Abstract

We use scientist-level panel data in order to estimate the effect which the number, type and source of research grants has on subsequent commercial contracts, publications and patent outputs. In so doing, we control for time-invariant factors including individual researcher preferences, the nature of the work and the business model of the researcher's laboratory. We find that whereas Fellowships and Project or program grants had a positive effect on whether the scientist subsequently signed a commercial contract, Equipment and Development grants had the largest impact per grant. Finally, we find that International grants were negatively associated with the number of commercial contracts signed. The data were drawn from 488 biomedical researchers at the Walter and Eliza Hall Institute over the period 2009 to 2012.

Introduction

Governments are increasingly keen to see that scientific discovery translates into commercial use, yet few studies indicate how this is best achieved. Most evidence to date is built upon case studies, anecdotes and cross-sectional data which have limited power to identify causality. In this study, we use scientist-level panel data in order to address the question of causality.

Although the research sector's ultimate aim is to maximise the use of scientific knowledge within the community, there is a perception that greater value could be captured if more research outputs were directly translated via commercial development contracts instead of relying on indirect routes through publications, education, on-line repositories and conferences. We do not test this perception, but instead examine how the number, type and source of research grants affects the number of new commercial contracts signed, publications produced and patents filed. In the process, we control for time-invariant factors which might include individual researcher preferences, the nature of the work and the business model of the researcher's laboratory.

Within this mix of drivers, the main lever under the control of government is the quantum of research funding and the conditions under which it is available. The Australian

Government currently provides a range of different funding schemes – administered by the Australian Research Council (ARC) and the National Health & Medical Research Council (NHMRC) – aimed at supporting basic and applied research, together with a variety of schemes directly aimed at providing matching funds conditional on industry contributions. Our contention is that changing the mix of funds according to their aims, conditions, and qualifying criteria, will shape the mix of outputs produced.

Our estimations use the unit-records of 488 medical researchers at Australia's oldest and largest medical research institute – the Walter & Eliza Hall Institute of Medical Research (the "Institute") – over the period 2009 to 2012. As well as publishing in leading international scientific journals, the Institute has forged successful collaborations with major healthcare and biotechnology companies including a tripartite agreement with Genentech and Abbott to discover new anti-cancer therapeutics (see Clark 2011). It has a long history of producing both world-class research and translation. We analyse the performance of 69 separate research laboratory groups at the Institute (accounting for more than 90 per cent of the Institute's research groups over the period of the study), and control for a range of characteristics about the individual scientists and the laboratories in which they worked.

The laboratories are organised along what we have referred to as different 'research business models'. By that we mean that different laboratories have divergent interest in, and capacity for, engaging in: collaboration with public and private sector partners, basic research, scientific publication, patenting and translational research. These laboratories typically consist of five to eight researchers with the advantages of scales being reaped through internal and external collaboration. The laboratory head is responsible for publications, invention disclosures and works together with the Business Development Office to foster commercial collaborations.

Our first broad finding is that there are strong relationships between the number of research grants received and the mix of outputs produced several years later. We find that the *number* of research grants awarded to the individual as a chief (or associate) investigator had a positive effect on the subsequent number of publications and patents but a negative effect on the subsequent number of commercial contracts signed. Secondly, when we break this down to focus on the *type* of grants received, we also find that

Equipment grants, and to a lesser extent Development grants, are strongly associated with more subsequent commercial contracts. Grants do not pre-date patent applications because patents are usually filed prior to development grant application to increase chance of grant success. Fellowships are associated with more subsequent commercial contracts but fewer patent applications. Thirdly, we find that the *source* of funds has an impact on the research productivity: scientists receiving funds from NHMRC and ARC, and Private and philanthropic sources tend to have more subsequent commercial contracts and journal publications. Whereas those sourcing funds from international sources are producing fewer commercial contracts but more journal publication citations.

Over and above this, our empirical analysis supports the intuitive notion, proposed by Gunnar Myrdal in 1956, that path dependency matters – in other words, success begets success. More journal publication cites generates more commercial contracts and more commercial contracts generates more cites.

Finally, there is clear evidence that the individual scientist matters most of all, which is a particularly important finding since it suggests that policy needs to either change researcher behaviour or affect the recruitment and retention of key researchers, if it is to successfully change outcomes. The time-invariant individual-scientist effect (i.e. the aptitude, ability and preferences of scientists) accounts for between 65-71 per cent of the variation in commercial contracts; 73-77 per cent of the variation in journal publications; and 52-62 per cent of the variation in patents filed.

