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Does Massive Funding Support of Researchers Work?: Evaluating the Impact of the South African Research Chair Funding Initiative*

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Abstract

Does knowledge and innovation need to come with a big price tag? The question of resource allocation to research is of perennial concern for management of both public and private entities. In this study we evaluate whether a substantial increase in public funding to researchers makes a material difference to their productivity. To do so, we compare performance measures of researchers who were granted substantial funding against researchers with similar scholarly standing who did not receive such funding. We find that substantial funding does raise researcher performance - though the impact is moderate. Moreover, the impact is strongly conditional on the quality of the researcher who receives the funding, and is more successful in some disciplines than others. Moreover the cost per additional unit of output is such as to raise questions about the viability of the funding model. The implication is that public research funding will be more effective in raising research output where selectivity of recipients of funding is strongly conditional on the established track record of researchers.

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1 Introduction

Strategic funding of research and development by public entities continues to be viewed as important to the ability of both business and other types of organization to innovate.[1] This makes funding for science of perennial concern, since the budget requirements of projects that carry scientific merit outstrips both public and private budgetary provision, and faces significant competition from other social spending priorities. Reductions in funding for science following the international financial crisis of 2007, has raised the salience of ensuring that limited funding is allocated to ensure maximum impact. In such a context, it is important to understand which funding mechanisms of science are effective, and which are not.

This raises a fundamental management issue, which has unusual dimensions, since the management of public research and development processes has similarities with the management of other activities, but also strong differences. Like many other investment projects, investment in research and development may require substantial up-front outlays on the promise of future success and returns in the form of increased knowledge. Such capital outlays limit the feasibility of relying on incentive mechanisms that reward research purely on the delivery of successful innovations. Investment in innovation represents commitment of resources to projects with an uncertain rate of return in knowledge. While any investment faces uncertainty,[2] where investment is in knowledge creation, uncertainty is magnified.[3]

In a market setting some recent research provides insights into efficient approaches to resource allocation. For instance, Klingebiel and Rammer (2013) in a study of innovation drawing on firm level evidence present evidence that supports funding allocation across a broad range of projects as more successful (in a sales metric) than a more focussed resource-intensive al-

[1]See for instance the discussions in Fagerberg (1994), Mowery and Rosenberg (1989), Nelson and Wright (1992), and Nelson (1992, 1996).

[2]See the seminal discussion in Dixit and Pindyck (1994).

[3]The high uncertainty and hence risk attaching to innovation and research and development is the subject of a substantial literature. See for instance the introductions in Mokyr (2002) and Rosenberg (1994).

location, since winners are difficult to predict.[4] The effectiveness of the broad-based funding allocation is found to be enhanced if coupled to monitoring tied to later-stage selection of successful innovations.[5]

A number of prior papers have examined the effectiveness of public funding of research. Arora and Gambardella (2005) find only a modest impact of National Science Foundation public funding with the exception of junior scholars. Chudnovsky et al (2008) report a significant impact of public funding on the quantity and impact of research output in Argentina.[6] Arora et al (1998) find that the impact of public funding of Italian biotechnological research is considerably enhanced where funded research teams are led by scholars of high standing - suggesting the importance of selectivity in public as well as private research funding.

In a public funding context, research funding faces difficulties over and above those faced by the private sector. Price mechanisms provide a disciplining device on market-based agents such as firms that are not present for public funding agencies devoted to the management of research. Firms can signal their prospects of successful innovation on capital markets through the return on financing that they are prepared to offer. Researchers applying for funding from public agencies have no equivalent price mechanism at their disposal. What is more, there is no reason to believe that the standard problems of moral hazard and adverse selection that characterize capital markets, would be absent from the signalling that researchers engage in when submitting funding proposals to public research funding agencies.

Problems associated with public research funding are not restricted to the difficulty of cor-

[4]See also Leiponen and Helfat (2010, 2011). The literature has also considered a range of additional determinants such as openness - see Aghion et al (2013) at an aggregate level and Laursen and Salter (2006) at micro level - and other features of strategic management and organizational structure - see Aghion, Van Reenen and Zingales (2013), Cassiman and Veugelers (2006), Garriga et al (2013), Leiblein and Madsen (2009), Li and Atuahene-Gima (2001). Approaches that tie inputs to research and development success are the subject of a vast literature in their own right- see for instance Crépon et al (1998), Mairesse and Mohnen (2002), and Van Reenen (2011).

[5]Klingebiel and Rammer (2013) also discuss the dangers associated with broad-based allocation mechanisms - particularly the dissipation of resources, lack of strategic focus, and diminished incentives.

[6]Ubfal and Maffioli (2011) also find that for Argentina public funding leads to increased research collaboration.

rectly assessing noisy signals received from applicants for funding. A number of empirical research findings show that public funding agency evaluations of researchers are often only weakly tied to the objective output and impact performance of researchers, and that funding allocations are similarly weakly correlated with research output and impact measures, in part because of inherent conservative risk-averse biases in public funding agencies that inhibit innovation.[7] The fundamental difficulty is that absent objective performance based output measures as the criterion of merit and funding allocation, there is an irreducable subjective element in the assessment process.[8] An alternative approach that has been suggested to circumvent these constraints in public funding agencies, is the use of performance-based output measures. Structuring recognition on objective output measures reduces conservative and subjective biases, and reduces the risk of adverse selection and moral hazard problems in the distribution of resources.[9]

Such complex and multi-faceted difficulties confronting public research management make it difficult to isolate the relative empirical significance of the various aspects of the challenges. In this paper we make use of a natural experiment, that allows us to isolate the impact of a resource-intensive investment in research through a public agency. To do so, we track the research output and impact of a group of researchers who receive substantial public funding, against a control group of researchers that the same public funding agency deems of equivalent scholarly standing, who do not receive such funding.[10] The research design is enabled by data

[7] On the poor correlation of evaluation and funding with objective performance see Fedderke (2013) and Grimpe (2012). On the conservative biases in public funding agencies see Braun (1998).

