Research Funding and Academic Engagement: a Singapore Case

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Abstract

Universities have been called upon working more closely with the industry and actively take part in economic development. Research funding has been used as an instrument to direct research agenda and promote technology partnership. The study examines how research funding is associated with various academic engagement in the context of Singapore, a country with explicit policies to encourage university-industry collaboration. Based on survey with 276 academics in STEM fields, we find that research funding does play a role in academic engagement. In particular, funding from industry is observed to have significant correlation with patent licensing, consultancy, and serving on advisory board. In addition to funding, more on-the-ground university and government effort to support academic scientists in their commercialisation activity, in particular new ventures, would be helpful.

Keywords: government funding; industry funding; academic engagement; STEM faculty

Introduction

Over the decades, universities have gradually moved beyond teaching and research, and are increasingly expected to be engines of economic advancement (Blumenthal, 2003; Philbin, 2008). However, the growth in new knowledge makes it difficult for individual universities to remain at the leading edge in all subject areas, necessitating them to seek relationships with firms to help them remain at the forefront (Hagen, 2002). The challenge of rising costs and funding constraints have also exerted enormous pressure on universities; industry thus becomes a viable source to obtain much needed resources. In addition, with the avenue to create valuable intellectual property for themselves, universities have greater impetus to be proactive in their collaborations with industry. Many governments have pushed for such a development, calling for closer interactions between universities and industry, and increased focus on the commercialisation of academic results. Such partnerships mean that universities can help industries innovate and participate in generating economic growth.

Academic engagement refers to knowledge-based collaboration between researchers and other organisations, most notably firms, involving either financial or non-financial benefits, and with broader goals of generating utility for the non-academic partners (Perkmann et al., 2013). Perkmann and colleagues note that commercialisation, whether intended or unintended, often results from academic engagement because working with industry could present researchers with insights to what would be commercially valuable, and the opportunity to produce inventions that can be patented, licensed or enable a spin-off.

This study aims to add to previous research by studying the relationship between the sources of research funding and academic engagement under a government-driven research climate — that of Singapore. Singapore presents an interesting case for studying the effects of funding as the government maintains a strong interest in growing research while providing significant support for industry collaboration with universities. Even as the Singapore

government continues to fund basic research, it supports more heavily applied and experimental research (i.e., systematic work directed at producing or improving substantially materials, processes and devices or installing such new systems). In fact, over the years, contrary to what is happening in many parts of the world (Howard and Laird 2013; OECD 2016), the Singapore government has been increasing the budget for research (Wang 2018). With billions invested in research, it is important to assess effects of the government's direct and indirect funding efforts, as well as the extent that industry funding is able to stimulate commercialisation in academic engagements. In addition, the majority of extant studies only investigated either government or industry funding, and few examined both (for exceptions, see Bozeman and Gaughan, 2007 and Drivas, Balafoutis, & Rozakis, 2015). As such, this study intends to explore the relationship between the sources of funding and academic engagement activities, in particular, examining whether and how industry funding appears different from government funding in terms of their associations with academic engagement in commercialisation, industry relationship and entrepreneurship. . Our data contains information on grant sources, productivity and entrepreneurial outputs of 276 Science, Technology, Engineering and Math (STEM) academic scientists from two major universities in Singapore. Understanding the effects of funding is important considering the economic payoffs that stem from the nation's academic research. Policy-wise, it can inform about the importance of the different sources of funding and adjustments that can be made.

Contextualising the Study: Singapore

The research scene in Singapore did not see much activity till about two decades ago. Resource-scarce, Singapore had to develop national R&D capability and capacity to enhance its economic competitiveness. MNCs were persuaded to establish R&D centres and regional bases locally to tap knowledge globally from competitors and universities, and to adapt

standard products to local and regional requirements (Hang, Low, & Yeoh, 2016). MNCs and SMEs were given access to research institutes and the research capability of the universities to meet their technological needs. Singapore's research and innovation system differs from other successful research-intensive countries around the world. While the research and innovation systems in countries such as Switzerland and Germany grew organically out of research-intensive universities or industries, Singapore's R&D push was largely a directed, government-led effort to upgrade and strengthen the competitiveness of the economy (Lim, 2016). Its R&D journey grew from a need for economic competitiveness and growth, and its research and innovation policies continue to emphasise economic outcomes and impact.

Singapore's investment in R&D has been substantial. Its Gross Expenditure on R&D (GERD) in 2016 was US$7billion, which was 2.2% of GDP (Agency for Science, Technology and Research 2017, Dec). While this amount was 0.4% lower than the US$7.1 billion it spent in 2015 (Agency for Science, Technology and Research 2017, Dec), it compares well with other developed countries: It was higher than the 1.7% by the United Kingdom in 2016 and Australia's 1.9% in 2015. Singapore also invested slightly more than up-and-coming research powerhouse China (2.1%) in 2016 (OECD n.d.). Singapore's investment, however, was less than the US whose R&D expenditure in 2015 was 2.8% of GDP, Japan (3.3% of GDP in 2015) and South Korea (4.2% of GDP in 2015) (The World Bank n.d.). The Compound Annual Growth Rate (CAGR) of Singapore's GERD from 2006 to 2016 was 6.6%, with GERD at US$3.7 billion and GDP at US$172.6 billion in 2006 (Agency for Science, Technology and Research 2017, Dec).

