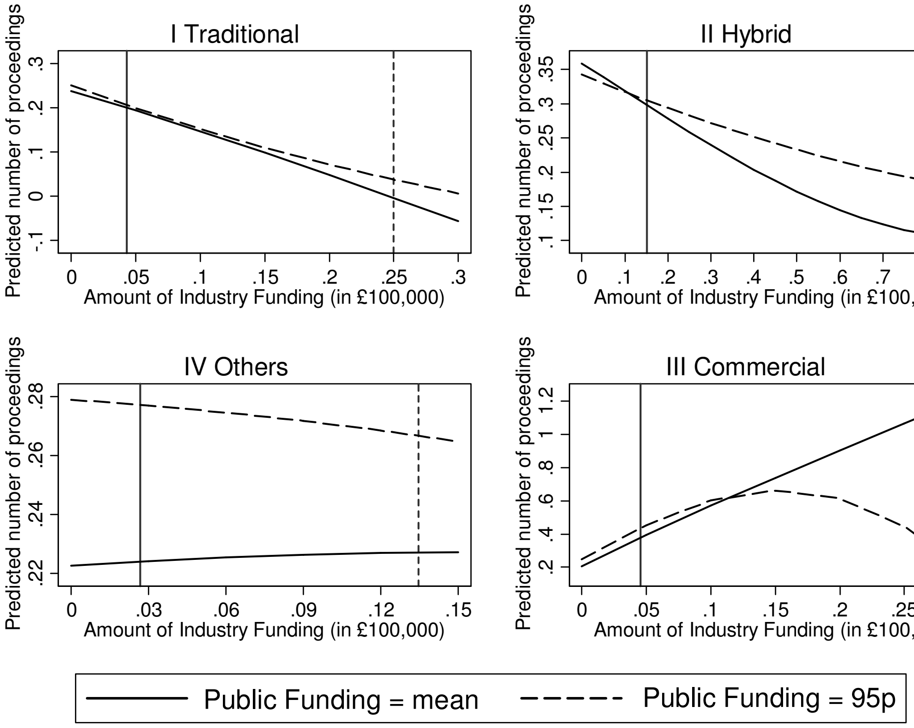

Figure 3: Effect of industry funding on the marginal effect of public funding on proceeding numbers (by type of academic)

Tables

Table 1: Descriptive statistics (4,790 observations)

	mean	sd	min	max
Productivity measures				
$PUBLICATIONS_{it}$ (Publication number)	2.26	3.21	0.00	32.00
$CITATIONS_{it}$ (Mean citations to publications)	7.99	13.98	0.00	391.00
PROCEEDINGS (Proceedings number)	1.06	2.41	0.00	41.00
Patent measure				
$PATENT_{it}$ (Patent dummy)	0.06	0.24	0	1
$PATENT\_NUMBER_{it}$	0.08	0.40	0	6
Funding measures(in 100,000 GBP)				
$FUNDING_{it-1}$	0.32	0.95	0	12.12
$PUBLIC\_FUNDING_{it-1}$	0.26	0.84	0	11.67
$INDUSTRY\_FUNDING_{it-1}$	0.06	0.27	0	7.22
$RC\_FUNDING_{it-1}$	0.20	0.77	0	11.15
$EU\_FUNDING_{it-1}$	0.04	0.17	0	3.02
$GOV\_FUNDING_{it-1}$	0.02	0.14	0	2.39
Individual characteristics				
$PROFESSOR_{it-1}$	0.34	0.47	0	1
$FEMALE_{i}$	0.07	0.25	0	1
NO_PHD_{i}	0.07	0.25	0	1
PHD_AGE_{i}	18.60	10.47	0	49
BIO_{i}	0.07	0.26	0	1
$PHYSICS_{i}$	0.15	0.36	0	1
$MECHANICAL_{i}$	0.13	0.34	0	1
$ELECTRICAL_{i}$	0.22	0.41	0	1
$CHEMICAL_{i}$	0.15	0.36	0	1
$CIVIL_{i}$	0.21	0.41	0	1
Individual heterogeneity measure				
PUB_Mean_{i}	2.05	2.58	0.00	26.00
CIT_Mean_{i}	14.35	45.61	0.00	1195.00
$PROC\_Mean_{i}$	0.94	1.51	0.00	16.67
PUB_Stock_{it-1}	7.36	11.14	0.00	150.00
CIT_Stock_{it-1}	31.04	43.19	0.00	445.00
$PROC\_Stock_{it-1}$	3.29	6.79	0.00	129.00