[8] See the discussion in Moxam and Anderson (1992) and Horrobin (1990).

[9] See for instance the discussion in Abramo et al (2009), Butler (2003) and Hicks (2012). There are also dangers to the approach. Butler (2003) indicates that it may favour quantity over quality. Hicks (2012) notes that performance-based reward structures focus specifically on excellence. Van Raan (2005) reports concerns regarding the lack of homogeneity in coverage of different scientific areas, and sensitivity to starting data bases. Korevaar and Moed (1996) point to the significance of potential disciplinary differences. However, these are limitations that can be overcome by the use of multiple measures of performance, and careful bottom-up construction of data. See the discussions in Abramo and D'Angelo (2007), Aksnes and Taxt (2004), Martin (1996), Oppenheim (1997), and Rinia et al (1998). Edere and Manso (2012) present experimental evidence demonstrating that reward for performance does not carry the disincentive effects feared in applied psychology, conditional on the correct design of the reward structure (mitigation of risk is important).

[10] The vast preponderance of the resarchers are located in universities - a few in public research bodies. Both are

drawn from the South African public research funding mechanism, which is to our knowledge unique in providing independent research grants and a peer review based mechanism that provides ratings of individual researchers on what claims to be a standardized scale across multiple disciplines.[11]

Since we are able to control for differences in scholarly standing through the peer review mechanism, we are able to isolate the impact of selectivity from the impact of differential resourcing. Since we have additional data on the specific disciplinary affiliation of researchers, we also test whether the resourcing and the selectivity effects are differential across different types of research.

We proceed as follows. In section 2 we provide a precise statement of the research question and explain the associated estimation methodology. Section 3 details data sources, section 4 presents results, while section 5 concludes.

2 The Research Question and Methodology

In this study we empirically examine whether a substantial increase in public funding allocations to researchers makes a material difference to their productivity and impact?

To answer this question, we compare the scholarly performance of a body of researchers who were granted substantial research funding, against the performance of a body of researchers of similar inherent scholarly standing, who did not receive such funding. The issue is whether there is an improved rate of scholarly returns (in terms of both output and impact), as measured by objective bibliometric measures under the Thomson ISI Web of Science citations database.

Our focus is on South African data, since the national research funding body provides very differential research funding support to two groups of scholars, that are directly comparable in

subject to essentially the same funding constraints and incentives.

[11] A more detailed description and discussion can be found in Fedderke (2013).

terms of an independent peer review mechanism, allowing for the creation of a control group against which the performance of highly funded researchers can be compared. The National Research Foundation of South Africa (NRF) is and independent government funded agency tasked with the promotion and support of research across all disciplines represented in the South African academy. In 2008-9, the South African National Research Foundation (NRF) awarded a total of 80 research chairs,[12] each of which was endowed with substantial research funding (approximately US$300,000 per annum) guaranteed over a period of 5 years, renewable for up to 15 years. The objective of the initiative was explicitly to increase the production of knowledge, by providing financial support to leading researchers.

In addition, the NRF provides a peer-review based system of ratings of scholars. The objective of the rating process is to "benchmark [the] performance of researchers." Ratings can fall into a range of categories. NRF research chairs are targeted at researchers with international academic leadership status. For this reason this study focusses on only two NRF rating classes. An A-rating is held to apply to researchers who are unequivocally recognized by their peers as leading international scholars in their field for the high quality and impact of their recent research outputs. The B-rating is applied to researchers who enjoy considerable international recognition by their peers for the high quality and impact of their recent research outputs.[13] The funding allocation by the NRF to A- and B-rated researchers is approximately US$10,000 and US$8,000 per annum respectively.

[12] See http://www.nrf.ac.za/sarchi/index.stm for a full description of the initiative. The South African initiative is modelled on the Canadian research chair initiative - see Neuman (2003) and Polster (2003). The Canadian case does not allow for the comparison of the research chair's performance against a comparable control group, as does the South African model. Hence our choice of the South African case. Note that in 2012 the NRF awarded an additional set of chairs. These are not included in our analysis, since not enough time has passed to assess the impact of the new chairs.

[13] For a detailed analysis of the full NRF peer-review based mechanisms, see Fedderke (2013). In addition to the A- and B-ratings we use here, the NRF recognizes four additional categories of scholars (though some are no longer awarded): C-rated, Y-rated, P-rated, and L-rated. A total of approximately 2000 researchers are rated, including the NRF chair holders. Since these are associated with ratings that fall below the international research excellence benchmark attributed to the NRF research chairs, they are not part of the control group used for this study.

NRF research chairs thus receive funding grants 30 times as large as A-rated researchers, and approximately 38 times as large as B-rated researchers. In order to test the success of the funding intervention in generating higher research productivity, we compare the scholarly output and impact of researchers who did receive the funding associated with an NRF research chair, with scholars of comparable standing who did not.