Business Expenditure on R&D (BERD) in 2016 was US$4.2 billion, corresponding to 1.3% of Singapore's GDP, and slightly lower than 1.4% registered in 2015 (Agency for Science, Technology and Research 2017, Dec). Public expenditure on R&D, however, remained stable at 0.9% in 2015 and 2016 (Agency for Science, Technology and Research

2017, Dec). The CAGR from 2006-2016 was 5.7% (Agency for Science, Technology and Research 2017, Dec).

The total expenditure of 69 public institutions (including research institutes, institutes of higher learning, hospitals and other public funded research organisations) that performed R&D in 2016 was US$2.8 billion, up 1.5% from US$2.7 billion in 2015, and represents a CAGR of 8.2% from US$1.2 billion in 2006 (Agency for Science, Technology and Research 2017, Dec).

Primary patent applications were at 2,002 in 2016 (Agency for Science, Technology and Research 2017, Dec). The CAGR from 2006-2016 was -0.2% from 2,036 patents filed in 2006. According to the Agency for Science, Technology and Research, a total of 917 patents were filed in the public sector in 2016, an increase of 7% compared to 2015 while 1,085 patents were filed in the private sector, representing a 12% decrease from 2015.

The Singapore government shows its commitment to research and innovation through its five-year Research, Innovation and Enterprise (RIE) plan. From S$16 billion (US$12 billion) invested over 2011-2015, Singapore's research funding body increased the funds available for academic scientists and public research institutes to tap on to S$19 billion (US$14 billion) for 2016-2020. The RIE plan provides a clear picture of the overall strong and increasing government support for research and innovation. The ratio of public to private funding for R&D is at 1:1.5, with government spending at about 1% of GDP. Thus, while there is much government effort in growing R&D, it also wants investment from the private sector because knowledge and innovation from the labs, whether public or private, will result in knowledge spillovers. The allocation of funding through the years while not neglecting basic research, reflects the emphasis on applied research that can benefit industry and economy. Table 1 shows the public and private expenditure on R&D. Of the public institutions performing R&D in 2016, 31 were government organisations, 25 were research

institutes and 12 were higher education institutes (Singapore Department of Statistics, 2016, Jul). In a recent move strongly indicative of the support for applied research, the country's largest public sector research agency guarantees funding for researchers of the 18 research institutes under its charge who work on industry-oriented projects while those in basic research have to compete for grants (Teng & Boh, 2018).

Insert Table 1 somewhere here

As part of its push for firms to innovate, there is a conscious effort by the Singapore government to foster close university-industry ties through R&D support. The government strongly advocates industry to partner public institutions (e.g., research institutes, institutes of higher learning, hospitals and other public funded research organisations) for their R&D needs, and establishing setups to connect industry with university academics. Compared to MNCs many of which can afford their own R&D teams, SMEs generally have limited resources and so are reluctant to spend on R&D, which is perceived as a future investment rather than a near benefit. To persuade the industry to participate in R&D, companies that do so can enjoy tax deduction. In addition, the government offers grants and vouchers to defray the costs of consultancy, training and equipment, some by up to 70%, which encourage industry to look for external assistance to scale up business capabilities, solve technical problems or produce innovation (Wang, 2018). For example, the research incentive scheme for companies co-funds up to 30% of project costs such as manpower, consultancy, equipment and intellectual property. Schemes that support the establishment of laboratories by industries in universities are in place to facilitate effective translation of research from the lab to the marketplace, and to ensure that universities achieve impact by developing advanced solutions for problems faced by industry. The Ministry of Education also has a Technology Transfer Office Fund for universities to build strategic engagement with industry, promote

close interaction between universities and research centres, and provide matching grants for industry funding. A list of grants available to both industry and institutes of higher learning can be found in the Appendix.

With this background of incentivised industry investment and robust government support, we examine the university's innovation and engagement activities, in order to understand the association with the different types of funding on promoting specific outcomes.

Conceptual Framework

Public-private partnerships have sparked some debate stemming mainly from the sources of funds. Both universities and industry have essentially different goals. As such, university research output, being both fundamental and difficult to appropriate, has different value to the researcher and the sponsor. For the researcher, in the traditional world of scientific research, the aim is to be the first to communicate an advance in knowledge (Merton, 1957). The output is important as an input to other researchers, and researchers are rewarded with recognition by the scientific community. Sponsors, on the other hand, would find value in the translatable aspect of the research (Goldfarb, 2008). Policy-makers meanwhile encourage industry to fund university research so that scientific knowledge can be made relevant to society's problems (Mowery & Ziedonis, 2002). However, research has presented mixed findings with respect to publications, consultation and commercialisation as a result of government and industry grants because contextual factors, such as degree of market orientation of the university system and volume of industry-funded university research may have an influencing role.

