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Please cite the final published version:

Bloch, C. W., & Sørensen, M. P. (2015). The size of research funding: Trends and implications. *Science and Public Policy*, 42 (1), 30-43. DOI: [10.1093/scipol/scu019](https://doi.org/10.1093/scipol/scu019)

Publication metadata

Title:	<i>The size of research funding: Trends and implications.</i>
Author(s):	<i>Carter Bloch and Mads P. Sørensen</i>
Journal:	<i>Science and Public Policy</i>
DOI/Link:	10.1093/scipol/scu019
Document version:	Accepted manuscript (post-print)

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Postprint version of article finally published as:

Bloch, C. W., & Sørensen, M. P. (2015). *The size of research funding: Trends and implications*. *Science and Public Policy*, 42 (1), 30-43. DOI: [10.1093/scipol/scu019](https://doi.org/10.1093/scipol/scu019)

The size of research funding – trends and implications

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Submitted to *Science and Public Policy*, 22 October 2013

Revised version submitted 9 January 2014

Abstract

This paper examines the role of grant size in research funding. There is an increasing focus in a number of countries on larger grant forms, such as centers of excellence, and in some cases also increases in the size of individual project grants. Among the rationales for this are economies of scale in research and redistribution of resources towards top researchers in order to increase scientific productivity and pathbreaking research. However, there may potentially also be negative impacts of increasing funding size, and there is limited empirical evidence on the actual consequences of increases in size. In this paper we critically examine the rationales behind increases in funding size and the empirical evidence on the impacts of size in research funding. Our goal here is to present a more coherent view of the potential impacts of these initiatives, both positive and negative, that can help inform funding design.

Keywords: grant size; research funding; research performance; centers of excellence; impacts.

Acknowledgement

Financial support from Aarhus University's Senior Management Strategic Funds for the project 'Contextualizing and Measuring Research Performance' (CoRe) is gratefully acknowledged. The authors would also like to thank Kaare Aagaard, Niels Mejlgaard and two anonymous reviewers for valuable comments to an earlier draft of this article.

Introduction

Drawing on the ideas behind the knowledge-based economy that spread from the OECD in the mid-1990s to developed as well as many emerging economies, there has been a strong focus on science and innovation as the main tools for creating prosperity and wealth. Correspondingly, in most countries there have been large increases in R&D investments both in the business sector and in academia. For example, among OECD countries over the last 25 years, R&D as a percentage of GDP has increased from an average of 1.6% in 1986 to 2.2% in 2011. R&D within higher education has almost doubled as a share of GDP in the same period, from 0.31% to 0.57%¹.

With these increases in investments has also come an increased policy focus on how to enhance the impact of research both on scientific performance and ultimately on societal and economic well-being. This includes funding mechanisms for universities and also the design of funding programs to individual researchers and groups via various forms of grants. While there have been a variety of different initiatives implemented across countries, there have been a number of examples of increasing use of large center grants to promote research, along with increases in the size of other funding forms, such as project grants. At the same time, total funding has increased markedly in most countries, often with increases in all funding forms, measuring in absolute terms. However, the number of researchers has also increased greatly, so that eventual increases in the relative share of funding devoted to larger grants may have distributive consequences, resulting in a greater concentration of resources among a smaller number of researchers.

The case of Denmark, which is described in greater detail below, provides an illustrative example. Over the last two decades, there has been both a shift in funding towards centers and large cooperative grants along with large increases in the size of individual project grants, resulting in a greater concentration of resources among a smaller share of researchers. While a number of other examples can be found in other countries, it is difficult to fully assess how widespread this trend is based on available data and statistics. While these examples of concentrations in funding provide an important motivation to better understand the implications of grant size for the impacts of research funding, the issue is also of central relevance for the design of funding mechanisms in general. The role of research group size has been the subject of a number of studies (von Tunzelmann et al. 2003), however the role of size in funding grants has been much less studied. There are a number of additional issues related to funding size, such as broader institutional impacts, allocation mechanisms for funding, and distributional consequences.

This paper seeks to assess the role of size in research funding, both recent trends and the potential implications of increases in grant size. In particular, we will address three questions: what are the objectives or rationales behind a concentration of funds and what are the potential consequences? Does policy take into account the full range of potential impacts of this concentration, both positive and negative? What empirical evidence exists on the role of grant size for the impacts of research funding?

¹ Own calculations based on data from the OECD Main Science and Technology Indicators database. Calculations are based on OECD countries that were members as of 1986. If all OECD member countries as of 2011 are included, the average shares for total R&D and higher education R&D are 2.0% and 0.48%, respectively.

The main rationale behind an increased concentration of funding appears in most cases to be that there are economies of scale in research funding and that a concentration of funding among top researchers can improve overall scientific performance. Hence, the increase in funding size is often closely connected to the pursuit of scientific excellence.

Our examination highlights a need for more careful analysis of the impacts of these measures, both towards gaining a full understanding of the potential impacts and in obtaining quantitative evidence on actual outcomes. How should we expect these funding programs to work? What are the potential effects, both direct and indirect? How does the design of programs influence their impacts?

This paper will first examine international trends in research funding, which provide examples of both an increase in the average size of standard research project grants and in increased allocation of funds to centers and other larger forms of funding. Our focus in this paper is on funding grants to individuals or groups as opposed to the allocation of block grants among universities. The increased use of performance based funding for universities² is related to developments in research grants, particularly through an increased concentration of resources among a select set of universities or departments, but there are also differences that complicate coverage of both types of research funding in a single paper. For example the allocation of funding to universities may also reflect a public management perspective to funding changes for universities and funding allocation to universities is often made on an ex post assessment as opposed to ex ante assessments of project proposals. Furthermore, funding to universities is more general, going to departments or universities as a whole, whereas grants are more clearly linked to individual researchers or groups.