The advantage of the research design of the study is as follows. There is a specific temporal point at which a clearly identifiable set of researchers received a substantial increase in funding toward their research. Since the NRF operates an independent peer review mechanism of researchers, the scholarly standing of the NRF chair incumbents is readily identifiable. There is an equally clearly identifiable control group of researchers available, who are highly (or equivalently) rated by the NRF, but who were not granted the funding associated with a research chair. We have a set of objective bibliometric measures of performance in terms of which the performance of researchers can be measured. Finally, since the NRF funding body covers all academic disciplines in South Africa, the study is not simply a reflection of performance in one area of intellectual endeavour, but carries general implications for the performance of the academy, it also allows for cross-disciplinary comparisons in the results we derive.

Our approach is straightforward.

We begin by recording the standing of three groups of researchers (NRF research chairs, A-rated researchers, B-rated researchers), at the time the NRF research chairs were awarded in 2009, across a range of bibliometric measures of absolute output, of scholarly impact, and in terms of a composite measure of absolute output and of impact.

We then record the change in the performance of the three groups of researchers from 2009 - 2012, across the same range of bibliometric measures, in order to establish whether there is an appreciable difference in performance between the NRF research chair incumbents, and A- and B-rated researchers who did not receive the funding associated with an NRF research chair.

The paper examines three separate hypotheses.

Hypothesis 1 (H1): Scholars who received the higher level of funding associated with an NRF chair award have a significantly higher performance as measured by output and impact than researchers of comparable standing (A- and B-rated researchers) who did not receive a research chair.

We examine *H1* through descriptive statistics, as well as by estimating:

$$\Delta M_i = \alpha A_i + \beta B_i + \eta N_i + \varepsilon_i \quad (1)$$

where ΔM_i denotes the change in the bibliometric index of interest for researcher i, A_i denotes a categorical variable for an A-rating for the $i'th$ researcher not holding an NRF chair, while B_i and N_i denote categorical variables for a B-rating without NRF chair or an NRF chair respectively. We denote the error by ε_i.

Our concern is whether $\eta \neq 0$, and whether $\eta > \alpha$, and $\eta > \beta$, in order to address the extent to which the funding allocated to research chair holders has had a differential impact.

An additional concern is whether selectivity across the quality of the researcher receiving funding makes a difference to the productivity impact of funding. This leads to our second hypothesis.

Hypothesis 2 (H2): The higher the scholarly standing of the recipient of the funding associated with NRF chairs in 2009, the higher the increase in performance as measured by output and impact.

To explore *H2*, i.e. whether the funding provided under the NRF chair initiative has a differential impact conditional on the scholarly standing of the recipient of the chair in 2009, we estimate:

$$\Delta M_i = \alpha A_i + \beta B_i + \sum_{k=1}^{3} \delta_k R_k N_i + \varepsilon_i \quad (2)$$

where R_k is a categorical variable for three possible ratings that NRF recipients held at the point where the chair was awarded in 2009, viz., an A-rating, a B-rating, or any rating other than A or B.

Our final hypothesis concerns the existence of disciplinary differences.

Hypothesis 3 (H3): Funding provided under the NRF chair initiative has a differential impact conditional on the discipline of the researcher.

To explore *H3*, i.e. to allow for disciplinary differences in terms of the success of the NRF research chair initiative, we consider:

$$\Delta M_i = \alpha A_i + \beta B_i + \sum_{j=1}^{7} \gamma_j D_j N_i + \varepsilon_i \tag{3}$$

where D_j denotes a set of categorical variables for the seven disciplinary groupings we code in our data, the Biological, Business and Economic, Chemical, Engineering, Medical, Physical and Social sciences.

3 Data

For this study we employed two sources of data.

The first was derived directly from the published list of rated scholars and research chairs of the NRF, in order to identify NRF chair holders, as well as A- and B-rated researchers.[14]

The second data source involved the compilation of bibliometric data on all identified researchers. Bibliometric data was collected for: all researchers that received a NRF chair in the 2008/9 round of awards for a total of 77 records (three names were excluded due to data availability); all A-rated researchers without NRF chairs, for a total of 67 records (one name was excluded due to data availability); a random sample of B-rated researchers without NRF chairs, for a total of 157 records (four names were excluded due to data availability). Note that

[14] Of course, peer review is itself subject to strengths and weaknesses - see the review in Bornmann (2011). For our purpose we only require that the NRF chairs are compared with comparable researchers, for which the NRF peer review process which considers all researchers against the same standards provides a means of selection.

the NRF chair holders may also hold an NRF researcher rating. Of the 77 NRF chairs included in the study, 9 were A-rated, 28 B-rated, and 40 either held a rating lower than A or B, or no rating at all.[15] The fact that NRF chair holders are of diverse scholarly standing as established by the NRF peer review mechanism, will allow us to explore the question of whether funding allocation has a differential impact conditional on the quality of the researcher to whom the funding is given. Details of the sample are reported in Table 1.

	Population	Sample	Percentage of Population	Excluded	Records in Study
NRF Chair	80	80	100	3	77
NRF: A-rated	9	9	100	0	9
NRF: B-rated	30	30	100	2	28
NRF: Other	41	41	100	1	40
A-rated w/o NRF chair	68	68	100	1	67
B-rated w/o NRF chair	441	161	39	4	157

Table 1: Sample Characteristics

For the range of objective measures of scholarly output and impact, our data was obtained through the ISI Thomson Web of Science citations database.