Government Funding

Different sources of funding often produce different output as the emphasis of the sponsors vary. In most economies, the government has traditionally been the largest funder of university research. Public funding may be disbursed through project grants from public funding agencies or contracts with government bodies. In allocating public funds to institutions, many governments make use of competitive mechanisms where funding is based on evaluation of project proposals, with the expertise of the researchers and their past performance taken into consideration in the selection process. Expected performance constitutes an important criterion of the funding decision (Jongbloed & Vossensteyn, 2001). The idea behind is that money given to the best performer should produce better results, and if the allocation is based on results then there would be motivation to achieve better results to be more competitive (Auranen & Nieminen, 2010).

Where such grants form the bulk of university research funds, the universities are highly dependent on these resources and are more affected by political steering. The way the research support is structured in different categories, for instance, disciplines, problem or focus areas, or types of research, steer applicants in a specific direction. Their criteria for evaluation influence expectations and orientations of applicants (Benner & Sandström, 2000). Thus, although universities enjoy autonomy, governments can make use of their sponsorship to focus attention on target areas of growth and steer universities to act according to national science policies. However, universities that have diverse sources of funding may experience less pressure from steering.

Studies on the output of government funding point out that government funding contributes to research output, both in terms of the quantity of publications (Drivas, Balafoutis, & Rozakis, 2015) and patents (Chen, Huang, & Chen, 2013; Rosenbloom, Ginther, Juhl, & Heppert, 2015), and the quality as measured by citations (Sandstrom 2009;

van Leeuwen et al. 2001; Wang and Shapira 2015). However, the impact of government funding on academic engagement is less obvious. For example, government sponsorship is positively associated with consulting (Jensen, Thursby, & Thursby, 2010), but it was found to have no effect on spinoff creation (Muscio, Quaglione, & Ramaciotti, 2016; Ramaciotti & Rizzo, 2015) or on future patent activity (Hottenrott & Thorwarth, 2011). Overall, government funding is influenced by the type of state steering model and the level of output orientation, which can affect productivity and innovation, resulting in output variation (Himanen, Auranen, Puuska, & Nieminen, 2009).

University policies have also been found to affect technology transfer performance. University technology transfer offices play a pivotal role in the commercialisation process by putting external resource providers in contact with researchers (O'Gorman et al. 2008). A clear university mission in support of technology (Friedman and Silberman 2003) and rules on the potential conflict of interest between researchers' academic and external activities (Caldera and Debande 2010) enhance university technology transfer. Clear and well-defined policies and procedures that incentivise researchers to participate in technology transfer can encourage patenting, licensing and entrepreneurship. Universities that grant inventors a larger proportion of royalties have been found to generate more licensing income (Caldera and Debande 2010; Lach and Schankerman 2008). Other factors, such as size and experience of the technology transfer office, affect the volume of contract research (Caldera and Debande 2010).

With government research funding reduced in a number of countries, there is concern that it will result in a greater dependence on industry funding. Excessive dependence or emphasis on commercially driven activities could reduce basic research efforts in universities as researchers shift their attention to applied research (Quaglione et al. 2015). Even though the Singapore government funds most of the basic research in universities, it has gradually

shifted its focus to applied research. As Table 1 illustrates, the difference in the amount awarded to basic and applied research has widened over the years.

The government also pushes strongly for industry to engage with universities for innovation. By funding universities, it nurtures scientific discoveries and innovation, making the universities suitable partners of industry. Government funding to universities complements funding from research contracts and consulting, thereby helping to increase universities' collaboration with industry (Jensen et al. 2010; Mansfield 1995). As Muscio et al (2013) argue, government support to universities enhance universities' capability to attract external funding. At the same time, organisations are offered tax incentives or grants to encourage partnership with institutes of higher education for problem-solving and innovative solutions. The government's plan is for industry to fund more of the R&D although it appears increasingly difficult to do so. In 2016, for every S$1 spent on research from public sources, S$1.51 was spent by businesses (Agency for Science, Technology and Research 2017, Dec), whereas in 2010, it was matched by S$1.55 spent by business (Agency for Science, Technology, and Research 2011, Dec). In addition, recent years have seen grant calls where the academic applicant is required to have an industry partner to ensure that the research outcome would have utility and societal benefit.

Due to the strong government support for research and explicit policies in place to encourage university-industry collaboration, we expect to see government funding positively associated with academic industry engagement, and hence the first hypothesis:

H1: Faculty who have more government funding tend to have higher engagement with the industry.

Industry Funding

University links with industry are viewed with increasing importance. University-industry collaboration can be a source of ideas for new research projects (Agrawal & Henderson, 2002; Mansfield, 1995) and researchers gain knowledge about practical problems. In addition, industry provides insights on the practical application of theory, and researchers gain insights in their own research. This can produce better quality and more refined ideas, leading to favourable research outcomes and high calibre papers. Beyond that, industry is a crucial source of funds which can help supplement government funding for research, assistantships and equipment, and where opportunities for student internships and job placement can be tapped (Lee, 2000). Especially under a general climate of diminishing government funds, industry plays an even more vital role to enable a stream of continuous research.

Researchers with funding are more productive than those without because they are able to procure equipment, materials and assistance (Gulbrandsen & Smeby, 2005), producing more publications. When researchers receive funding from industry, there is greater expectation that a valuable result would be produced because external funding is not neutral, but carries expectations of specific outcomes and processes that may or may not be similar to what would have happened had the funding came from an "internal" source (Gulbrandsen & Smeby, 2005).