Background and Literature Review

The largest domestic source of funds in the Australian bio-medical area is the National Health and Medical Research Council (NHMRC) which provides support in the form of project grants, program grants (which are typically large, long-term grants) and for other *ad hoc* targeted research. An example of the latter is the call in 2012 for research on the Hendra virus outbreak in Australia. The NHMRC also provides translation and development grants, together with a range of grants aimed at supporting capacity building – such as training, fellowships, and early-career researcher development grants. In 2013, the NHMRC committed $811m of funds to 1,226 different grants, the vast majority of which was provided to project grants (52 per cent) and program grants (13 per cent). The next largest category was for individual grants: research fellowships (17 per cent) and PhD support (1 per cent). Development grants (1 per cent) represented the smallest component (NHMRC 2014). In addition, there are a range of international funding schemes that are open to and commonly accessed by Australian researchers. The Australian health and medical research funding system is highly concentrated: approximately three quarters of all funds are awarded to the top 9 research institutions. The Walter and Eliza Hall Institute is one of these leading research organisations, receiving 5.8% of the total NHMRC funds in 2012. This makes it the highest placed research institute.

There is some specific empirical evidence supporting the contention that *type of funding* affects the nature (quantity, quality and type) of the academic outputs produced.[1] Possibly the best example of this is the research by Azoulay, Graff-Zivin and Manso (2011) which analyses the outcomes of two different grant schemes in the US based on the different structure of incentives. These authors found that scientists who are free to pursue more high-risk research are more likely to produce high-impact research and explore novel lines of scientific inquiry. Other research has shown that small team size is correlated with highly creative research outputs (Heinze 2008).

Another stream of the literature examines how the mix of government-industry funds shapes outcomes. This research shows that research funds provided by industry to university professors increases outputs in terms of both publications and patents, which suggests the two are complementary rather than substitutes (see Bozeman and Gaughan 2007; Gulbrandsen and Smeby 2005). This finding should partially allay concerns that scientists funded by industry focus purely on their funders' (short-term, applied) needs at the expense of their pure academic (long-term, basic) interests.

However, this result is not universally supported. For example, based on a large sample of over 2,000 academics in the 50 universities that receive most NIH funding, Blumenthal et al.

[1] This research is part of a long stream of work in the economics and sociology literatures that looks at the productivity of scientific researchers, including (but certainly not limited to) the research on age and scientific productivity (Levin and Stephan 1989, 1991; Oster and Hamermesh 1998; Hall et al. 2007; Jones et al. 2014); the effects of productivity on promotion (Lissoni et al. 2011); and the impact of collaboration on productivity (Lee and Bozeman 2005). Our intent here is not to provide a comprehensive overview of this literature, but to focus on the specific issue at hand: the effects of research funding and outputs.

(1996) find that industry-funded academics who receive more than two-thirds of their total funding from industry are less productive in terms of academic publications than those receiving a smaller share of total funds from industry. In other words, there could be a threshold effect. While reduced publication need not be synonymous with reduced translational impact, Blumenthal et al. (1996) found that the research of these academics had less impact (using a citation-based 'publication influence' indicator developed by Pinski and Narin, 1976) than that of scientists who received less industry research funds.[2] In addition, in a study of Australian biologists, Bourke and Butler (1999) found that the nature of the researcher's appointment – i.e. whether they were appointed in a full-time research position or not – was a greater determinant of publication outcome than the type or source of funds.

A detailed study by Goldfarb (2008) of academics who participated in NASA-funded projects on aerospace engineering projects over a long period of time – starting in 1981 – finds that maintaining a relationship with NASA over time reduced academic output. In other words, researchers who received funds from NASA in two separate rounds – in both 1981 and 1988 – do not do as well (in terms of publications and citations) as those who received funds from an alternative research funder, *ceteris paribus*. [3]

Other research examines the effect of NIH funds – both research grants and postdoctoral training grants – on scientific productivity (Jacob and Lefgren 2011a, 2011b). In both papers, data were collected on NIH grant *applications*, so the researchers are able to compare the performance of successful with unsuccessful applicants. In Jacob and Lefgren (2011a), they find that receipt of a standard NIH research grant leads to one additional research publication over the next 5 years: a small, but nontrivial increase in research productivity.[4] Jacob and Lefgren (2011a) show that receipt of an NIH postdoctoral fellowship improves 5-

[2] That said, the Blumenthal et al. (1996) is by now quite old and it seems obvious that scientists' behaviour has changed in the intervening decades.

[3] However, it is hard to know how to interpret these results: it could be that repeat funding from industry does not rely on academic reputation, that potential productivity is hard to screen *ex ante*, that publishing researchers choose not to work on directed research projects, that longer-term open-ended funding can cause researchers to move from the research frontier, or that industry funded researchers see the results of their work translated without the need for publication.

[4] It is important to note that this may understate the true effect since researchers have other funding options should their application be refused by the NIH.

year publication rates by about 20 per cent relative to those who were just below the threshold for receipt of the fellowship.

Arguably the main empirical challenge in this literature is controlling for confounding characteristics of the individual and their team. Some of these characteristics, such as gender, position (seniority), cohort or career age (year of PhD), employment status (e.g. tenured, full-time), and discipline, can be observed. However, we expect that there are significant unobserved characteristics such as technical and social ability, determination, competitiveness, and brilliance. As is common, we control for all time-invariant characteristics (both observed and unobserved) by exploiting the panel quality of the data.