Four bibliometric measures were employed for this study.[16] We employ the bibliometric measures of output and impact to measure a researcher's standing in 2009, and the change in the standing over the 2009-12 period. Total Publications measures the total accumulated number of publications attributed to an author. The associated 2009-12 change measure records publications over the 2009-12 period. Total Citations measures the total number of citations to the work of a researcher up to 2009. The associated change measure records citations to work published between 2009 and 2012. Average Citations per Item is the Total Citations count

[15] Since the NRF officially claims that NRF research chairs are aimed at world-leading scholars, the fact that more than 50% of the population of research chairs holds low ratings on the NRF peer review mechanism is surprising. For a more extensive analysis and discussion of this anomaly see Fedderke (2013).

[16] We also considered three additional bibliometric measures: Citations without Self-citations; Total Citing Articles; Total Citing Articles without Self-citations. Since the results from these measures do not differ materially from those we report, we omit them for the sake of parsimony.

normalized on the Total Publications count. Hirsch's h-index is a measure which provides a composite measure both of absolute output and of the impact of the output. A scholar has an index of h if h of his/her papers have at least h citations each, and the remaining papers have no more than h citations each. Though there are now a wide array of composite bibliometric measures available with varying properties, the h-index is arguably the most widely cited objective measure of scientific standing, which explains our use of the metric.[17]

We employed the ISI Web of Science search engine to generate the bibliometric data for each author. Two major issues arise from the use of any search engine. The first is that each of the major alternatives (ISI, Scopus, Google Scholar) has strengths and weaknesses.[18] In what follows, we therefore examine the sensitivity of findings to the use of Google Scholar rather than ISI to generate the bibliometric indexes. The summary result is that the inferences of the present study are not sensitive to the search engine employed.[19] The second major concern regarding our data arises from the fact that the researchers in our data are drawn from very diverse disciplines, ranging from the arts to the hard quantitative sciences. Evidence from the literature suggests that there is strong cross-disciplinary variation in bibliometric indices.[20] For this reason we also explore the sensitivity of our results to coding scholars in terms of the broad dis-

[17] For a discussion of the properties of the h-index, see Bornmann and Daniel (2007), Cronin and Meho (2006), Egghe and Rousseau (2006), Glänzel (2006), Hirsch (2005) and Van Raan (2006).

[18] A non-comprehensive list of concerns with ISI-based searches are that it: does not include citations to scholarly output that has even small mistakes in its referencing; is subject to more citation noise; provides overrepresentation to English language and US and UK based journals;is biased toward citations to journal articles (as opposed to books, etc.); significantly restricts citations to non-ISI database journals; underreports citations in disciplines with long delays to publication; underreports citations in general; is sensitive to institutional subscriptions. The reliability of Google Scholar has also been questioned, on the grounds of attribution of publications to phantom authors, inclusion of non-scholarly publications, exclusion of some important scholarly journals, uneven disciplinary coverage, less comprehensive coverage of publications prior to 1990, and inconsistent accuracy. See the discussion in Archambault & Gagné, (2004), Belew (2005), Bornmann et al (2009), Bosman et al. (2006), Butler (2006), Derrick et al (2010), Falagas et al (2008), García-Pérez (2010), Gray et al (2012), Harzing (2007-8, 2008), Jacsó (2005, 2006a/b, 2010), Kousha & Thelwall, (2007, 2008), Kulkarni et al (2009), Meho and Yang (2007), Nisonger (2004), Roediger (2006), Testa (2004), and Vaughan and Shaw (2008).

[19] For a detailed discussion of the impact of alternative search engines on the South African data, see Fedderke (2013).

[20] See the discussion in Rehn et al (2007) and particularly Iglesias and Pecharromán (2007).

ciplinary fields proposed by Iglesias and Pecharromán (2007), and adjusting their bibliometric scores in the light of disciplinary weights as determined by their principal institutionally defined disciplinary affiliation. Again, to preempt the findings, the inferences of the present study are not affected by the use of disciplinary weightings.

4 Did NRF Chairs Improve Research Productivity?

4.1 Characterizing the Research Performance as of 2009

Mean values across our sample, for the standing of scholars at the time the NRF research chairs were awarded in 2009, are reported in Table 2. What is evident from the central tendency data is that the holders of NRF research chairs had both absolute levels of output (Total Publications), impact (Total Citations, Citing Articles, both with and without self-citations), and a joint output and impact measure (h-index) which lay between the A- and B-rated scholars without research chairs in our sample. The implication is thus that the funding intervention by the NRF was not targeted at the very strongest scholars in the South African academy (the A-rated scholars are consistently stronger in terms of absolute output, citations impact, and the joint h-index measure). However, NRF chair holders, while not having the highest level and impact of research output, score higher than either A- or B-rated scholars in terms of citations per publication. It thus appears as if the award of the research chairs targeted scholars that have not yet reached maximum impact (levels of output and impact are not the highest), but which show significant promise (output and impact is higher than B-rated scholars, and impact per publication is higher even than A-rated scholars).[21]

There is one important nuance to report in the results, however. When considering the NRF chairs' performance, we found that chairs who hold A- and B- ratings have demonstrably

[21] Regression analysis provides the same result. We estimated $M_i = \alpha A_i + \beta B_i + \eta N_i + \varepsilon_i$, for each of the four bibliometric measures. The implications are entirely symmetrical to those reported and discussed in Table 2.

stronger performance compared to those with lower or no rating (more than 50% of the chairs). NRF chairs with low or no rating perform worse than B- rated researchers without a chair. This allows us to explore the difference in performance given the quality of the researcher.