Indeed, in terms of innovative output, industry funding and collaboration are significantly correlated with commercial results like patents, spinoffs, commercial products and consulting agreements (Gulbrandsen & Smeby, 2005) because industry is more likely to fund commercially-oriented research, and the commercial orientation will have a positive impact on academic entrepreneurship (Di Gregorio & Shane, 2003). Similarly, Thursby and Thursby (2011) found industry funding to be more conducive to innovation output than government funding. Other studies, however, indicate that industry funding has no effect on

likelihood of starting a company (Boardman & Ponomariov, 2009), and no effect on the number of patents, but a positive impact on patent citations and citations per patent (Hottenrott & Thorwarth, 2011). The latter reflects a novelty and quality effect of industry funds since patents can only receive citations if they were granted (Hottenrott & Thorwarth, 2011). It can be said that research supported by industry generate patents that may be more successful in the granting process, and more visible and relevant for further applications in industry, hence the forward citations.

There is concern that industry funding may decrease publications. The higher the share of industry funds relative to their total budget, the less professors publish in subsequent years, supporting the skewing problem (Hottenrott & Thorwarth, 2011). This effect has a detrimental impact on the development of science since publications are the main channel for dissemination of knowledge from science to industry (Hottenrott & Thorwarth, 2011). If industry funding reduces publications, not only the development of science but also technology transfer could be impeded. Other findings, however, seem to suggest that the skewing problem is not so serious, and even reveal an opposite result — researchers with funding or collaboration with industry produce more publications than those without such assistance or cooperation (Blumenthal, Causino, Campbell, & Louis, 1996; Godin, 1996; Gulbrandsen & Smeby, 2005; Svider et al., 2013; Van Looy, Ranga, Callaert, Debackere, & Zimmermann, 2004). Likewise, graduate students engaged in research with an external sponsor produce more publications compared to those without (Behrens & Gray, 2001). Industry grants also increase likelihood of university scientists engaging in co-publishing (Boardman & Ponomariov, 2009).

Funding is indirectly beneficial to expanding social networks as collaborations are formed to capitalise on funding opportunities. Even though funding does not increase researcher productivity in the short term, they promote effective future collaborations

(Defazio, Lockett, & Wright, 2009), making such industrial links valuable. Thus, those who have grants from industry collaborate more extensively with industry (Gulbrandsen & Smeby, 2005). Both government and industry funding strengthen industry-science collaboration although the effect of government grants is more moderate (Bozeman & Gaughan, 2007). Industry grants also increase likelihood of scientists initiating contact with industry about research and their working as paid consultants (Boardman & Ponomariov, 2009). Therefore, in our second hypothesis we postulate:

H2: Industry funding is positively associated with the level of academic industry engagement.

Data and Method

Data was mainly obtained from a survey conducted with STEM faculty in the two largest autonomous universities in Singapore. The National University of Singapore and Nanyang Technological University were selected as they have a comparatively longer history so their STEM departments are more established and a higher number of faculty would have experience with innovative output as well as other collaborative activities. STEM disciplines are also more likely to have tangible innovative output compared to humanities or social sciences, for example.

A list of faculty members from the two universities in 2015 was compiled using information on the university websites. Using a variety of sources, such as CVs and other profile information on websites, basic demographic information like name, gender, title, education and employment history, and contact information including email, telephone and office addresses were collated. With the faculty listing, we invited faculty members via email to participate in an online survey that asked about their research activities and grant sources. A response rate of about 22% with 532 responses was reached by December 2015. After

restricting to STEM faculty and removing empty or partially completed responses that contained only demographic information, we were left with 275 cases. Information drawn from the survey was then complemented with profile data obtained from the CVs for analysis.

The sample of STEM faculty was male dominated (86%). Most of them were within the age range of 36-45 (40%) and 46-55 (31%) years old, and holding either assistant professor position (34%) or associate professor position (45%). Close to 90% of the sample received PhD education overseas, mostly from the US (33%) and the UK (15%), and 65% of them have worked in another university as faculty or postdoc research fellows before they moved to Singapore (Figure 1).

Insert Figure 1 somewhere here

Dependent Variable

Academic engagement refers to the mechanisms that academic knowledge is transferred to the industry (Nilsson, Rickne, and Bengtsson, 2010) and it varies by the amount of contact with the industry (Louis, Blumenthal, Gluck and Stoto, 1989). Following Perkmann (2013), this study selects four types of engagement: patent licensing, consultancy, advisory and academic spin-off. Patent licensing is to exploit an academic invention with financial rewards (Perkmann 2013). Consultancy is to provide personal expertise to solve a specific problem for the industry (Klofsten, and Jones-Evans, 2000) and advisory refers to service on the advisory board of a firm. Academic spin-off refers to the creation of a private firm based on university research. The four dependent variables measure different levels of academic engagement, distinguished by the amount of contact with the industry (Louis, Blumenthal, Gluck and Stoto, 1989) and range from more passive engagement such as patent licensing, to more active engagement such as establishing spinoff companies. The activities

were measured on a five-point Likert scale from being not active to very active in the survey. Approximately a third of respondents claimed to be active or very active in patent licensing, while 44% were not active. A quarter of respondents claimed to be inactive in serving on advisory boards while 9% described themselves as very active. Comparatively fewer respondents were involved in consultancy and spinoff activities. Only 5% were very active in consultancy; 44% were not active. In terms of establishing spinoffs, more than half (57%) were not active and only 4% considered themselves very active.