The essence of these studies is that the rules and aims of specific grants and granting bodies do matter for research outputs. We expect to find systematic patterns within the Australian context as well. Although we have some prior propositions – that grants targeting translation will result in more patents or more commercial contracts; or that fellowships will result in more highly cited publications – this study is exploratory in that we are testing for evidence of an association between grant type and source and research outputs.

Data

The complete panel dataset used for our study covers the period 2009 to 2012 and includes a number of research input and output indicators at the individual scientist level. Data include the quantum, type and source of research funds the scientist received as a nominated chief or associate investigator, the project outputs (scientific publications, commercial contracts and patent applications), team size, scientist seniority and PhD granting university. Data were collected during March to June 2013.

Publication data were derived from Web of Science, an online citation database capturing the bibliographic and citation information for publications published in over 12,000 of the highest impact journals (including Open Access) worldwide across 250 disciplines. We collated information on publication and citations to these publications by Institute research staff (namely scientific journal articles and book chapters) during the period of January 2008 to December 2012, including the title, authors, journal and publication date.

Four key internal Institute datasets were used to augment the publication data, including:

1. Commercial agreement data capturing exchanges between parties including collaboration and project agreements;
2. Grants data including the name of the grant, the chief investigator, the associate investigators, the funding source;
3. De-identified human resource data capturing scientist's tenure at the Institute, laboratory, position and qualifications;
4. IP data.

We categorised the grant data into a number of different types: Travel and/or training award; Fellowship; PhD scholarship; Equipment, infrastructure or enabling grant; Development, translation or linkage grant; and Project or program grants. The total amount per grant does provide some context regarding the quantum and type of research grants, reflecting the Institute's staffing profile and mix of basic/translational research. It is also important to note that the categories are not mutually exclusive, so a 'fellowship award' that was specifically geared towards overseas travel would also be included in the 'travel grant' category.

According to Table 1, the mean size of the grants awarded over the period 2009-2012 was $759,753 and the total value of grants awarded was $437million. Fellowships and project and program grants were the dominant source of funds. Equipment, infrastructure or enabling awards were the most lucrative grant on average ($1,576,609) but less important as a source of total funding. The largest average grant is from the NHMRC ($968,728), following by funds sourced from US agencies ($827,462). About 80 per cent of funding was derived from the NHMRC.

Table 1: Amount Awarded by Research Grant Type/Source, 2009 to 2012

Type (source) of research grant (not mutually exclusive)	Average amount awarded ($ current prices)	Total amount awarded ($ current prices)
Travel grant	4,187	33,499
Training award	254,256	7604275
Fellowship	542,161	110,000,000
PhD scholarship	72,991	3,722,560
Equipment or infrastructure	1,576,609	17,300,000
Development, translation, linkage	308,019	3,080,188
Project or program (i.e. general)	1,039,818	334,000,000
Private or philanthropic	428,692	58,700,000
Private	598,259	1,794,778
NHMRC	968,728	387,000,000
ARC	417,384	19,200,000
Non-USA international	522,896	27,200,000
USA	827,462	26,500,000
Not included above	139,018	3,058,392
All (does not double count)	759,753	473,000,000

Table 2 presents the average characteristic of the variables used in the estimations. It shows that the average number of publications; citation to publications, patents and commercial contracts are 12.022, 0.608 and 0.070 respectively per research staff member each year. In the value-adding flow terms, this means the average researcher needs 172 cites to journal publications to achieve inventor status on 9 patents resulting in 1 commercial contract. As the grant and commercial contract variables only relate to chief and associate investigators, the absolute means appear low but the data are informative from a comparative perspective. Briefly, it shows that project or program grants and fellowships make up almost all the grants (by number).

Table 2: Average characteristic per research staff member each year, 2009 to 2012, data used in estimations

Characteristic	Average per research staff member per year
Outputs	
Total cites to journal publications	12.022
Number of patents filed*	0.608
Number of commercial contracts	0.070
Number of journal publications	1.591
Inputs	
Number of grants	0.586
Type of grant awarded	
Travel grant or training award	0.013
Fellowship	0.117
PhD scholarship	0.014
Equipment or infrastructure	0.004
Development, translation, linkage	0.011
Project or program (i.e. general)	0.132
Source of grant awarded	
Private or philanthropic	0.098
NHMRC or ARC	0.143
International	0.045
Source other	0.031
Investigator(s)	
Institute lead	0.179
Australian collaborators	0.036
International collaborators	0.002
Senior positions	
Level E or equivalent	0.059
Level D or equivalent	0.033

Note: sample=1632. * includes provision, PCT and standard applications.