	Total Publications		Total Citations		Average Citations				h-index			
	Raw		Raw		Raw		Adj.		Raw		Adj.	
	ISI	PP	ISI	PP	ISI	PP	ISI	PP	ISI	PP	ISI	PP
NRF Chair (All)	60.40	86.61	1575.99	823.95	19.75	8.49	28.50	12.78	16.61	10.64	17.66	12.31
NRF: A-rated	86.67	105.00	2641.56	1403.11	20.56	12.69	32.42	18.09	21.22	13.44	24.04	15.50
NRF: B-rated	86.00	103.00	2421.04	1111.79	28.29	10.49	41.40	14.95	22.86	14.29	24.14	15.51
NRF: Other	36.58	70.43	744.70	492.15	13.59	6.15	18.60	10.07	11.20	7.45	11.69	9.35
A-rated (w/o chair)	143.49	193.96	3150.48	2017.22	16.25	7.86	20.47	10.54	23.34	17.99	23.36	18.60
B-rated (w/o chair)	61.50	93.25	1011.60	602.59	12.85	5.78	18.66	9.36	14.26	10.46	15.33	12.11

Table 2: Mean Values of Bibliometric Indexes: Raw denotes recorded ISI Values, Adj denotes discipline weight adjusted measures, ISI denotes ISI Web of Science results, PP denotes the Publish or Perish Google Scholar based search results

In aggregate, therefore, it appears as if the NRF funding intervention is targeted at a group of scholars that might reasonably be expected to transform the funding they have been granted into a significantly increased level of output.

The data confirms that there are strong disciplinary differences in terms of the bibliometric measures, as reported at the time the chairs were awarded in 2009.[22] One pattern that is common across disciplines, is that the NRF chairs at the time the chairs were awarded in 2009, reported the highest Average Citations score. This finding is consistent with the suggestion that the selection of NRF chairs targeted promising researchers that had not yet accumulated the sheer body of work of A-rated researchers, for instance, but which showed promise in terms of per publication impact. On the other hand, we also continue to find that the strong average citations performance of NRF research chairs is driven mainly by chair holders that are A- and B-rated, while for the remaining majority of NRF research chairs historical research performance fell

[22] A detailed presentation of the descriptive evidence is available from the authors on request - section 4.4 of the paper presents the principal insights relevant to our question.

below that of A- and B-rated researchers.[23]

In the analytical work that follows this section, we also adjusted the ISI reported h-index by discipline-specific weights as suggested by Table II of Iglesias and Pecharromán (2007).[24] Table 2 reports the impact on the bibliometric measures. While changing the absolute magnitude of the bibliometric measures,the inferences drawn regarding the relative rankings of the NRF chairs against rated scholars are unaffected.

4.2 The Performance Change over the 2009 to 2012 Period

Our concern is with whether the award of the funding associated with NRF research chairs made an appreciable difference to the research output and impact of the scholars receiving the higher level of funding associated with the research chairs, relative to researchers of comparable standing, who did not receive a research chair. To do so, we examine the *change* in the bibliometric measures for the NRF chairs, and A-rated and B-rated researchers without research chairs over the 2009-12 period. To do so, we estimate specification (1) for the four measures of researcher standing, which we report in Table 3.

As the results of Table 3 show, all researchers, be they A-rated, B-rated, or NRF chair holders increased the number of recorded publications and total citations over the 2009-12 period. The strongest increases in publications and in total citations are reported by A-rated researchers without NRF chairs. By contrast, B-rated researchers without NRF chairs, while also increasing their publications and citations counts, do so by a considerably lower margin than do A-rated researchers. NRF chair holders, while starting with a lower publication and citation count than

[23]The inference from the descriptive evidence is thus that the claim that the selection of researchers for the NRF chairs is based on merit, needs strong qualification at the very least. This mirrors the earlier finding of Fedderke (2013) on 1932 researchers that the NRF rates. It is also the finding of Grimpe (2012) on the distribution of research grants across a sample of 800 researchers in Germany, when evaluated against the research output and impact of the researchers.

[24]The weights for the disciplinary categories in our study are as follows: biological 0.89; business 1.32; chemical 0.92; engineering 1.73; medical 0.67; physical 1.16; social 1.6.

either A- or B-rated researchers without NRF chairs, after the award of the chair increased their publication count almost as much as A-rated researchers without NRF chairs (by 21.03 publications vs. 22.61), and total citations by a considerably closer margin than B-rated researchers (84.97 citations vs 105.31 by A-rated researchers). The net result is that the increase of B-rated researchers' publications was more than 50% lower than that of A-rated researchers, that of NRF chairs was less than 10% lower. For citations, B-rated researchers' increase was more than 60% lower than that of A-rated researchers, while that of NRF chairs was less than 20% lower.

Change in:	Publications	Citations	Avg Citations		h-index	
	Raw	Raw	Raw	Adj.	Raw	Adj.
α_A	22.61*** (2.43)	105.31*** (17.29)	−1.99*** (0.36)	−2.56*** (0.54)	0.19*** (0.07)	0.23*** (0.08)
α_B	10.53*** (1.59)	38.00*** (11.30)	−1.58*** (0.24)	−2.29*** (0.36)	0.11** (0.04)	0.10* (0.05)
α_N	21.03*** (2.27)	84.97*** (16.13)	−3.94*** (0.34)	−5.59*** (0.50)	0.27*** (0.06)	0.30*** (0.07)
adj-R^2	0.07	0.03	0.09	0.09	0.01	0.01
N	301	301	301	301	301	301
*** denotes significance at 1%, ** at 5%, and * at 10% levels						
Figures in round parentheses denote standard errors						

Table 3: Change in Researcher Performance from 2009 to 2012: Raw denotes recorded ISI Values, Adj denotes discipline weight adjusted measures

This improved output and level of citations is reflected in the recorded h-index. The strongest increase after 2009 occurs for NRF chairs (0.27), followed by A-rated researchers (0.19), while B-rated researchers show the smallest increase (0.11).