Table 2: Means by funding structure

	1	2	3	4	5
Funding	No funding	Public=0; Industry>0	Public>0; Industry=0	Public>0; Industry>0	Anova F-Test
Observations	2851	303	1105	537	Sig.
Researcher IDs	651	140	365	194	
Productivity measures					
PUBLICATIONS$_{it}$	1.75	1.98	2.75***	4.12***	***
CITATIONS$_{it}$	6.83	7.11	9.71***	11.16***	***
PROCEEDINGS$_{it}$	0.72	1.10***	1.43***	2.09***	***
Patent measure					
PATENT$_{it}$	0.04	0.06	0.07***	0.13***	***
PATENT_NUMBER$_{it}$	0.06	0.07	0.11*	0.20***	***
Funding measures (in 100,000 GBP)					
FUNDING$_{it-1}$	0.00	0.22***	0.62***	1.42***	***
PUBLIC_FUNDING$_{it-1}$	0.00	0.00	0.62***	1.05***	***
INDUSTRY_FUNDING$_{it-1}$	0.00	0.22***	0.00	0.38***	***
RC_FUNDING$_{it-1}$	0.00	0.00	0.48***	0.80***	***
EU_FUNDING$_{it-1}$	0.00	0.00	0.09***	0.13***	***
GOV_FUNDING$_{it-1}$	0.00	0.00	0.05***	0.11***	***
Individual characteristics					
PROFESSOR$_{it-1}$	0.25	0.35***	0.45***	0.61***	***
FEMALE$_{i}$	0.07	0.04**	0.07	0.06	**
NO_PHD$_{i}$	0.09	0.06*	0.03***	0.03***	***
PHD_AGE$_{i}$	18.20	17.83	18.95**	20.41***	***
BIO$_{i}$	0.07	0.06	0.08	0.10**	***
PHYSICS$_{i}$	0.13	0.16	0.18***	0.16*	***
MECHANICAL$_{i}$	0.12	0.17***	0.14*	0.16***	***
ELECTRICAL$_{i}$	0.22	0.19	0.21	0.23	n.s.
CHEMICAL$_{i}$	0.16	0.11***	0.15	0.10***	***
CIVIL$_{i}$	0.20	0.25**	0.22	0.22	**

Note: Stars in columns 2-4 indicate significance of mean comparison with column 1 (observations with no funding). Analysis of variance (column 5) compares the four groups of researchers. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3: Pairwise mean comparison tests by type of academic

	(1) traditional	**(2) hybrid**	**(3) commercial**	**(4) other**
Observations	1409	872	459	2050
Researcher IDs	239	147	77	345
	PUBLICATIONS$_{it}$			
Mean	3.10***	4.33***	0.95***	1.58***
diff = mean(#)-mean(1)		1.23***	-2.15***	-1.52***
diff = mean(#)-mean(2)			-3.38***	-2.75***
diff = mean(#)-mean(3)				0.63***
	CITATIONS$_{it}$			
Mean	11.55***	12.97***	3.99***	5.51***
diff = mean(#)-mean(1)		1.42	-7.57***	-6.05***
diff = mean(#)-mean(2)			-8.98***	-7.47***
diff = mean(#)-mean(3)				1.30**
	PROCEEDINGS$_{it}$			
Mean	1.08***	1.77***	0.56***	1.87***
diff = mean(#)-mean(1)		0.68***	-0.52***	0.79***
diff = mean(#)-mean(2)			-0.20***	0.10
diff = mean(#)-mean(3)				- 1.22***
	PUBLIC_FUNDING$_{it-1}$			
Mean	0.28***	0.46***	0.17***	0.18***
diff = mean(#)-mean(1)		0.20***	-0.12***	-0.10*
diff = mean(#)-mean(2)			-0.32***	-0.30***
diff = mean(#)-mean(3)				- 0.02
	INDUSTRY_FUNDING$_{it-1}$			
Mean	0.04***	0.15***	0.03***	0.05***
diff = mean(#)-mean(1)		0.11***	-0.02**	-0.00
diff = mean(#)-mean(2)			-0.12***	-0.11***
diff = mean(#)-mean(3)				- 0.02*

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$; no difference in mean comparison between HYBRID and commercial types in terms of patent numbers.