Thereafter, we explore the main rationales behind increases in funding size. We identify three interrelated objectives behind increases in funding size: the creation of a critical mass of research competences; linking research to social and economic impacts; and concentrating resources towards excellence. While we make these distinctions, to a certain degree all objectives can be linked to the pursuit of excellence. However, it is not always clear what is meant by excellence, and how it is defined may have implications for funding and design.

Next, we critically examine these rationales, identifying potential positive and negative consequences of increases in funding size and reviewing empirical evidence on the role or impacts of size in research funding. Our goal here is to present a more coherent view of the potential impacts of these initiatives, both positive and negative, that can provide a broader understanding of how funding can reach stated objectives or what conditions should be fulfilled. The amount of empirical work in this area is somewhat limited, in particular in relation to the amount of resources that have been allocated to centers and other larger grants in recent years. Nevertheless, these results are instructive in giving an initial indication of potential impacts. The paper concludes by highlighting the implications of the analysis for research funding policy and discussing the key questions that should be addressed in future empirical work.

Towards larger grants and a concentration of research funding - international examples

Research funding systems have undergone major change in the last decades. Worldwide there has been a shift away from a national trust based system of funding towards a more performance-based

² See e.g. OECD (2010) and Sörlin (2007).

system. Within the new performance based system Sörlin (2007, p. 426) points to four new trends. First, research funding is becoming more and more project based, with a growing tendency towards supporting centers and consortia instead of individual projects. Second, new tax laws enable citizens and businesses in many countries to make tax deductible contributions towards university research. Third, a growing number of actors within industry, non-profit organizations, foundations etc. have shown a growing interest in university research. Lastly, as a consequence of the last three, Sörlin points to the rise of academic superstars and a resulting 'winner takes all' trend in funding.

One potential implication of these trends is a concentration of funding in larger project grants and centers, partly at the expense of individual and smaller grants. The development of the research funding system in Denmark provides an illustrative example. Over the last three decades the Danish public research funding system has undergone significant change (Aagaard 2011). Public research funding traditionally went directly to the universities and was a function of the number of students enrolled at the university. This system was partly altered in 1968 when national councils of research were established. However, the new research councils played a minimal role up until the 1980s when new, large programs for strategic research were established. These programs sought to support large projects with a critical mass and to combine research funding with demands for outcomes that could benefit society as a whole.

This tendency towards large, targeted research initiatives continued in 1991 when The Danish National Research Foundation was established to support large centers and thereby supplement the discipline based national councils of research. This was followed by the establishment of the Danish Council for Strategic Research in 2004 and finally in 2005 with the Danish National Advanced Technology foundation. Average grant size is quite large for all three of these new institutions. In 2011, average grant size was around 53 million DKK (9 million USD) for the Danish National Research Foundation, 17 million DKK (3 million USD) for the Danish Council for Strategic Research and 10 million DKK (1.7 million USD) for the Danish National Advanced Technology foundation (FI 2012, p. 43).

These changes have led to a situation where in 2010 44% of public financed funding in Denmark was performance based and 56 % of the research funding was allocated directly through block grants to research institutions. The goal is to reach a fifty-fifty distribution between performance based and basic funding (Aagaard and Ravn 2012, p. 174). Both this shift towards competitive funding in general and the emergence of these three new funding institutions in particular have led to an increased concentration of resources and larger grant size. These developments have been accompanied by fairly significant increases in grant size from the original Danish Council for Independent Research.

In 2001, 65% of all project grants from the Council for Independent Research were below 1 million DKK (app. 170,000 USD), while 19% were higher than 1.5 million DKK (app. 260,000 USD) (Bloch et al. 2011). In 2009, the share of small grants for less than 1 million DKK had dropped to 16%, while the share of project grants for more than 1.5 million DKK had increased to 70%. One consequence of this development has been that the success rate has dropped from 28% in 2001 to 12% in 2009.

The same pattern can be found in the Norwegian Research Council. Over the period from 2005 to 2010, average grant size has increased from 3.0 million NOK (app. 500,000 USD) to 5.6 million NOK (app. 930,000 USD), while success rates fell from 19% to 11% (Langfeldt et al. 2012).

In the USA there has been a 41% increase (in current dollars) from 2000 to 2005 in the annual mean award size provided by the National Science Foundation, from \$101,200 to \$142,600 per year (NSF 2007, pp. 4-5). Although the annual mean award size decreased to \$134,500 in 2006 this is still a fairly sizable increase, which has been motivated by the wish to "... increase productivity by minimizing the time PIs (principle investigators) would spend writing multiple proposals and managing administrative tasks, providing increased stability for supporting graduate students, and facilitating collaborations to address particularly complex issues." (NSF 2007, p. 5)

In the same period of time, the number of research proposals submitted to the NSF increased by almost 50% from approximately 21,000 to 31,000 proposals per year. So, even though the NSF budget rose by nearly 44% from \$3,923.4 million in 2000 to \$5,645.8 million in 2006, it was not enough to hinder a decrease in the success rate for research proposals. The rate of success fell from 30% in 2000 to 21% in 2006 (NSF 2007, pp. 4-6).