The improved performance of NRF chairs has come at a cost. Recall that the descriptive evidence showed that while NRF chairs did not report the level of publications, or citations of A- and B-rated researchers, they were distinguished by the fact that they had the highest citations per publication of any researcher grouping. The implication was that while perhaps not as prolific as the other two groupings of researchers, their output was item-for-item of greater impact. Since 2009 this has changed. For all categories of researcher, the average citations per item have fallen since 2009. One interpretation of this finding is that the new publications have not yet had a chance to generate a full citation count. It could also reflect a change in the publication patterns of South African researchers toward a greater emphasis on quantity rather than quality. The strongest decline is reported for the NRF chair holders (-3.94 citations per publication), approximately twice as great as the decline for A-rated researchers, who reported a stronger increase than the NRF chairs in publications.

Note that the use of the discipline-normalized Average Citations and h-index values does not change any of the qualitative inferences drawn on the raw data - indeed the use of the normalized data serves to strengthen the conclusions.

What thus emerges is that the performance of NRF Chair awardees certainly changed after the granting of the chair: publications and citations rise; but citations per publication decline strongly.

4.3 Breaking Down the NRF Chair Holders by Scholarly Standing

As we have already noted, the NRF chair holders are not an homogeneous grouping. More than half of the chair holders have either no NRF rating of any kind, or a rating that falls below the most highly ranked A- or B-ratings.

A question of interest is whether the granting of research funding has a differential impact conditional on the level of scholarly experience and/or standing of the awardee. For this reason, we also consider the results from the estimation of specification (2), results of which are reported in Table 4.

The results demonstrate that the peer-reviewed standing of a researcher matters considerably in terms of the impact of research funding on performance. While on average, across all NRF re-

Change in:	Publications	Citations	Avg Citations		h-index	
	Raw	Raw	Raw	Adj.	Raw	Adj.
α_A	22.61^{***} (2.42)	105.31^{***} (17.24)	-1.99^{***} (0.36)	-2.56^{***} (0.54)	0.19^{***} (0.07)	0.23^{***} (0.08)
α_B	10.53^{***} (1.58)	38.00^{***} (11.27)	-1.58^{***} (0.24)	-2.29^{***} (0.36)	0.11^{**} (0.04)	0.10^{*} (0.05)
$\delta_{N\times A}$	25.67^{***} (6.60)	83.78^{*} (47.05)	-3.56^{***} (0.98)	-5.22^{***} (1.46)	0.22 (0.18)	0.31 (0.21)
$\delta_{N\times B}$	26.86^{***} (3.74)	124.54^{***} (26.68)	-5.25^{***} (0.56)	-7.80^{***} (0.83)	0.32^{***} (0.10)	0.35^{***} (0.12)
$\delta_{N\times O}$	15.90^{***} (3.13)	57.55^{**} (22.32)	-3.10^{***} (0.47)	-4.13^{***} (0.69)	0.25^{***} (0.09)	0.26^{***} (0.10)
adj-R^2	0.08	0.04	0.11	0.11	0.004	0.007
N	301	301	301	301	301	301
*** denotes significance at 1%, ** at 5%, and * at 10% levels Figures in round parentheses denote standard errors						

Table 4: Change in Researcher Performance from 2009 to 2012 with NRF Chair Breakdown by Peer Review Rating: Raw denotes recorded ISI Values, Adj denotes discipline weight adjusted measures

search holders, publications and citations after 2009 increased by less than A-rated researchers, this is not true for all types of holders of research chairs. In particular, both A- and B-rated NRF research chair holders increased total publications by more than A-rated researchers without NRF chairs. In terms of increased total citations, the largest increase is reported by B-rated NRF research chair holders (124.54), though in this instance A-rated researchers without NRF chairs still outperform A-rated researchers with NRF chairs. Once again, however, this improved performance on the part of NRF chair holders, comes at the cost of a strong fall-off in the number of citations per publication (-3.56 and -5.25 for A- and B-rated NRF chair holders).

The notable result here, however, is the substantial gap in performance between A- and B-rated NRF chair holders, and those who are not rated, or are rated lower than A or B. These NRF chair holders do report an increase in publications, but only approximately 60% of the increase for A- and B-rated chair holders. For the increase in citations, the improvement lies between 50% (relative to B-rated chair holders), and 75% (relative to A-rated chair holders).

Note that the use of the discipline-normalized Average Citations and h-index values does not change any of the qualitative inferences drawn on the raw data - indeed the use of the normalized data serves to strengthen the conclusions.

Thus the averages for the NRF chair holders (in section 4.2) are biased upward by the relatively strong performance of the A- and B-rated NRF chair holders, while the performance of unrated or lower rated chair holders is considerably less strong, even after the award of the chair. The prior scholarly standing of research chairs, thus is of material importance to the subsequent performance of chair incumbents on average.