Empirical Model

Our empirical model is a reduced form model which allows us to focus in on the role that different grant characteristics have on the number and quality of scientific outputs (contracts, publications and patents). Given this reduced form approach, and following the previous empirical literature, we include a number of research input and output indicators at the individual scientist level into our empirical model. Explanatory variables included in the model are the quantum, type and source of research funds the scientist received as a nominated chief or associate investigator, the project outputs (scientific publications, commercial contracts, and patent applications) and scientist seniority.[5] On the output side, we model four categories of scientist outputs – commercial contracts, journal publications, cites to journal publications and patents filed – as functions of the number and type of grants each scientist received in the previous 3 years as either a chief or associate investigator. We have chosen to model cites to journal publications to capture the quality of the publication (adjusting for truncation bias in the estimation). Although the focus of the paper is to explain the number of commercial contracts executed, we are also interested to explain journal publications and patents as they are likely inputs into the commercial pipeline.[6]

We model research output (commercial contracts, journal publications and cites to these publications or patents filed) for each researcher i in each year t, Y_{it}, as a function of recently awarded research grants according to four dimensions: (a) prior recent other outputs $\boldsymbol{O}_{it-n}$. The rationale is straight forward: we expect that where contracts, patents and publications occur as a cluster, this may reflect a more substantial and important research program than otherwise; (b) the number of grants in the previous year, $\boldsymbol{N}_{it-n}$; (c) the type of grants in the previous year, $\boldsymbol{T}_{it-n}$; and (d) sources of grants in the previous year, $\boldsymbol{S}_{it-n}$. To complement these grant-related variables, we have a vector of control variables, $\boldsymbol{X}$, which account for factors that may independently influence both the scientist's research output and their probability of getting a grant.

[5] Note that the time-invariant observed characteristics such as laboratory size and PhD granting university are captured by the fixed effect and are not directly modelled.
[6] The Institute's administrative system may tie specific commercial contracts, grants, patents and publications together as part of their reporting obligations however we do not believe this information gives wholly realistic cause and effect connections. Scientists work in-and-around ideas which have multiple antecedents, numerous funding sources and many outputs. As such we follow the standard economics analytic method of inferring causation from revealed behaviour.

The main confounding factors within $\boldsymbol{X}$ are derived from the constellation of influences associated with the specific scientist. This includes personal preferences, stage of career, aptitude and abilities, and workplace environment. Personal preferences, may, for example, influence the subject matter of the research and therefore its publication or commercial potential. Stage of career will affect the mix of basic/applied outputs scientists attempt to produce and the acquired skills each scientist brings to the workplace (and those outputs). Some may have well-established relationships with commercial partners or a stronger reputation amongst journal editors than others. Following a similar reasoning as above, more able and motivated individuals may achieve more outputs and win more grants and/or file more patents. Individual scientists are associated with specific laboratories which have differing unobservable cultural or managerial environments. A clever laboratory leader or efficient work environment may lead to both a larger number of scientific outputs, and, greater success in winning grants and filing patents, although individual manager experience and preference may encourage one path over another. Even if the grants and patents have no causal effect on the number of contracts and publications, we may observe a statistically significant correlation due to the presence of the 'laboratory effect'. We control for all these individual differences, to the extent they are time invariant over the estimation period, by including a full set of individual-level dummy variables in the estimation model.

For the equations explaining journal publications and their citations, we include the number of authors to adjust for the scientist's likely pro rata contribution. To control for the practice of nominating senior people as either chief or associate investigators in grant applications, we include two variables depicting the scientist's seniority.[7] Finally, we include variables on whether an Institute scientist was the lead researcher or the team included other Australian or international collaborators.

Ideally, we would model all the characteristics of the research grants in a single equation or single system of equations. However, as the correlations are over 0.8 for some of the explanatory variables, we have split the model into three separate equations. Formally we model each research output, *j,* (commercial contracts; journal publications; cites to journal publications; patents) as:

[7] The type of PhD awarding university was not significant in any of our estimations, *ceteris paribus*, and we exclude this from our model.

$$Y_{it}^{j} = \boldsymbol{O}_{\boldsymbol{it-n}}\boldsymbol{\alpha}_{\boldsymbol{o}}^{\boldsymbol{j}} + \boldsymbol{N}_{\boldsymbol{it-n}}\boldsymbol{\alpha}_{\boldsymbol{N}}^{\boldsymbol{j}} + \boldsymbol{T}_{\boldsymbol{it-n}}\boldsymbol{\alpha}_{\boldsymbol{T}}^{\boldsymbol{j}} + \boldsymbol{X}_{\boldsymbol{it}}\boldsymbol{\beta}_{\boldsymbol{X}}^{\boldsymbol{j}} + u_{i}^{j} + \varepsilon_{it}^{j} \qquad (1)$$

$$Y_{it}^{j} = \boldsymbol{O}_{\boldsymbol{it}-n}\boldsymbol{\alpha}_{\boldsymbol{o}}^{\boldsymbol{j}} + \boldsymbol{N}_{\boldsymbol{it}-\mathrm{n}}\boldsymbol{\alpha}_{\boldsymbol{N}}^{\boldsymbol{j}} + \boldsymbol{S}_{\boldsymbol{it}-n}\boldsymbol{\alpha}_{\boldsymbol{S}}^{\boldsymbol{j}} + \boldsymbol{X}_{\boldsymbol{it}}\boldsymbol{\beta}_{\boldsymbol{X}}^{\boldsymbol{j}} + u_{i}^{j} + \epsilon_{it}^{j} \qquad (2)$$

where u captures the time-invariant factors associated with each individual scientist and ε and ϵ comprise all the time-varying factors that drive each scientist's outcome j.