Increases in project grant size can also be found in the European Union's funding programs. However, the EU Framework Program presents an example where increases in project size do not necessarily reflect a goal of concentrating funds in a fewer number of hands. Drawing on the 2000 communication "Towards a European Research Area" (European Commission 2000), EU research funding was reorganized into larger projects as part of the sixth framework program (FP6, 2002-2006). The objective was to establish a more coherent European Research Area (ERA) through the development of research collaborations. Hence, European programs were streamlined to focus on a limited number of priorities and measures in order to 'coordinate, structure and integrate' European research. The new instruments such as Integrated Projects (IP) and Networks of Excellence (NoE) were large, multipartner projects with participants from a number of countries. Hence, while funds were concentrated in larger projects, they were typically also distributed across a wide range of countries.

In Australia, funding by the Australian Research Council (ARC) towards independent research projects has not increased in size in recent years, though new and larger instruments have been introduced. The average size of project grants for independent research (Discovery Projects) has increased by 23% in nominal terms over the period 2001-2011³, which is less than the rate of inflation for that period. Funding grants for centres of excellence, which were offered in 2004 and 2010, have remained relatively stable both as share of total funding from the ARC and in average size. However, a new type of individual grant, Future Fellowships, was introduced in 2008 to attract and maintain top researchers in Australia. Average size for these new grants is around double the size of that for Discovery Project grants and accounted for around 15% of total ARC grant funding in 2011.

In Japan, the Japan Society for the Promotion of Science (JSPS) awards a number of research grants varying in size, including larger grant types (Scientific Research (S), (A) and (B)) and smaller grants (Scientific Research (C) and Exploratory Research). Based at least on the period 2005 to 2011, there has generally not been an increase in average size among JSPS grants. The average size of smaller project grants has actually fallen from 2005 to 2011⁴, though there has been a moderate shift in

³ Source: NCGP Trends, June 2013 (www.arc.gov.au).

⁴ From 1.8 to 1.6 million yen. Source: www.jsps.go.jp/english/e-grants/award_trends.html.

resources devoted to smaller projects, where the share of total funding to smaller projects among the above mentioned grant types has fallen from 46% in 2005 to 35% in 2011.

As noted above, center grants have been in increasing focus in a number of countries. If we take the Nordic countries as an example, relatively comprehensive CoE-schemes have been introduced in Denmark, Finland, Norway, and Sweden within the last 20 years. CoEs in these countries are today supported by €0.5 to €1.4 million (\$0.65 to \$1.8 million) per year in public funding plus additional funding from other sources (Aksnes et al. 2012, pp. 7-8). The total number of CoEs supported in the four countries are 88 in Sweden, 75 in Finland, 71 in Denmark and 53 in Norway. CoE schemes make up between 2.5 and 6.1% of total public sector research expenditures in the four countries.

These excellence initiatives have been launched in a number of countries, in some cases taking up a fairly significant share of the collected public research funds. This is e.g. the case in Germany where an Excellence Initiative with a budget of €1.9 billion (\$2.5 billion) was launched in 2005 by the German Research Foundation, DFG, and the German Council of Science and Humanities, WR. The initiative was sponsored by the Federal and State Governments together, and according to the webpage of the Excellence Initiative the overall aim of the initiative was "... to strengthen cutting-edge research and to make German science and research more visible in the scientific community." (DFG 2013) The initiative was launched along three funding lines: Graduate schools, Clusters of Excellence and Institutional Strategies.

From 2008 to 2010 17.3% of the total funding of the DFG was allocated to the Excellence initiative, 10.2% or €747.5 million (\$977 million) was spent on Clusters of Excellence. The introduction of this new funding scheme in Germany has on the one hand contributed to a substantial increase in the research budget of the DFG – from €3,548 million (\$4,639 million) in the period 1999-2001 to €7,308 million (\$9,560 million) in 2008-2010. (DFG 2003, p. 27; DFG 2012, p. 37) On the other hand, it has also meant an increase in the relative share of funding devoted to larger grant forms. The share of individual research grants has thus gone down from 39.9% in the period 1999-2001 to 28.7% in the period 2008 to 2010 (DFG 2003, p. 27; DFG 2012, p. 37).

There has also been an increase in funding of research centers in the US. Many of these fall under the heading of "multipurpose, multi-discipline university research centers" or MMURCs (Bozeman and Boardman, 2003). They typically cross traditional boundaries of academic university departments and are given roles in enhancing university-industry collaboration. In addition to promoting interdisciplinary research and commercial impacts, the centers also seek to make science and engineering education more 'hands on' in relation to applied science and technology R&D (Bozeman and Boardman, 2003). The NSF supports a variety of center-based programs, such as Engineering Research Centers (ERC), Science and Technology Centers (STC), Materials Research Science and Engineering Centers (MRSEC) and Nanoscale Science and Engineering Centers (NSEC). Center-based programs however comprise a relatively small share of the overall NSF budget, between 4-5 percent in 2007⁵ (MRSEC Impact Assessment Committee et al. 2007).

⁵ The corresponding share for the National Institutes of Health (NIH) was around 9 percent of the overall budget in 2007 (MRSEC Impact Assessment Committee et al. 2007).

Examining the potential impacts of a concentration of research funding

These examples are clearly not sufficient to give a full overview of international trends in research funding size, though they do provide some indications. The picture based on these examples is quite mixed. While there are a number of examples of increases in the size of standard research project grants, this is not the case in all countries. On the other hand, there are a number of examples of increased emphasis on other, typically much larger grant forms, such as centres or large individual grants. This section explores in more detail the rationales that can underlie increases in funding size and potential implications.