4.4 Breaking Down the NRF Chair Holders by Discipline

Section 4.2 shows that NRF chair holders on average showed an increase in publications comparable to A-rated researchers, and in the h-index that exceeds A-rated researchers, an increase in citations relatively close to A-rated researchers, at the cost of a decline in citations per publication. In all dimensions NRF chairs outperformed B-rated researchers by a considerable margin. Section 4.3 adds the nuance that the improved performance was concentrated amongst A- and B-rated NRF chair holders, with the chair holders with other ratings performing much worse.

But what about the chair holders in different disciplines? To explore this question we estimate the specification given by (3), as reported in Table 5.

The results imply substantial disciplinary differences across the NRF chairs. Strong increases in publications are concentrated in the Medical, Chemical, Biological and Physical sciences (in that order), while there is essentially no improvement increase in the publications of NRF chairs in the Business and Economic, Engineering and Social sciences (on average).

With respect to citations, the performance of the disciplines is even more skewed. Increases are concentrated in the Medical and Physical sciences. While both the Biological and Chemical sciences report positive (and strong) coefficients, only the Biological sciences are statistically

	Publications	Citations	Avg Citations		h-index	
	Raw	Raw	Raw	Adj.	Raw	Adj.
α_A	22.61^{***} (2.42)	105.31^{***} (17.19)	-1.99^{***} (0.36)	-2.56^{***} (0.54)	0.19^{***} (0.07)	0.23^{***} (0.08)
α_B	10.53^{***} (1.58)	38.00^{***} (11.23)	-1.58^{***} (0.23)	-2.29^{***} (0.35)	0.10^{**} (0.04)	0.10^{*} (0.05)
$\gamma_{N\times Bio}$	17.07^{***} (4.32)	69.17^{**} (30.76)	-3.54^{***} (0.64)	-3.08^{***} (0.97)	0.15 (0.12)	0.10 (0.14)
$\gamma_{N\times Bus}$	1.36 (7.81)	-6.89 (55.68)	-0.75 (1.16)	-1.94 (1.76)	0.04 (0.22)	0.04 (0.26)
$\gamma_{N\times Chem}$	19.87^{***} (5.68)	50.36 (40.46)	-1.25 (0.84)	-1.41 (1.28)	0.26^{*} (0.16)	0.31^{*} (0.19)
$\gamma_{N\times Eng}$	-0.02 (5.29)	-9.15 (37.67)	-0.81 (0.78)	-4.61^{***} (1.19)	0.04 (0.15)	0.10 (0.17)
$\gamma_{N\times Med}$	21.99^{***} (5.53)	138.30^{**} (39.38)	-4.22^{***} (0.82)	-2.60^{**} (1.24)	0.31^{**} (0.15)	0.22 (0.18)
$\gamma_{N\times Phy}$	13.80^{***} (5.09)	66.82^{*} (36.27)	-3.63^{***} (0.75)	-5.58^{***} (1.15)	0.07 (0.14)	0.09 (0.17)
$\gamma_{N\times Soc}$	2.16 (4.84)	-2.65 (34.49)	-1.19^{*} (0.72)	-3.48^{***} (1.09)	0.13 (0.14)	0.24 (0.16)
adj-R^2	0.14	0.07	0.15	0.11	0.004	0.000
N	301	301	301	301	301	301
*** denotes significance at 1%, ** at 5%, and * at 10% levels						
Figures in round parentheses denote standard errors						

Table 5: Change in Researcher Performance from 2009 to 2012 with NRF Chair Breakdown by Discipline: Raw denotes recorded ISI Values, Adj denotes discipline weight adjusted measures

significant, while the improvement in the Business and Economic, Engineering and Social sciences is negligible. With respect to the h-index, it is only the Chemical sciences that report a statistically significant, or for that matter meaningfully large increase.

Improved performance of NRF chairs is thus concentrated in the Medical, Physical and Biological sciences - and it is in these disciplines that the higher level of output has led to a decline in the average citations per publication.

Note that the use of the discipline-normalized Average Citations and h-index values does not change any of the qualitative inferences drawn on the raw data. Note that particularly for the Average Citations measure, the decline in citations of NRF chair holders in particular is exacerbated for the Engineering, Physical and Social sciences, and moderated for the Medical sciences, under the adjusted data.

It is worth noting that the distribution of disciplinary performance shows a correspondence with how closely the NRF chairs showed strong performance at the time at which the chair was awarded. NRF chairs in the Medical, Physical and Biological sciences reported strong research track records in terms of bibliometric measures in 2009, at the time the chairs were granted. By contrast, for the Social, Engineering and particularly the Business and Economic sciences this correspondence was much weaker. The award of the NRF chairs does not appear to have changed this pattern.

4.5 Adding the Cost Dimension

We have seen that the granting of the NRF chairs did have a statistically significant impact on the bibliometric measures associated with researchers.

But recall that A-rated researchers receive NRF grants valued at US$10,000 per annum, B-rated researchers receive grants valued at US$8,000, while the budgetary allocation for NRF chairs is US$300,000 per annum (approximately: we use an exchange rate of ZAR10:US$1).[25] In Table 6 we report the implied costs per additional publication and citation after 2009 across the various researcher rating categories. The very substantial differential in budgetary allocation across the various classes of researcher, and the limited increased productivity of the NRF research chairs over other researchers, results in a strong cost differential per publication and per citation between NRF research chairs and A- or B-rated researchers. This is irrespective of whether the NRF chair is A-, B- or otherwise rated.