Independent and Control Variables

The independent variables were government and industry grants. Responses to the questions on the level of research productivity in terms of securing industry and government research grants since they took up position in Singapore universities were measured on a five-point Likert scale. The responses were converted to dummy variables where "1" represents when they are active with funding while "0" represents otherwise. Around 60% of respondents felt they were getting more government grants while only 29% of respondents reported with more industry grants.

We included a number of control variables as these likely exert an influence on engagement activities. The number of publications was used to measure research performance of the researcher (Jensen, Thursby and Thursby 2010). Research outputs in the format of publications or patents would be influenced by faculty's interest in curiosity-driven or application-oriented research. Scholarly research may have conflicting or reinforcing relationship with entrepreneurial activities (Looy, Callaert, and Debackere 2006). The number of years working in Singapore is intended to measure the level of familiarity with local environment as 90% of respondents were recruited from overseas. Two dummy variables – whether they have had industry experience and whether they have tenure – were

used to capture the effect of prior industry experience and job security. Institutional support, for instance in terms of technology transfer office, can greatly assist in commercialisation efforts. As such, we include a measure of institutional administrative support to control for this effect. Lastly, we included demographic variables such as gender, age and discipline. The variables and the descriptive statistics can be found in Table 2.

Insert Table 2 somewhere here

Analysis

To determine the effect of various sources of funding on output, we ran ordered logistic regression since the dependent variables are ordinal. Results show that industry funding was significant with patent licensing ($b = 1.28$, $p < .01$), consultancy ($b = 1.53$, $p < .001$) and service on advisory boards ($b = 1.28$, $p < .01$) (Table 3). It was not significant in producing spinoffs. Government funding was not significant with all of the outputs.

Insert Table 3 somewhere here

The number of years working in Singapore was only significant for consultancy. A longer working stint in a country increases academic scientists' understanding of the local environment, and their research may also be more locally relevant, which makes them well-suited to consult for organisations that require such knowledge. Being in different disciplines is not relevant to their participation in community activities or commercialisation, except for spinoffs. Industry experience and institutional administrative support have no effect on all types of output.

Robustness check

Our results in the analysis showed that industry funding leads to patent licensing, consultancy and advisory activities. However, there is a possibility of reverse causality,

where the commercialisation activities, for instance, attract more funding. An approach to this problem is to compare the performance of similar researchers that have funding with those who do not. Coarsened exact matching (CEM; Iacus et al. 2012), a variation of exact matching, is adopted. It is suitable for causal inference (Iacus et al. 2012) and has been successfully implemented in social science (Ejermo and Toivanen 2018; Libaers and Meyer 2011), management (Han et al. 2017) and public health (Haider et al. 2013). CEM matches on a coarsened range of covariates instead of on their exact values, alleviating the significant demands that exact matching imposes on the data. Treatment and control units are grouped by exact matching. Covariates are then returned to their original values and any group without at least one treatment and control unit is dropped. As CEM prunes control and treatment cases for which there are no good matches, regressions fit on smaller samples. An advantage of CEM is that it allows the balance between the treatment and control groups to be chosen before estimation rather than having it revealed through an iterative process of checking after the estimation, re-specifying a matching model and estimating it again (Blackwell et al. 2009).

Our relatively small sample size of 276 does not permit the categorisation of the treatment variable into four groups of no funding, only government funding, only industry funding, and both government and industry funding as it leads to unworkable results. As such, we first separate the sample into two groups of those with government funding and those without and then performed CEM using industry funding as the treatment. As CEM is generally only feasible when the set of matching variables is small relative to the number of observations, it is not possible to include a very large set of covariates. Following Stuart's (2010) recommendation, priority is given to covariates believed to be related to the outcome. These include industry experience, gender and discipline. As CEM attempts to use as much of the data as possible, strata with different numbers of treated and control units are

produced. To compensate for the different strata sizes, CEM returns weights that are used to estimate the average treatment effect on the treated. The process is then repeated with two groups consisting of those with industry funding and those without, with government funding as the treatment.

Results remain consistent for a matched sample (Table 4). The CEM regressions affirm the robustness of our findings that industry funding is a significant predictor of patent licensing, consultancy and advisory activities.

Insert Table 4 somewhere here

We also tested for the relationship using different coding of dependent variables. When dependent variables were measured as binary, 0 for being not so active and 1 for being more active, we ran logit regression with the same set of independent and control variables and obtained consistent results (Table 5). Industry funding was found to be significant with patent licensing, consultancy and advisory, but insignificant with spin-offs. Government funding was not significant with any of the engagement activities.