We examine here objectives and impacts grouped according to three dimensions: the creation of critical mass; linking research to social and economic impacts; and concentrating resources towards excellence. While we view it as helpful to identify these three types of objectives individually, it is clear that they are very interrelated. For example, economic and societal objectives will typically rely on the achievement of scientific progress and its applications, while scientific goals are motivated by the economic and societal benefits that they may contribute with. And while economic and societal goals may differ, much research will contribute to both aims.

Critical mass

A central argument behind the concentration of resources in centers or larger projects is that it creates a critical mass that is needed to promote scientific excellence. The basic idea here is that, given the nature of research, there are economies of scale and agglomeration effects, implying that scientific productivity is increasing in size. There are a number of factors that lie behind this. One is the nature of knowledge and the importance of close interaction (David and Foray 1995; Herstad et al. 2010; Hagedoorn 1993). The concentration of research funds among larger projects and centers is seen as an important vehicle in promoting interaction and mutual learning. Lee and Bozeman (2005) discuss the related idea that collaboration increases research productivity. Arguments that collaboration enhances productivity are based on knowledge transfer and the tacit nature of knowledge, and a number of studies have found evidence of a positive relation between collaboration and productivity (such as Price and Beaver 1966, Zuckerman 1967, Pravdic and Oluic-Vukovic 1986, Katz and Martin 1997, and Oliver 2004) and impact in terms of citations (Narin et al. 1991, Diamond 1985). However, Lee and Bozeman (2005) note that this positive relation cannot be taken as given, as there may be costs of collaboration that reduce productivity, such as the administration and organization of group work, group dynamics, and communication and training costs. Also related to this is the idea that the synergies of top-researchers working together have a positive impact on research performance (Zucker et al. 2002).

As a number of authors make clear, the idea of critical mass varies greatly according to field. Research groups can be viewed as complex systems that depend on a variety of forms of interaction and knowledge exchange (Kenna and Berche 2011). Generally, applied fields tend to benefit more from larger groups than theoretical fields. This also implies that critical mass levels can be expected to be higher within the natural, physical and medical sciences, compared to social sciences and the humanities. An additional element here is the need for equipment and infrastructure, where a certain size may be necessary to justify costly apparatus. On the other hand, some groups may be dependent on very costly facilities for which only a few examples are found internationally. An

example here is particle generators. In these cases, group size and own equipment may be less important than contacts and access to larger international facilities.

Critical mass is also viewed as generating a number of other positive impacts. For example, it pools resources for large research projects that would otherwise not be possible, and achieves economies of scale in terms of teaching, administration, and applications for additional funding. Larger grants create more visibility for research funding, which may help in communicating the benefits of research funding to the broader public. They may also act to attract top researchers from other areas.

Fairly extensive research has been conducted on the role of research group or university department size for research performance. The results vary greatly and offer little support to the existence of economies of scale. A general result for research groups appears to be that there exists a critical mass threshold of around 5-8 members in a research group, but with no conclusive evidence of economies of scale. Productivity increases linearly with size and at a certain point may decline (von Tunzelmann et al. 2003, Johnston 1994). It should though be added here that 'research group' is a very loosely defined concept in these types of studies. Most typically, article collaborations (either within an institution or also between institutions) are used as a proxy to delimit research groups and estimate their size. To a certain degree, these may in some cases resemble a network, where there is ongoing contact and occasional collaboration, but not necessarily the closer interaction that would typically be characterized by a group of researchers involved in a project grant.

Economic or social impacts

In some cases, the concentration of funding in centers or specific areas is explicitly linked to economic or social outcomes, with the rationale that strong research environments will help boost growth in their region (Power and Malmberg 2008). Global competition has also motivated the concentration of funding with the goal of achieving or sustaining a technological edge over other nations.

A theoretical basis can be found for this, both in early theories of knowledge and innovation such as mode 1 knowledge creation or the linear innovation model, which focus on the one way channel of academic research towards innovation, and in more recent theories that focus on the interaction between science and industry or society, such as Mode 2, the Triple Helix and regional innovation systems (Gibbons et al. 1994; Etzkowitz and Leydesdorff 2000; Cooke 2007). In sum, public research is both seen as a central driver of innovation and also obligated to take economic and societal needs into account.

A concentration of funding in areas deemed of key importance, either towards innovation and competitiveness or meeting societal challenges, can thus act to improve the public value of scientific research. There are a number of examples cited above of centers or other large research initiatives that are linked to strategic economic or social areas, such as those for Canada, Denmark, Finland and the US.

Canada was among the first countries to establish a program for supporting Centers of Excellence: Canada's Network of Centers of Excellence (NCE) established in 1989. A key feature of the centers supported in the initial phase of the program was the creation of new partnerships between science

and industry – also motivated by the hope that Canadian universities would do better in exploiting intellectual property rights (Fisher et al. 2001, p. 310). Around the same time, the NSF launched new center programs that focused on interdisciplinary research (Bozeman and Boardman, 2003). While the programs supported independent research (including block funding that allowed flexibility to pursue new ideas), a key element in these programs was that centers should engage in outreach activities to collaborate with industry and the commercialization of results (MRSEC Impact Assessment Committee et al. 2007, Rogers et al. 2012)

In Denmark, the recently established Strategic Research Council supports large projects and centers within pre-specified areas deemed to be of economic or societal importance. In Finland, large Strategic Centers of Science, Technology and Innovation (SHOKs) were introduced in 2006 as a new innovation policy instrument (Aksnes et al. 2012). SHOKs are specifically focused on the economic impact of research within key sectors for the Finnish economy, such as ICT, metals and forest industries.