We also separately model the variables on the status of the investigators (whether an Institute scientist was the lead researcher or the team included other Australian or international collaborators, which we denote as, $\boldsymbol{I}_{\boldsymbol{it}-n}$):

$$Y_{it}^{j} = \boldsymbol{O}_{\boldsymbol{it-n}}\boldsymbol{\alpha}_{\boldsymbol{o}}^{\boldsymbol{j}} + \boldsymbol{N}_{\boldsymbol{it}-n}\boldsymbol{\alpha}_{\boldsymbol{N}}^{\boldsymbol{j}} + \boldsymbol{I}_{\boldsymbol{it}-n}\,\boldsymbol{\alpha}_{\boldsymbol{I}}^{\boldsymbol{j}} + \boldsymbol{X}_{\boldsymbol{it}}\boldsymbol{\beta}_{\boldsymbol{X}}^{\boldsymbol{j}} + u_{i}^{j} + \vartheta_{it}^{j} \qquad (3)$$

Where ϑ comprises all time-varying factors as above.

We can estimate each equation (1) – (3) using a Seemingly Unrelated Regressions (SUR) model with fixed effects. The unobserved factors, ε, ϵ and ϑ, may be correlated across outcomes as it is quite feasible that a particularly promising research program produces more commercial contracts, publications and patents. The SUR model has the advantage of taking into account the correlation of errors across offices to improve the efficiency of the estimates (Wooldridge 2012).[8]

Estimation results

To minimise the possibility of reverse causation – i.e. that outputs *cause* contemporaneous grants – the main explanatory variables are calculated as the average of the past three years. This time delay is also a reasonable period for research inputs to be felt as outputs given the rather rapid publication and technology cycle in the biomedical area. The first publication outcomes typically appear within 2-3 years after receipt of the grant. The Business Development Office follows the project closely for potential commercial contacts which usually occur from year three onwards. Provisional patent applications are lodged as appropriate prior to publication.

[8] We have also modelled each equation (being 12 in total) separately as an OLS fixed effect but as the estimated coefficients are similar in magnitude, we only present the SUR results.

Tables 3, 4 and 5 present our estimations results. The explanatory variables in Table 3 comprise prior research outputs, the number and type of recent grants over the past three years and the control variables. With respect to commercial contracts (column 1), we find that cites to journal publications, and all grant types but travelling, training and PhD scholarships had a statistically significant effect. Notably, the Equipment grants had the largest impact per grant which is probably explained by their relative generosity (see Table 1). Interestingly, the number of grants had a negative impact on commercial contracts which may speak to the negative effect of small grants. The prestigious Fellowship grants had a smaller impact per grant than the Equipment grants, Development grants and Project grants.

With respect to the number of publications and cites to these publications (columns 2 and 3), we found that the number of prior commercial contracts had a positive impact (as did the number of authors). This suggests the existence of a positive reinforcing circle between commercial contracts and publications, especially those that are highly cited. The number of prior research grants raised the number of publications, but not their citation rate. Equipment etc grants also affected the number of publications but not the citation rate.

Finally, recent publications had no effect on patents filed (column 4) and prior possession of a Fellowship was associated with a lower patent rate. This is perhaps unsurprising since it is only recently been the case that performance indicators for translation activities have been included into the fellowship system (and these will take some time to be taken seriously by the senior members of the research community). The only positive impact came from the number of grants awarded. Patenting activity appears to stand apart from our system: it explains little of the other research outputs and is influenced by few of our explanatory variables. This could be because the decision to patent is a very individual decision which reflects the desire to focus on invention rather than (or in tandem with) discovery.[9]

[9] It is worth noting, however, that this has recently changed within the Institute – outcomes and impact are now part of its core mission statement, as well as discovery.

Table 3: Research outputs in 2011-2012, Type of grant awarded, SUR.