Insert Table 5 somewhere here

Discussion

In previous studies conducted in countries where research activities are more spontaneous, funding from government and industry sources seems to have produced mixed results. The aim of this study was to examine the relationship between research funding and academic engagement in a context where increased university-industry collaboration, and university funding for researchers are mainly government-directed so as to understand how the relationship could vary in different institutional contexts.

Based on survey data collected from STEM faculty in two major universities in Singapore, coupling with data from other sources such as CV and publication records, we

tested the effect of government funding and industry on a number of academic engagements. Ordered logistic regression models are used for this purpose as the dependent variables are measured on ordinal scales. Industry funding was found to have positive and mostly significant relationship with academic engagements, but not government funding. However, there lacks time sequencing in the variables and the model may be subject to endogeneity. In view of this, we further adopted a matching method (CEM) to improve the estimation of causal effect. CEM – a Monotonic Imbalance Bounding matching method – has its advantage in softening requirement on assumptions and reducing imbalance, model dependence and bias (Iacus, King and Porro 2012). It allows us to construct matched groups based on temporarily coarsened attribute variables and compare the likelihood of academic engagement of the two groups, with and without funding. The results supported earlier findings that industry funding exhibits engagement tendencies different from government funding.

Our findings reveal that industry funding is significantly associated with many engagement activities of academic scientists. Industry funds may help to build connections and support a closer relationship between industry and academic scientists. In tandem with increased interaction with industry, academic scientists may be more frequently called upon to work with firms in terms of consultancy work, serving on advisory boards and giving expert advice. In particular, those who work closely with industry may also understand better their needs and abilities, and have greater access to and awareness of the state-of-the-art in terms of industrial technology issues.

Aligned with previous research which shows that industry funding is correlated with commercial results, we find industry funding leads to patent licensing. While industry funding correlates with spinoffs in other research, this relationship was not seen in our study. Scholars like Van Looy et al. (2004), however, have argued that the relationship between industry funding and commercial outputs may not be significant if we look beyond the

industry contacts themselves, and Gulbrandsen and Smeby (2005) have pointed out that for academic researchers there may be a tension between regular contract work for established firms and starting new companies.

The results indicate that government funding does not appear to have direct association with academic engagement, despite the fact that government is actively promoting collaboration with industry, which might be due to the fact that industry collaboration is not a required component in most government grants yet. While some grants specifically call for a joint application between university and industry, most funding schemes supporting university-industry collaboration target industry directly. For example, the Innovation & Capability Voucher scheme provides a S$5000 voucher for companies to procure R&D services from universities (Wang 2018). Therefore, the government support for academic engagement is not reflected directly in government funding, but indirectly through industry funding. However, as the government continues to push ahead for more university-industry linkages, more grants for universities can be expected to require an industry partner and the situation may change. It would be useful to assess the impact of this change through academic engagement output from government funding again in the future.

Through different grant channels, the government has managed to drive research in the universities as well as in industry. As industry has less interest working with researchers doing basic research, it is pertinent that these researchers are able to tap into government and university grants. Continuing with the current policy ensures that both basic and applied research are not neglected while helping industry to continue funding R&D.

New research-based ventures play an important role in Singapore's economic and technological progress so the finding that none of the sources of funding contributes to spinoff companies requires closer examination. The risk and complexity of setting up a new company outweighs that of other commercialising activities, such as patenting or licensing

(Tijssen, 2006). Unlike patenting and licensing, forming spinoffs require moving from the academic environment to the business environment, which involves competencies required to start and grow a business that firms originating from a university have limited access to (Rasmussen & Wright, 2015). Some studies have shown that academic researchers with more abundant resources are more likely to develop spinoffs, however, even with adequate resources, the enterprise still requires strong ties with academic research laboratories and client involvement from an early stage of product or technology design (D'Este, Mahdi, & Neely, 2010). Support from the universities and government agencies to utilise their laboratories, put academic scientists in contact with potential clients, and provide advice in designing a business plan and commercialising activities is important. Muscio et al. (2016), for instance, found strong evidence of the positive role of the availability of entrepreneurial support in the form of guidelines for business plan preparation. At the institutional level, clear policies and professional support infrastructure are strong indications of support from the management. The establishment of new ventures can also be considered in promotion criteria, and departments can create operational space for academic scientists to work on their spinoff projects.

There are a few caveats to be noted for this study. The analysis is based on cross-sectional data, which limits the derivation of definite causal-effect relationship. Future studies with longitudinal data will delineate the relationship and direction of influence more clearly. Secondly, the context was Singapore, a country where research direction and focus areas are highly government-led. As a result of government intervention, policies and measures emphasise and support the need to innovate and stay ahead of the competition. The findings should be interpreted with this climate in mind, and so it may be difficult to draw parallels with other countries that have more laissez-faire governments or whose research and

innovation systems are the result of organic development. Future studies may try to draw comparisons with these countries.