These centers may contribute to international competitiveness by better producing state of the art research, strengthening research competences and attracting new talent and businesses. The increased internationalization element is explicit in some programs, such as the Danish fundamental research centers which have a key goal of increasing international recognition of Danish research. This focus on internationalization and international visibility can also be found in Norwegian, Finnish and Swedish centers of excellence (Aksnes et al. 2012).

Excellence

The third dimension is excellence. Whereas the main rationale for concentrations of funding has previously been centered around critical mass and achieving economies of scale (Johnston 1994), focus is now increasingly placed on concentrating funding among top researchers, both to increase production of high quality research and in an attempt to enhance conditions for the generation of path-breaking research results.

The main rationale here is that the best researchers are the most productive, with the greatest potential to produce world class research and path-breaking results (Hicks and Katz 2011). Hence, the most effective allocation of funding is to provide the very best with optimal conditions for conducting research with large amounts of funding. Ample funding in effect seeks to remove any hindrances to their research, reducing the need to continuously seek funding and providing greater opportunities to engage in collaboration with other top international researchers, and to conduct projects that otherwise might not be possible (European Commission 2005). An added argument here in particular for national programs among EU countries, is that large grants will help strengthen researchers in securing additional international funding, for example from the European Research Council.

Scientific productivity is characterized by extreme inequality among researchers (Stephan 1996). Hicks and Katz (2011) show for example that scientific performance follows a power law distribution. Though, this is not a new phenomenon, and inequality is not solely based on ability and motivation, but also on “cumulative advantage” and the ability to leverage past successes (Stephan 1996). Merton called this the Matthew Effect: “the accruing of greater increments of recognition for particular scientific contributions to scientists of considerable repute and the withholding of such

recognition from scientists who have not yet made their mark.” (Merton 1968, p. 58). Active efforts to concentrate funding grants in effect serves to further amplify this “cumulative advantage” in terms of access to funding.

All the center initiatives described above include the goal of promoting scientific excellence, though there may be different meanings of excellence, in particular whether focus is on breakthrough research or on high level research in general. Excellence concepts that focus on breakthrough research are the European research council’s “frontier research” (European Commission 2005) or NSF’s “transformative research” (NSB 2007). Centers of excellence initiatives in Norway, Denmark and Sweden appear to focus first on high quality research, though with the intention that this may also lead to breakthrough research results. The goal of the German initiative is “cutting edge research”. The Finnish CoE program seeks to foster creative and efficient research environments in order to reach top international levels and scientific breakthroughs.

A critical review of the impacts of grant size

While the objectives for most funding programs are fairly clear, it is often less clear how they will reach stated objectives or what conditions need to be fulfilled. Having examined the rationales behind increases in grant size, this section looks more critically at potential impacts of the concentration of research funding in larger grants, and at existing evidence concerning the impact of grant size on research performance. What is important to consider is that there are a number of potential negative consequences of increased grant size. Of particular interest here are negative externalities that go beyond project participants, such as impacts on equity and potentially on the overall development of research fields. We examine potential negative impacts here, drawing also on existing empirical evidence.

The first concerns potential administrative or organizational inefficiencies. Large projects or centers may actually increase bureaucracy or administrative burdens, adding an additional organizational level that must be managed for large projects as opposed to small groups. Centers will typically also involve turning the best researchers into managers (Lowe 1991); it is not fully clear that this is beneficial for productivity and the development of high quality research results. Furthermore, while large centers may provide access to facilities that would not have been possible at a smaller scale, there may also be a number of cases where access to facilities is actually reduced as they have to be shared among a larger group of researchers (Etzkowitz 1992).

Administrative burdens are not only in terms of management. Centers effectively create an additional role for many researchers, who must balance their role and obligations to the academic department with those to the center. This may result in ‘role strain’, competing demands that can adversely affect both the individual welfare of researchers and their productivity (Boardman and Bozeman 2007). While impacts vary across individuals and depend greatly on the relation between the center and the university department, potential impacts are work overload, incompatible role expectations and lower valuation of (interdisciplinary) center work by department heads.

Large projects may also affect the nature of the research, also when taking into account the application and evaluation processes (Harrison 2009). A concentration of funding within individual research areas may result in a lack of diversity in research given the smaller number of projects. There may also be a concern both from applicants and evaluators that large projects are too big to

fail; that applicants will tend to focus to a greater extent on research with more certain outcomes, and that evaluators will be more conservative when assessing large grant applications (National Science Board 2007). It has also been argued that large centers may be self-perpetuating both in terms of the direction of research work and in center participants, and thus act to hinder the flexibility of a research area to adjust to change (Lowe 1991).

There are also a number of potential risks associated with initiatives that target strategic economic areas. First, these initiatives have an element of being top-down in their planning. This may risk an overemphasis on short term applied research, and that funding agencies do not succeed in choosing the areas with greatest potential. An additional aspect that may in particular be relevant for small countries is that these research initiatives will typically have a narrow disciplinary focus in order to excel within a specific area. This degree of specialization may thus come at the expense of advancement in a number of other areas..