Table 4: Marginal effects of external funding on publication outcomes

	1		2		3	
VARIABLES	PUBLICATIONS$_{it}$		CITATIONS$_{it}$		PROCEEDINGS$_{it}$	
	NBREG		NBREG		NBREG	
	dy/dx	SE	dy/dx	SE	dy/dx	SE
PUBLIC_FUNDING$_{it-1}$	0.228***	(0.059)	0.734**	(0.301)	0.224***	(0.040)
PUBLIC_FUNDING$_{it-1}^{2}$	-0.091***	(0.027)	-0.293**	(0.131)	-0.106***	(0.019)
INDUSTRY_FUNDING$_{it-1}$	0.467***	(0.177)	-1.112	(0.873)	0.295**	(0.122)
INDUSTRY_FUNDING$_{it-1}^{2}$	-0.843**	(0.374)	0.615	(1.838)	-0.398*	(0.240)
PUBLIC_FUNDING$_{it-1}$*INDUSTRY_FUNDING$_{it-1}$	-0.246*	(0.129)	0.264	(0.694)	-0.208***	(0.060)
PATENT_NUMBER $_{it-1}$	0.135*	(0.070)	0.204	(0.408)	0.089	(0.167)
PROFESSOR$_{it-1}$	0.928***	(0.136)	3.416***	(0.551)	0.966**	(0.483)
FEMALE$_{i}$	-0.032	(0.196)	-0.876	(1.081)	-0.672	(0.459)
NO_PHD$_{i}$	-1.940***	(0.367)	-7.339***	(1.809)	-1.196	(0.779)
PHD_AGE$_{it}$	-0.042***	(0.007)	-0.140***	(0.034)	-0.052**	(0.025)
BIO$_{i}$	0.508**	(0.209)	4.286***	(0.968)	0.428	(0.495)
PHYSICS$_{i}$	0.791***	(0.177)	2.669***	(0.844)	1.477*	(0.758)
MECHANICAL$_{i}$	0.142	(0.191)	-0.253	(0.968)	0.699	(0.457)
ELECTRICAL$_{i}$	0.474***	(0.161)	1.191	(0.826)	2.170**	(0.968)
CHEMICAL$_{i}$	0.844***	(0.173)	2.710***	(0.811)	0.555	(0.417)
CIVIL$_{i}$ (Reference)						
ln[Pub_Mean]|ln[Cit_Mean]|ln[Proc_Mean]	0.765***	(0.082)	1.348***	(0.283)	0.938**	(0.386)
[Pub_Mean=0]|[Cit_Mean=0]|[Proc_Mean=0]	-1.625***	(0.229)	-1.218	(1.070)	-1.847**	(0.802)
Pub_Stock|Cit_Stock|Proc_Stock	0.075***	(0.012)	0.062***	(0.011)	0.151*	(0.091)
Joint sign. of university dummies χ2 (14)	100.18***		98.28***		4.74	
Joint sign. of subject dummies χ2 (5)	32.55***		33.86***		5.33	
Joint sign. of year dummies χ2 (5)	13.93**		46.08***		4.11	
Log-likelihood	-8105.877		-13406.915		-5415.2588	
Lnalpha	-1.069***		0.838***		0.129*	
Cluster	808		808		808	
Observations	4790		4790		4790	

Note: Marginal effects are reported. Marginal effects for funding variables are calculated following eq. (4) - (5). All other variables are held at the mean.
Robust clustered standard errors in parentheses; clustered by individual researcher. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Marginal effects for funding values and their interactions for different types of academics