EXPLANATORY VARIABLES (Average previous 3 years)	Dep var = Commercial contracts	Dep var = Number journal publications	Dep var = Total cites to journal publications	Dep var = Patents filed
Recent outputs				
Total cites to journal publications	0.002***			0.000
	(0.000)			(0.001)
Number patents filed	-0.002	-0.024	0.107	
	(0.005)	(0.019)	(0.089)	
Number of commercial contracts		0.406*	5.406***	-0.072
		(0.210)	(0.963)	(0.154)
Recent inputs				
Number research grants	-0.342***	0.424**	0.078	0.671***
	(0.051)	(0.197)	(0.913)	(0.145)
Type of grant awarded				
Travel grant or training award	0.420	-0.895	2.603	-0.651
	(0.288)	(1.128)	(5.224)	(0.829)
Fellowship	0.396***	-0.316	3.853	-0.862**
	(0.144)	(0.557)	(2.581)	(0.408)
PhD scholarship	-0.167	-1.084	-2.214	-1.185
	(0.338)	(1.311)	(6.071)	(0.962)
Equipment, infrastructure or enabling	5.243***	15.122***	16.458	0.084
	(0.925)	(3.429)	(15.882)	(2.633)
Development, translation or linkage	0.912**	-2.501*	-1.762	-0.020
	(0.366)	(1.426)	(6.602)	(1.044)
Project or program (i.e. general)	0.721***	0.911	0.779	-0.565
	(0.163)	(0.635)	(2.942)	(0.466)
Control variables				
Number of authors		0.090***	0.252***	
		(0.008)	(0.036)	
Individual fixed effects	Yes	Yes	Yes	Yes
Seniority	Yes	Yes	Yes	Yes
Year 2012 (for truncation)	Yes	Yes	Yes	Yes
Groups	488	488	488	488
Observations	849	849	849	849
R-squared	0.694	0.914	0.640	0.657

Note: * Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Constant included.

The explanatory variables in Table 4 comprises the same set of prior research outputs and recent number of grants, as for Table 3, but replaces the 'type of grant' explanators with the 'source of grant'. It shows that commercial contracts are more likely if the scientist had a Private or philanthropic; or NHMRC or ARC award. Prior International awards were less likely to lead to a commercial contract. Scientist receiving awards from Private and philanthropic sources appeared to lead to a higher publication rate, and NHMRC and ARC awards and International grants were associated with higher citation rates. Finally, there was no clear evidence that the source of the award mattered for patenting.

The grant status explanatory variables in Table 5 are replaced with information on the status of the investigators. It shows that commercial contracts are more likely to follow Institute-lead grants than those with other Australian collaborators (the numbers with international collaborators were very small and this variable was dropped from the estimation). However, Institute-lead grants were associated with fewer patents but other Australian collaborators were associated with more patents, *ceteris paribus*.

Table 4: Research outputs in 2011-2012, Source of grant awarded, SUR.

EXPLANATORY VARIABLES (Average previous 3 years)	Dep var = Commercial contracts	Dep var = Number journal publications	Dep var = Total cites to journal publications	Dep var = Patents filed
Recent outputs				
Total cites to journal publications	0.002***			-0.000
	(0.000)			(0.001)
Number patents filed	-0.004	-0.024	0.099	
	(0.005)	(0.020)	(0.088)	
Number of commercial contracts		0.477**	4.769***	-0.083
		(0.210)	(0.945)	(0.152)
Recent inputs				
Number research grants	-0.242***	0.356	-0.817	0.697***
	(0.057)	(0.219)	(0.989)	(0.158)
Source of grant awarded				
Private or philanthropic	0.404***	1.091*	2.273	-0.459
	(0.151)	(0.580)	(2.614)	(0.419)
NHMRC or ARC	0.513***	0.190	6.483**	-0.708
	(0.171)	(0.664)	(2.995)	(0.477)
International	-0.499**	-0.124	9.280**	-0.447
	(0.216)	(0.840)	(3.787)	(0.606)
Not included above	0.009	-2.357**	-11.977***	-1.461**
	(0.262)	(1.006)	(4.538)	(0.731)
Control variables				
Number of authors		0.091***	0.239***	
		(0.008)	(0.035)	
Individual fixed effects	Yes	Yes	Yes	Yes
Seniority	Yes	Yes	Yes	Yes
Year 2012 (for truncation)	Yes	Yes	Yes	Yes
Groups	488	488	488	488
Observations	849	849	849	849
R-squared	0.681	0.911	0.647	0.656

Note: * Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Constant included.

Table 5: Research outputs in 2011-2012, Investigators, SUR.

EXPLANATORY VARIABLES (Average previous 3 years)	Dep var = Commercial contracts	Dep var = Number journal publications	Dep var = Total cites to journal publications	Dep var = Patents filed
Recent outputs				
Total cites to journal publications	0.003***			0.000
	(0.000)			(0.001)
Number patents filed	-0.004	-0.024	0.103	
	(0.005)	(0.020)	(0.089)	
Number of commercial contracts		0.551***	5.400***	-0.191
		(0.212)	(0.958)	(0.151)
Recent inputs				
Number research grants	-0.325***	0.319*	0.732	0.479***
	(0.048)	(0.190)	(0.859)	(0.134)
Grant investigator(s)				
Institute lead	0.763***	0.560	1.759	-1.047**
	(0.153)	(0.605)	(2.745)	(0.425)
Other Australian collaborators	0.583**	0.268	-8.029*	3.546***
	(0.261)	(1.016)	(4.608)	(0.718)
International collaborators				
Control variables				
Number of authors		0.092***	0.264***	
		(0.008)	(0.036)	
Individual fixed effects	Yes	Yes	Yes	Yes
Seniority	Yes	Yes	Yes	Yes
Year 2012 (for truncation)	Yes	Yes	Yes	Yes
Groups	488	488	488	488
Observations	849	849	849	849
R-squared	0.683	0.910	0.639	0.667

Note: * Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Constant included.