Empirical evidence on the impact of project size for grants is fairly limited, though a larger number of analyses have been conducted concerning the size of research units or groups where, as noted earlier, groups are typically estimated based on publication collaborations. Von Tunzelmann et al. (2003) and Johnston (1994) review earlier work with similar conclusions⁶. There are a number of studies that find a size effect in terms of a critical mass threshold for groups of around 5 to 8 persons. Though again it should be noted that these concepts of research groups are much looser than that of a project team involved in a grant. Beyond this threshold little if any evidence has been found that there are economies of scale in research group size. An example here is the bibliometric analysis by Seglen and Aksnes (2000) of Norwegian microbiological research for the period 1992-1996, where the authors find no correlation between group size and scientific productivity. A more recent analysis of size and performance for UK research units does not find evidence of a relation between size and performance, either in terms productivity or citation impacts (University Alliance 2011).

Among the limited number of analyses that look specifically at the role of size for research grants, a recent example is a NIH analysis of the scientific productivity of researchers funded by grants from the NIH National Institute of General Medical Sciences (UNIGMS) for 2006 (Wadman 2010). The analysis found that the median number of publications was highest for medium sized grants, peaking at around \$750,000. However, in terms of publications per dollar spent, the smallest grants at around \$250,000 had the highest productivity. The analysis, however, does not look into other performance measures such as citation impacts.

Two other studies, the first for the NSF and the second for the Danish Council for Independent Research, look in more detail at the role of size for project grants. The NSF commissioned a study on precisely this topic, the efficiency of grant size and duration, though the study relies solely on a survey of principle investigators (PI) and did not measure impact on scientific productivity (Ballou et al. 2002). The study covered all PIs for the fiscal year 2001 (in all 4,989). Grant sizes were small to medium sized, with roughly a third each under \$162,000, between \$162,000-330,000, and over \$330,000. Respondents noted limitations due to both amount and length, citing time spent writing proposals and lack of continuity as key reasons why grant size and duration should be increased. However, taking funding constraints into consideration, there is a tradeoff between size and success

⁶ See also Bonaccorsi and Daraio (2005).

rates; i.e. the larger the grants, the lesser number of researchers that can receive them. If forced to choose between increasing the amount only, the duration only or the number of awards, 40 percent of PIs chose amounts, 24 percent length and the remaining 36 percent the number of awards.

A recent study of grants from the Danish Council for Independent Research covered project grants of a similar size as those for NSF, focusing on a broad range of impacts, both qualitative and quantitative (Bloch et al. 2011). The study covered project grants for the period 2001-2008, examining impacts for PIs and for project groups as a whole, through a survey, interviews and analysis of bibliometric and career data. Bibliometric analysis on a matched sample of PIs and rejected applicants indicated that PIs for larger projects (over \$160,000) had both a higher number of publications and citation rates before and after the grant period, and also a larger increase in productivity over the period. However, while performance of PIs appears to increase with grant size, this does not appear to be the case for the project as a whole. Based on survey data on publications for projects as a whole, the average number of peer-reviewed articles per \$100,000 granted was found to be substantially higher for small projects (under \$160,000), more than double that for larger projects in 4 out of 5 main fields. Differences were statistically significant at a 5% level for the sample as a whole and for all individual fields (Medical Sciences, Physical Sciences, Social Sciences and Humanities) with the exception of Natural Sciences⁷. Though, it should also be noted that it is likely more difficult for PIs to accurately account for all publications for larger projects, which may lead to underestimation⁸.

One qualitative aspect worth highlighting is that virtually all interviewees in the Danish analysis stressed the importance for their subsequent careers, and hence also the quality of their research, of simply having been awarded a project grant of any size from the Danish council (Degn et al. 2012). Small projects were often cited by interviewees as 'kick-starting' research careers, leading to larger projects and important research results. On the other hand, some interviewees complained that grants that were too small limited what they were able to do, and the need for funding from other sources could result in a loss of continuity in research work. Larger projects also held a potential for 'second generation effects' for the young researchers involved in the project. And, according to both survey and interview results, small and large projects were given equal importance in establishing collaborative relationships with other researchers. Finally, both small and large projects were found to increase the probability of career progression.

Rigby (2009) compares the scientific performance of the two main funding instruments of the Austrian Science Fund, project grants and collaborative networks. The aim of his analysis is to examine whether the increased focus on collaboration in network funding can be justified through higher productivity and scientific excellence. He examines all papers in 2001 that received funding from the Austrian Science Fund and citations of these papers from 2001 to 2005. He does not find any significant difference in scientific quality (measured in citation counts) for the two types of instruments.

⁷ The average number of publications within Natural Sciences was higher for smaller projects, but the difference between smaller and larger projects was not significant.

⁸ On the other hand, potential bias is not likely to be large given that the average number of researchers per project is around 4.

As we have noted above, the EU Framework Programme is somewhat different in relation to increased project size, since there is also a distributional aspect to them. Studies have though been conducted on the relation of size to performance. Surveys of FP6 participants reflected that the far majority thought that projects were too large, and that excess size actually did not help in creating a critical mass, but instead led to fragmentation (Marimon Report 2004; EPEC 2009). Though, these projects are extremely large. Participants felt that Integrated Projects should be under 20 participants while for Networks of Excellence the perceived maximum was 48 participants. Breschi and Malerba (2011) analyze the effect of size on scientific production for FP6 projects within ICT. They find a U-inverted relationship between the scale of projects (in terms of number participants) and scientific output. However, they find that the largest instruments (NoE) were the most productive per participant.