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Figure 1: Profile of the sample

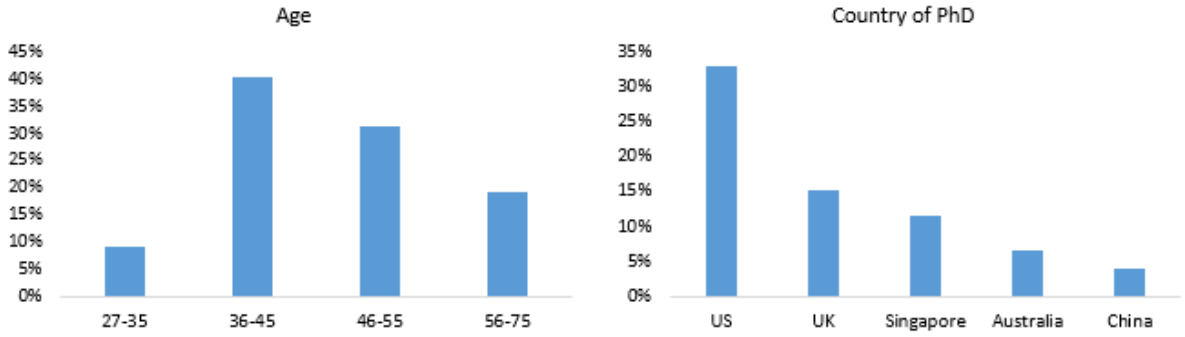

Table 1: Public and private expenditure on R&D

Sector	Type of research	2010	2016
Public	Basic	S$383.5 m	S$441.6 m
	Strategic basic [#]	S$558.1 m	S$880.9 m
	Applied	S$906.9 m	S$1,1308.0 m
	Experimental development [^]	S$692.9 m	S$1,155.4 m
Private	Basic	S$397.9 m	S$915.2 m
	Applied	S$1.23 b	S$1.66 b
	Experimental development	S$2.3 b	S$3.2 b

Source: Agency for Science, Technology and Research

[#] Refers to research that will produce a broad base of knowledge likely to form the basis of solution to current or future problems.

[^] Refers to systematic work directed to substantially produce or improve materials, products and devices, or installing new processes, systems and services.

Table 2: Variables and descriptive statistics

Variable	Description	Source	Obs	Mean	Std. Dev.	Min	Max
Patent licensed	Level of activity in patent licensing	Survey	190	2	1.122	1	5
Consultancy	Level of activity in consultancy	Survey	214	2.075	1.192	1	5
Advisory	Level of activity in serving on advisory boards	Survey	220	2.527	1.240	1	5
Spinoff	Level of activity in setting up companies	Survey	189	1.751	1.070	1	5
Industry funding	Respondent's research productivity in industry grants	Survey	161	0.472	0.501	0	1
Government funding	Respondent's research productivity in government grants	Survey	219	0.726	0.447	0	1
Publications	Total number of publications in Scopus by 2016	Scopus	275	96.28	92.803	1	630
Years in Sg	Number of years working in Singapore (universities)	Survey	271	4.004	1.185	1	5
Industry experience	Whether with industry experience	CV	255	0.157	0.364	0	1
Tenure	Whether respondent is tenured or not	Survey	274	0.934	0.248	0	1
Institutional support	Satisfaction with institutional administrative assistance	Survey	253	0.581	0.494	0	1
Male	Gender of respondent	Survey	276	0.862	0.345	0	1
Age	Age of respondent	Survey	275	47.091	9.250	27	75
Engineering	Whether in engineering or not	CV	273	0.465	0.500	0	1
Life sciences	Whether in medical/life sciences or not	CV	273	0.234	0.424	0	1
Physical sciences	Whether in physical and mathematical sciences or not	CV	273	0.300	0.459	0	1

Table 3: Estimation results

VARIABLES	(1) Patent licensed	(2) Consultancy	(3) Advisory	(4) Spinoff
Industry funding	1.280**	1.533***	1.278**	0.861
	(0.438)	(0.427)	(0.432)	(0.497)
Government funding	0.826	- 0.265	-0.846	0.091
	(0.574)	(0.484)	(0.518)	(0.623)
Publications	0.000	-0.001	-0.000	-0.002
	(0.002)	(0.002)	(0.001)	(0.002)
Years in Sg	0.231	0.931***	0.257	-0.118
	(0.251)	(0.251)	(0.226)	(0.272)
Industry experience	0.574	0.863	0.045	-0.145
	(0.548)	(0.559)	(0.487)	(0.641)
Tenure	1.824	0.055	0.330	-0.606
	(0.548)	(0.890)	(0.769)	(0.943)
Institutional support	- 0.102	- 0.055	0.586	-0.182
	(0.401)	(0.391)	(0.382)	(0.461)
Male	0.096	0.913	2.227**	1.935
	(0.772)	(0.763)	(0.798)	(1.171)
Age	0.002	0.003	0.012	0.049
	(0.032)	(0.028)	(0.029)	(0.037)
Engineering	0.138	- 0.341	-0.177	3.059**
	(0.528)	(0.542)	(0.502)	(1.109)
Life sciences	- 0.395	- 0.704	-0.421	2.224*
	(0.640)	(0.619)	(0.580)	(1.153)
Constant cut1	3.790 *	4.338**	2.597	5.831**
	(1.799)	(1.578)	(1.453)	(2.117)
Constant cut2	5.020**	5.459**	3.887**	7.236**
	(1.824)	(1.620)	(1.470)	(2.152)
Constant cut3	6.366**	3.840***	5.408***	8.441***
	(1.850)	(1.656)	(1.510)	(2.176)
Constant cut4	7.463***	8.287***	6.522***	9.360***
	(1.884)	(1.692)	(1.544)	(2.210)
Observations	105	115	112	102

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4: Sample average treatment effect of funding on commercialisation and community activities

	Industry funding			Government funding		
	SATT^	Robust SE	p-value	SATT	Robust SE	p-value
Patent licensed	1.314	0.401	0.001	1.368	1.558	n.s.
Consultancy	1.100	0.408	0.007	- 0.259	0.814	n.s.
Advisory	1.244	0.407	0.002	- 1.376	1.988	n.s.
Spinoff	0.780	0.407	0.056	1.587	1.080	n.s.