Finally, there is consistent anecdotal evidence that the individual scientist has a large impact on research outputs. To quantify this, we examined the fixed effects noting that these reflect only the time-invariant individual effect. In the first place, we counted the number of scientists who attract a statistically significant fixed-effect coefficient in the SUR estimates. These coefficients indicate whether or not the individual scientist had an impact on research outputs over and above the number, type, source of the previous year's held grants and the collaborator variables. Our estimates reveal 31 scientists who excel (statistically speaking) in their achievement of commercial contracts; 75 and 21 who excelled at publishing and publishing with citations respectively; and 14 who excelled at patenting. Only four people excelled at all four activities.

The second method involves calculating the share of the estimated variance of the overall error accounted for by the individual effect. Table 6 presents this estimate (rho) from 12 single OLS panel model estimations based on equations (1) to (3). It reveals, that after accounting for the explanatory variables, the time-invariant personal attributes of the scientist accounts for between 65 to 71 per cent of the variation in commercial contracts; between 73 to 77 per cent of the variation in the number of journal publications (the range for citations was 37 to 44 per cent) and between 52 to 62 per cent of the variation in patenting.[10] These individual effects assume all other things are held constant, such as the strategy and resources of the laboratory. This is consistent with other research that finds that individual preferences and characteristics are an important predictor of the number of patent applications that faculty produce (Huang, Feeney and Welch 2011).

Table 6: Share of variance of overall error due to individual effect (rho), OLS panel estimation

Model	Dep var = Commercial contracts	Dep var = Number journal publications	Dep var = Total cites to journal publications	Dep var = Patents filed
Equation (1)	0.69	0.77	0.37	0.52
Equation (2)	0.65	0.75	0.44	0.53
Equation (3)	0.71	0.73	0.39	0.62

Note: Full results not shown

[10] Note that this method captures the combined effect of all factors that don't change over time.

Conclusions

In this study, we compiled data at the individual scientist level from a leading Australian medical research institute to investigate the effects of different research funding mechanisms on academic outputs. We found that Fellowships and Project or program grants had a positive effect on whether or not the scientist subsequently signed a commercial contract, but that Equipment and Development grants had the largest impact per grant. Finally, we found that International grants were negatively associated with subsequently signing a commercial contract. The latter may speak to the selection process and procedures for grantees.

Our fixed-effects approach allowed us to analyse the proportion of variance in our results attributable to the individual's time-invariant characteristics, after accounting for the observed explanatory factors. Specifically, this individual-scientist effect (i.e. the aptitude, ability and preferences of scientists) accounts for over half of the remaining explanation in research outputs. This is an important policy finding as it suggests that research granting bodies should perhaps place more emphasis on the person rather than the project when allocating research funds. In the current system, the effort invested by both the research and the assessors with regard to preparing and evaluating proposals might be wasteful if it is the individual that matters most.

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Table 1: Amount Awarded by Research Grant Type/Source, 2009 to 2012

Type (source) of research grant (not mutually exclusive)	Average amount awarded ($ current prices)	Total amount awarded ($ current prices)
Travel grant	4,187	33,499
Training award	254,256	7604275
Fellowship	542,161	110,000,000
PhD scholarship	72,991	3,722,560
Equipment or infrastructure	1,576,609	17,300,000
Development, translation, linkage	308,019	3,080,188
Project or program (i.e. general)	1,039,818	334,000,000
Private or philanthropic	428,692	58,700,000
Private	598,259	1,794,778
NHMRC	968,728	387,000,000
ARC	417,384	19,200,000
Non-USA international	522,896	27,200,000
USA	827,462	26,500,000
Not included above	139,018	3,058,392
All (does not double count)	759,753	473,000,000

Table 2: Average characteristic per research staff member each year, 2009 to 2012, data used in estimations

Characteristic	Average per research staff member per year
Outputs	
Total cites to journal publications	12.022
Number of patents filed*	0.608
Number of commercial contracts	0.070
Number of journal publications	1.591
Inputs	
Number of grants	0.586
Type of grant awarded	
Travel grant or training award	0.013
Fellowship	0.117
PhD scholarship	0.014
Equipment or infrastructure	0.004
Development, translation, linkage	0.011
Project or program (i.e. general)	0.132
Source of grant awarded	
Private or philanthropic	0.098
NHMRC or ARC	0.143
International	0.045
Source other	0.031
Investigator(s)	
Institute lead	0.179
Australian collaborators	0.036
International collaborators	0.002
Senior positions	
Level E or equivalent	0.059
Level D or equivalent	0.033

Note: sample=1632. * includes provision, PCT and standard applications.

Table 3: Research outputs in 2011-2012, Type of grant awarded, SUR.