The increased focus on excellence in recent initiatives raises some additional issues concerning the impacts of increased concentration of funds. One issue is whether the provision of ample funding is the most efficient allocation of funding resources. One can surely find examples of top researchers that are able to administer substantial amounts of funding⁹, but it is less certain whether this is the case overall for excellence programs. Heinze et al. (2009) identifies examples where large increases in funding and group size (as a result of research accomplishments) can have a detrimental impact on the group's research.

Heinze (2008) identifies a number of funding programs that target creative research. The nine programs he examines are all either individual or project grants. Some of them have long durations of five years, while others are around three years in length. Grant size varies, though most of these programs award small to medium size grants.

An additional question is whether the program seeks to promote excellence in terms of research that makes incremental improvements in the state of the art or to support truly pathbreaking (and high-risk) work. Concerns have been made that large grants are not necessarily the best vehicle to promote high risk research, and in effect may contribute to risk aversion. The U.S. National Science Board has for example stated that "transformative research frequently does not fit comfortably within the scope of project-focused, innovative, step-by-step research or even major centers, nor does it tend to fare well wherever a review system is dominated by experts highly invested in current paradigms or during times of especially limited budgets that promote aversion to risk" (NSB 2007, p. 4). This is a point that deserves emphasis, as many excellence programs appear to aim at least in part towards improving the chances of scientific breakthroughs.

Dietz and Rogers (2012) examine the interpretation of transformative or pathbreaking research and implications for funding design. They use four characterizations. The first is a focus on high risk which likens funding of path breaking research to stock portfolio management. Individual projects may have very high risk, but one should look at the overall risk and return of a group of projects. The second is evolutionary, that maintaining diversity is essential for the dynamics and development of research. The third sees pathbreaking research as a process of pop culture and hot events, looking not only at the discovery itself but also the process of establishing a new paradigm. The last concerns exploration of the unknown, in essence answering the unanswered research questions of today.

⁹ See for example Hand (2008) for an example of a top biology researcher with 11 NIH grants at the same time.

Heinze et al. (2009) explores what types of institutional and organizational conditions are considered most conducive to creative research. Their analysis draws on 20 cases of breakthrough research achievements within nanotechnology and human genetics. In terms of research processes, flexibility, adaptability and autonomy are seen as important to facilitate the pursuit of creativity. In line with most other work, path breaking results are typically generated by small groups, where close interaction and communication is stressed as essential. Access to stable and flexible funding was also highlighted, in particular for researchers that do not have institutional core funding (Laudel 2006, Heinze 2008).

Sandström et al. (2010) conduct a bibliometric analysis for a subsample of the excellence centers in Sweden, examining the number of publications and (field normalized) citations for the entire group of senior researchers in each center. In the far majority of cases, they find performance (both in terms of publications and citations) after the establishment of the center to be lower than before, and also lower than for the group of rejected applicants. They also note that center grants typically awarded a large amount of funding per person, with the purpose of freeing participants from seeking other funding during the center grant period. However, Sandström et al. (2010) find that most center leaders and participants continue to apply for and obtain funding from other sources.

In contrast to Sandström et al. (2010), Ida and Fukuzawa (2013) generally find a positive impact of centers of excellence on scientific productivity. They examine productivity for the Japanese 21st Century Centers of Excellence, comparing publication and citation counts of center participants with a control group across eight fields. In comparing productivity before and after the grant (difference in difference) for the two groups, they found significant increases in publication counts within four out of eight fields (life sciences, humanities, medical sciences and mechanical engineering) and positive and significant increases in citation counts within three out of eight fields (life sciences, information sciences and medical sciences). In contrast, a significant negative result was found for citation counts within mathematics and physics.

Rogers et al. (2012) examine the impacts of NSF funded NSEC centers. They find in general that centers play an important role in creating critical mass and networks through collaboration. They argue that NSECs have been crucial in coordinating and facilitating collaboration, both among academic researchers and with industry. In terms of publication and citation results, they find that centers perform much better than the field as a whole. For example, median numbers of citations are typically two to four times higher for NSEC papers compared to all papers within the field. However, it is difficult to conclude from this result what impact the centers themselves have had, given in particular that center participants are likely among the top researchers in their field (and thus likely would have performed better than field median values regardless). An analysis of publications and citations for the NSF funded MRSECs arrives at a similar conclusion; that the centers produce top research, but the analysis was unable to isolate effects that were due to centers, or to assess the value for money in terms of publication performance (which is only one of many goals for the centers).

An important dimension to examine when considering the merits of large research grants is potential impacts on equity. A focus on excellence can be seen in terms of its consequences for equity in terms of distribution of resources across regions, universities and other dimensions such as gender. In particular, gender imbalances in research have received increasing attention, prompting

the examination of potential sources of gender bias in peer review and other forms of scientific assessment (Addis 2010; European Commission 2008). Given that gender imbalances are greatest for the highest academic positions, such as professorships, concerns can be raised that an increased focus on large research initiatives such as centers will exacerbate existing gender inequalities (Sandström et al. 2010; Aksnes et al. 2012).