The inference is that while the expenditure on the NRF chairs has increased output, it has come at some cost - and the cost is substantial. As Table 6 demonstrates, the smallest differential

[25] We do not have data on other sources of funding available to researchers. However, given the status that attaches to the NRF research chairs, there is no reason to suppose that holders of chairs have a lower capacity to raise research funding than other researchers.

	Per New Publication	Per New Citation
A-rated	442	95
B-rated	760	211
A-rated NRF Chair	11,688	3,581
B-rated NRF Chair	11,170	2,409
Other Rated NRF Chair	18,868	5,213
Ratio:	Per New Publication	Per New Citation
A-rated NRF Chair : A-rated w/o chair	26	38
A-rated NRF Chair : B-rated w/o chair	15	17
B-rated NRF Chair : A-rated w/o chair	25	25
B-rated NRF Chair : B-rated w/o chair	15	11
Other Rated NRF Chair : A-rated w/o chair	43	55
Other Rated NRF Chair : B-rated w/o chair	25	25

Table 6: Cost of Additional Productivity Across NRF Researcher Rating Categories in US Dollars and Ratio of Costs per Publication and Citation between NRF research chairs and A and B-rated researchers

in cost between the NRF chairs and the A- and B-rated researchers, is a factor of 15:1 per publication, and 11:1 per Citation. And the differential rises to 43:1 in the case of Publications, and 55:1 in the case of Citations. In short, the implication is that if the objective is to raise the research output of the academy-based research system, a more productive means of doing so may well be by allocating more funding at the margin to A-rated and B-rated researchers, rather than allocating the very substantial budgetary resources associated with the NRF research chairs.

5 Discussion and Policy Inferences

So providing substantial funding to researchers makes a difference. The evidence from our data suggests that substantial funding can raise the number of publications produced and the number of citations associated with the work of funded researchers, though arguably the increase is moderate when compared to the performance of researchers of equivalent standing, and certainly the citations rate (average citations per publication) as a measure of impact under the increased funding declines.

What matters even more is *how* the funding is allocated. The performance impact of NRF research chair funding is strongly conditional on the scholarly standing of the recipient. Scholars that are highly ranked in terms of peer review demonstrate a far higher rate of return on investment in terms of research output than those that have a low peer review ranking.

What is more, strong funding increases do not show the same rate of return across all disciplines. Publications increase in the Biological, Chemical, Medical and Physical sciences. They do not increase statistically significantly for Business and Economic, Engineering or the Social sciences, while both A- and B-rated scholars report statistically significant (and generally stronger) rates of increase in publications. In terms of Citations, only the Biological, Medical and Physical science research chairs report statistically significant increases, while the Business and Economic, Chemical, Engineering and Social sciences do not. Funding thus seems to be differentially productive across disciplines, suggesting that disciplines do not all require the same degree of financial support.

Factoring in the cost of the productivity gain realized through the NRF research chairs, shows that the cost per unit of additional research output proves to be substantial. It follows that if the objective of research funding is to raise the level of research output and impact, it is not clear that heavy focus on a small group of researchers is the most effective funding model to adopt. Spreading funding more equally across all highly rated researchers may elicit a stronger output response than bunching resourcing on a few individuals to the exclusion of all others. Once the funding is guaranteed over substantial periods of time, negative incentive effects are only likely to compound this problem.

So what policy conclusions can be inferred from this evidence?

What the evidence shows is that while funding raises research output, the impact of funding is enhanced where it is conducted under selectivity - choosing researchers with strong a performance records at the point at which the award is made. We have also seen that at least for the South African funding agency the attention paid to selectivity is incomplete at best, with less than 50% of the research funding recipients being of the highest possible research ratings. The first policy inference is therefore that under efficiency criteria research grants should be tied to selectivity at the point of award.

But there is no reason why selectivity should be restricted to the point of award. Again, if the objective is to maximize research output from the allocation of necessarily limited and scarce resources, monitoring ongoing performance of researchers after the award, evaluating performance, and making funding conditional on performance significantly above that of comparable peer groups who did not receive the funding support, would serve as an incentive to maximize the return from the investment from the public funding agency. If a small group of researchers are to be singled out through disproportionate funding support, it is entirely appropriate that the level of support be justified in terms of exceptional productivity levels. Continued funding should be strictly tied to performance.

That the impact of big funding for research has a differential success across disciplines (we found strong impacts strictly speaking only in the Chemical and Medical sciences, and to a lesser degree in the Biological and Physical sciences; none in the Business and Economic, Engineering and Social sciences) suggests that policy might also fruitfully consider stricter allocative criteria across disciplines with proven rates of return on investment. However, provided that selectivity in the funding process is implemented, the disciplinary selectivity would be of secondary importance, since only successful research initiatives would receive continued funding.

There is a final policy consideration, which posits a different funding model altogether. The research findings on private sector resourcing of innovation suggest that the optimal starting point is broad-based funding of innovation initiatives, given the difficulty of selecting winners a priori, coupled to selection of top performing projects on the basis of objective performance leading to additional funding support. Given that there is evidence that in our sample at least some of the non-funded researchers performed comparably to those that received the strong funding support, the implication is that for public funding contexts the inference might well be symmetrical. Employ broad-based funding for as large a group of researchers who meet minimum quality standards at the outset of a funding initiative; then increase funding to those researchers who demonstrate objective performance improvements in terms of both quantity and quality of research after the initial funding awards; increasingly concentrate funding on the most promising research initiatives over time. As a result, both adverse selection and moral hazard are reduced, and the most productive research initiatives are rewarded.

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