EXPLANATORY VARIABLES (Average previous 3 years)	Dep var = Commercial contracts	Dep var = Number journal publications	Dep var = Total cites to journal publications	Dep var = Patents filed
Recent outputs				
Total cites to journal publications	0.002***			0.000
	(0.000)			(0.001)
Number patents filed	-0.002	-0.024	0.107	
	(0.005)	(0.019)	(0.089)	
Number of commercial contracts		0.406*	5.406***	-0.072
		(0.210)	(0.963)	(0.154)
Recent inputs				
Number research grants	-0.342***	0.424**	0.078	0.671***
	(0.051)	(0.197)	(0.913)	(0.145)
Type of grant awarded				
Travel grant or training award	0.420	-0.895	2.603	-0.651
	(0.288)	(1.128)	(5.224)	(0.829)
Fellowship	0.396***	-0.316	3.853	-0.862**
	(0.144)	(0.557)	(2.581)	(0.408)
PhD scholarship	-0.167	-1.084	-2.214	-1.185
	(0.338)	(1.311)	(6.071)	(0.962)
Equipment, infrastructure or enabling	5.243***	15.122***	16.458	0.084
	(0.925)	(3.429)	(15.882)	(2.633)
Development, translation or linkage	0.912**	-2.501*	-1.762	-0.020
	(0.366)	(1.426)	(6.602)	(1.044)
Project or program (i.e. general)	0.721***	0.911	0.779	-0.565
	(0.163)	(0.635)	(2.942)	(0.466)
Control variables				
Number of authors		0.090***	0.252***	
		(0.008)	(0.036)	
Individual fixed effects	Yes	Yes	Yes	Yes
Seniority	Yes	Yes	Yes	Yes
Year 2012 (for truncation)	Yes	Yes	Yes	Yes
Groups	488	488	488	488
Observations	849	849	849	849
R-squared	0.694	0.914	0.640	0.657

Note: * Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Constant included.

Table 4: Research outputs in 2011-2012, Source of grant awarded, SUR.

EXPLANATORY VARIABLES (Average previous 3 years)	Dep var = Commercial contracts	Dep var = Number journal publications	Dep var = Total cites to journal publications	Dep var = Patents filed
Recent outputs				
Total cites to journal publications	0.002***			-0.000
	(0.000)			(0.001)
Number patents filed	-0.004	-0.024	0.099	
	(0.005)	(0.020)	(0.088)	
Number of commercial contracts		0.477**	4.769***	-0.083
		(0.210)	(0.945)	(0.152)
Recent inputs				
Number research grants	-0.242***	0.356	-0.817	0.697***
	(0.057)	(0.219)	(0.989)	(0.158)
Source of grant awarded				
Private or philanthropic	0.404***	1.091*	2.273	-0.459
	(0.151)	(0.580)	(2.614)	(0.419)
NHMRC or ARC	0.513***	0.190	6.483**	-0.708
	(0.171)	(0.664)	(2.995)	(0.477)
International	-0.499**	-0.124	9.280**	-0.447
	(0.216)	(0.840)	(3.787)	(0.606)
Not included above	0.009	-2.357**	-11.977***	-1.461**
	(0.262)	(1.006)	(4.538)	(0.731)
Control variables				
Number of authors		0.091***	0.239***	
		(0.008)	(0.035)	
Individual fixed effects	Yes	Yes	Yes	Yes
Seniority	Yes	Yes	Yes	Yes
Year 2012 (for truncation)	Yes	Yes	Yes	Yes
Groups	488	488	488	488
Observations	849	849	849	849
R-squared	0.681	0.911	0.647	0.656

Note: * Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Constant included.

Table 5: Research outputs in 2011-2012, Investigators, SUR.

EXPLANATORY VARIABLES (Average previous 3 years)	Dep var = Commercial contracts	Dep var = Number journal publications	Dep var = Total cites to journal publications	Dep var = Patents filed
Recent outputs				
Total cites to journal publications	0.003***			0.000
	(0.000)			(0.001)
Number patents filed	-0.004	-0.024	0.103	
	(0.005)	(0.020)	(0.089)	
Number of commercial contracts		0.551***	5.400***	-0.191
		(0.212)	(0.958)	(0.151)
Recent inputs				
Number research grants	-0.325***	0.319*	0.732	0.479***
	(0.048)	(0.190)	(0.859)	(0.134)
Grant investigator(s)				
Institute lead	0.763***	0.560	1.759	-1.047**
	(0.153)	(0.605)	(2.745)	(0.425)
Other Australian collaborators	0.583**	0.268	-8.029*	3.546***
	(0.261)	(1.016)	(4.608)	(0.718)
International collaborators				
Control variables				
Number of authors		0.092***	0.264***	
		(0.008)	(0.036)	
Individual fixed effects	Yes	Yes	Yes	Yes
Seniority	Yes	Yes	Yes	Yes
Year 2012 (for truncation)	Yes	Yes	Yes	Yes
Groups	488	488	488	488
Observations	849	849	849	849
R-squared	0.683	0.910	0.639	0.667

Note: * Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Constant included.

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Note: Full results not shown