^ Sample average treatment effect of the treated

Table 5: Logit regression

VARIABLES	(1) Patent licensed	(2) Consultancy	(3) Advisory	(4) Spinoff
Industry funding	2.596*	2.475**	1.371*	1.970
	(1.109)	(0.825)	(0.595)	(1.273)
Government funding	-0.337	-0.544	-0.481	-1.414
	(1.198)	(0.865)	(0.783)	(1.391)
Publications	0.004	-0.002	-0.002	-0.002
	(0.003)	(0.004)	(0.002)	(0.004)
Years in Sg	0.577	2.245**	0.365	0.324
	(0.441)	(0.680)	(0.336)	(0.601)
Industry experience	1.574*	1.139	-0.355	0.407
	(0.802)	(0.839)	(0.767)	(1.095)
Tenure	omitted	-1.407	1.143	-1.063
	-	(1.244)	(1.235)	(1.392)
Institutional support	-0.470	- 0.914	0.350	-0.532
	(0.708)	(0.694)	(0.555)	(0.988)
Male	-1.314	0.170	omitted	omitted
	(0.976)	(1.076)	-	-
Age	-0.031	-0.072	0.037	-0.005
	(0.060)	(0.050)	(0.040)	(0.079)
Engineering	1.637	0.012	0.778	omitted
	(1.400)	(0.851)	(0.873)	-
Life sciences	1.438	- 0.764	0.816	omitted
	(1.541)	(1.015)	(0.984)	-
Constant	-4.811*	-7.147*	-7.02**	-1.555
	(2.488)	(3.090)	(2.250)	(2.760)
Observations	99	115	103	60

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix: Funding schemes for industry and academia

Agency	Scheme	Aim	Target group
Industry			
Enterprise Singapore	**Enterprise Development Grant** For product development - SMEs enjoy support of up to 50% for software and equipment costs, up to 70% for other qualified costs - Non-SMEs can obtain support of up to 30% for software and equipment costs; up to 50% for other qualified costs	Help businesses upgrade, innovate or venture overseas	Start-ups to SMEs and high-growth companies
	Pact programme - Support for SMEs capped at 70% of qualifying costs, and 50% for non-SMEs.	For partnerships in capability development - including co-innovation and knowledge transfer	
Singapore Israel Industrial R&D Foundation	**Full-scale R&D & commercialisation project** - 40-50% of total qualified project cost **Mini R&D & commercialisation project** - 50% of total qualified project cost	For joint R&D projects between Singapore and Israeli companies.	Singapore-registered and Israel-registered companies, non-commercial R&D entities in Singapore
Economic Development Board	**Research Incentive Scheme for Companies** - Co-funding support of up to 30% of qualifying R&D project costs	Encourage companies in Singapore to conduct or expand their R&D activities in science and technology	Companies incorporated in Singapore
Inland Revenue Authority of Singapore	**R&D tax benefits** - Up to 250% tax deduction for qualifying expenses incurred on R&D done in Singapore	Support businesses to build their own innovations	Companies involved in R&D and innovation

	- 200% tax deduction for IP registration fees		
Agri-Food and Veterinary Authority of Singapore	**R&D scheme** - Co-funding support of 70% of project	Boost R&D in commercially viable food farming technology with direct practical industry application to local agricultural industry	Farms, tertiary / research institutions or companies
Academic			
National Research Foundation	**Competitive Research Programme** - Funding support of up to 5 years	Support use-inspired basic research projects in areas of science and technology	Institutes of Higher Learning, Research Institutions and Medical Institutions
	Central Gap Fund - Funding support for projects of quantum greater than S$750K for up to 2 years	Encourage the translation of research outcomes into useful products, processes and services that generate economic and societal benefits	Publicly-funded research performers and government-linked entities
Ministry of Education	**Academic Research Fund** - Tier 1: Support for projects with a total value below S$180K (for Sciences and Engineering) or below S$150K (for Humanities) over 3-years - Tier 2: Support of up to $1 m over 3 years - Tier 3: Support of up to S$25m	Support research that provide a foundation for discoveries that have or will have direct impact on the economy and society Advance research that challenges current understanding or opens new frontiers; research that shows promise for applied purposes. Fund high impact R&D areas	Academic faculty or on research track at autonomous universities

Temasek Foundation Innovates	**Singapore Millennium Foundation Grant** - Up to $750,000 for 3 years	Support novel research that break new ground, and have a clear and direct impact to Singapore	Researchers affiliated to a Singapore-based institution