	1	2	3	4	5	6	7	8	9	10	11	12
Dependent Variable:	PUB_{it}	PUB_{it}	PUB_{it}	PUB_{it}	CIT_{it}	CIT_{it}	CIT_{it}	CIT_{it}	$PROC_{it}$	$PROC_{it}$	$PROC_{it}$	$PROC_{it}$
Quadrant:	Traditional	Hybrid	Commercial	Other	Traditional	Hybrid	Commercial	Other	Traditional	Hybrid	Commercial	Other
Estimation Method:	NBREG	NBREG	NBREG	NBREG	NBREG	NBREG	NBREG	NBREG	NBREG	NBREG	NBREG	NBREG
PUBLIC_FUNDING$_{it-1}$	0.123	0.634***	0.709**	0.142***	0.186	1.269	2.485	0.637*	0.200***	0.302***	0.335	0.210***
	(0.159)	(0.212)	(0.346)	(0.049)	(0.698)	(0.817)	(1.711)	(0.356)	(0.065	(0.088)	(0.235)	(0.054)
PUBLIC_FUNDING$_{it-1}^2$	-0.034	-0.303**	-1.784	-0.036	-0.211	-0.440**	-4.771**	-0.296	-0.081***	-0.112**	-0.135	-0.119***
	(0.060)	(0.126)	(1.120)	(0.028)	(0.286)	(0.438)	(2.297)	(0.189)	(0.025)	(0.053)	(0.357)	(0.033)
INDUSTRY_FUNDING$_{it-1}$	3.029***	0.174	-0.031	1.508***	7.877*	-4.137**	-4.875	0.765	0.710	0.543**	-0.428	0.330
	(0.887)	(0.530)	(0.733)	(0.520)	(4.504)	(2.002)	(4.838)	(2.246)	(0.490)	(0.264)	(0.594)	(0.282)
INDUSTRY_FUNDING$_{it-1}^2$	-11.085***	-1.281	-5.862	-8.509**	-26.939	2.405	10.572	-7.065	-1.584	-1.235**	3.613	-0.036
	(2.989)	(1.256)	(6.034)	(3.590)	(17.99)	(4.773)	(22.49)	(8.581)	(2.173)	(0.543)	(3.278)	(1.177)
PUBLIC_FUNDING$_{it-1}$*	-3.429***	-0.800**	-2.999	-1.199**	2.097	0.155	-2.317	0.067	-0.951***	-0.550**	3.295*	0.045
INDUSTRY_FUNDING$_{it-1}$	(1.297)	(0.347)	(3.906)	(0.471)	(6.035)	(1.851)	(20.13)	(1.781)	(0.517)	(0.265)	(1.979)	(0.200)
PATENT_NUMBER $_{it-1}$		0.114	-0.001			0.475	-0.348			0.250***	0.016	
		(0.106)	(0.140)			(0.676)	(1.114)			(0.083)	(0.446)	
PROFESSOR$_{it-1}$	1.452***	0.816**	-0.080	0.373***	4.833***	3.534**	1.230	2.495***	0.616***	0.116	-0.724	0.396***
	(0.270)	(0.380)	(0.270)	(0.087)	(1.121)	(1.447)	(1.535)	(0.628)	(0.231)	(0.277)	(1.117)	(0.147)
FEMALE$_i$	0.392	0.795*	-0.344	-0.143	-0.598	1.632	6.558	-1.489	-0.886**	0.465	-7.239	-0.104
	(0.331)	(0.435)	(0.425)	(0.158)	(1.373)	(1.667)	(8.325)	(1.272)	(0.422)	(0.497)	(8.484)	(0.141)
NO_PHD$_i$	-2.725***	-1.582**	-1.641	-0.604***	-7.730**	-2.839	-14.700**	-4.798***	-0.657	-0.016	-8.018	-0.449*
	(0.803)	(0.788)	(1.191)	(0.181)	(3.409)	(7.123)	(6.964)	(1.336)	(0.673)	(0.559)	(9.846)	(0.265)
PHD_AGE$_{it}$	-0.079***	-0.035*	-0.027	-0.010**	-0.207***	-0.073	-0.099	-0.083**	-0.048***	-0.000	-0.075	-0.013**
	(0.013)	(0.018)	(0.018)	(0.004)	(0.067)	(0.077)	(0.127)	(0.032)	(0.013)	(0.014)	(0.101)	(0.007)
ln[Pub_Mean]|ln[Cit_Mean]|ln[Proc_Mean]	0.498***	1.438***	0.806***	0.185***	2.235***	1.703***	0.795	0.684**	0.591***	0.727***	2.218	0.268***
	(0.153)	(0.327)	(0.192)	(0.061)	(0.721)	(0.572)	(0.709)	(0.331)	(0.121)	(0.140)	(2.120)	(0.092)
[Pub_Mean=0]|[Cit_Mean=0]|[Proc_Mean=0]	-0.900**	-2.953*	-0.567*	-0.587***	5.237**	-2.006	-0.358	-1.241	-0.813***	-1.525***	-4.309	-0.766***
	(0.458)	(1.555)	(0.303)	(0.109)	(2.234)	(3.453)	(2.391)	(0.955)	(0.259)	(0.331)	(4.524)	(0.194)
Pub_Stock|Cit_Stock|Proc_Stock	0.092***	0.071***	0.100***	0.072***	0.033***	0.057**	0.044	0.083***	0.109***	0.030***	0.203	0.079**
	(0.013)	(0.017)	(0.021)	(0.011)	(0.010)	(0.026)	(0.030)	(0.020)	(0.038)	(0.010)	(0.309)	(0.037)
Log-likelihood	-2799.679	-1925.503	-684.928	-2437.184	-4674.272	-3036.176	-1126.035	-4115.176	-1670.902	-1267.331	-640.430	-1658.980
Lnalpha	-1.266***	-1.814***	-1.255***	-0.922***	0.485***	-0.215**	0.977***	1.429***	0.193	-0.677***	-0.548**	0.338***
Cluster	239.000	147.000	77.000	345.000	239.000	147.000	77.000	345.000	239.000	147.000	77.000	345.000
Observations	1409	872	459	2050	1409	872	459	2050	1409	872	459	2050

Note: Marginal effects are reported. Marginal effects for funding variables are calculated following eq. (4) - (5). All other variables are held at the mean.

Year and university fixed effects included in all regressions. Robust clustered standard errors in parentheses; clustered by individual researcher. *** $p<0.01$, ** $p<0.05$, * $p<0.1$