Sandström et al. (2010) analyzes the Swedish initiatives, Centers of Excellence and Strong Research Environments, examining both impacts on gender balance and on scientific productivity. Sandström et al. (2010) shows that these excellence initiatives have had a highly damaging impact on the gender balance in research for Sweden, with a very low share of female center leaders, in addition to a low share of women among participating researchers. As Aksnes et al. (2012) shows, this was the case for all four Nordic countries examined in their study (Denmark, Finland, Norway and Sweden). Shares of female center leaders range from only 7% in Denmark to 19% in Finland. In comparison, shares of female professors were between 6 and 12 percentage points higher in the same countries in 2010. Also in Germany the introduction of the Excellence initiatives seems to pose potential problems for gender balance. In 2010 18.1% of the individual grants of the German Research Foundation were given to women but only 13.3% of the Excellence initiatives were led by a woman (DFG 2012, p. 41).

An additional issue concerns the merits of excellence initiatives that distribute a large amount of funds based on an ex post assessment of performance. Hicks and Katz (2011), for example, argue that funding should take account of the fact that a relatively small number of researchers typically produce a disproportionately high amount of research and concentrate funding based on past performance. However, many of the potential top performers of the future may not have been top performers in the past. Rewarding past performers may disadvantage researchers with lesser track records, and limit the likelihood that promising projects from this group receive support. In addition, many earlier top performers may have already reached the peak of their career and may not be able to match previous results in the future. This line of argument suggests that funding should seek to gauge the potential of further research and may likely seek to spread funding more widely.

Table 1 summarizes potential positive and negative effects of concentrating research funding in larger research grants.

Table 1. Potential positive and negative impacts of enlarging research grants

Positive impacts	Negative impacts
The synergies of working together are assumed to lead either to greater production or to increase the likelihood of pathbreaking research.	Administrative burdens can be large for centers or large projects, resulting in a lower share of funding actually going to research activity. Centers can create role strain due to competing demands from centers and university departments.
Large grants or centers facilitate larger projects that otherwise are not possible	Large grants or centers are under greater pressure to succeed or to deliver as promised. This may have an adverse effect on risk taking, actually reducing the chances of producing breakthrough research.
Centers facilitate interdisciplinary research and training that may not be possible in traditional university departments.	
Participants are typically better positioned to successfully obtain additional funding from other sources (e.g. the European Research Council). (Matthew effect)	The same researchers that obtain funding for large projects or centers may have a greater tendency to win other national funding, leading to a further concentration of resources among the few. (Matthew effect)
The evaluation and award process is typically less costly (in relative terms) for large projects or centers.	Proposals for centers are less detailed and less scrutinized (in relative terms) than smaller projects. There is thus less quality control of large proposals and the application process itself may have a lesser effect on proposed research ambitions.
Centers enhance the ability to attract top researchers from other locations. Their participation adds to the critical mass.	
Centers contribute to international competitiveness by better producing state of the art research, strengthening competences and attracting new talent and businesses.	Large centers may act to reduce heterogeneity of research within the field. This can potentially reduce the chances for the development of truly transformative research.
Centers either directly or indirectly promote industry-science collaboration, thereby strengthening the impact of research on innovation and international competitiveness.	
By building strong research centers within areas deemed of strategic economic importance, they help both to direct research towards economic goals and to enhance the quality of research within these areas.	Top down allocation of resources may be inefficient as it moves research decision making away from researchers and market forces.
By giving top researchers ample funding, they are freed from exhausting resources to search for funding and have better conditions for conducting research. Centers allow block funding that enables pursuit of new ideas and higher risk projects.	Providing ‘ample funding’ may prove inefficient and actually result in a decline in scientific productivity compared to leaner and more competitive project funding. Increases in funding per project or researcher imply lower success rates
Greater allocation of funding to top researchers will increase returns to public funding, as they are the most productive.	There may be limits to how much top researchers can accomplish, either as researchers or research managers. There may be a size threshold beyond which the returns of public research investments are declining.
The concentration of funding in terms of research areas is needed for small countries to create international, top class research environments.	A high degree of specialization may deprive funding from other (important) subfields.
	Center funding will tend to go to the most established and recognized researchers (at the expense of less experienced talents), who may have already peaked in terms of research performance.
	A concentration of resources has an adverse effect on equity, which needs to be taken into account when considering overall impacts. This includes a worsening of already existing gender imbalances in research.

Conclusion

This paper has examined the role of size for research funding grants, both recent trends and the potential implications of increases in grant size. We recognize that no country has chosen to exclusively focus on large centers of excellence or any other single type of funding instrument. It also seems equally clear that an optimal funding approach should involve a mix of different instruments. Nonetheless, it is important to have a good understanding of the implications of increased allocation of funding into larger grants, particularly in light of the many examples provided above. The purpose of this paper has been to provide a coherent overview of the potential positive and negative impacts of increases in the size of research funding and to review existing evidence on the role of size. In this conclusion, we highlight the key implications of our analysis and suggest directions for future research to better understand the role of size in research funding.

First, it is crucial to gain more knowledge on the development of research grant sizes worldwide. Is there a genuine global trend towards concentrating research funding? The evidence put forward in this paper shows that while increases have not taken place in all countries, there are a number of indications of increases in funding size. However, our examination of trends in funding size was greatly hampered by a lack of accessible data across countries. Greater access to data and indicators on research funding, including the average size of different instruments, would be very helpful both in understanding international developments in research funding and in facilitating analysis of the impacts of these developments.

An important factor behind impacts of increases in funding size is the extent to which it has led to a concentration of research resources among a smaller share of researchers globally. Our impression from the data is that this is indeed the case; shifts in the share of funding towards larger grants are often accompanied by increases in overall funding, but the number of researchers has also increased greatly. However, it would be valuable to examine this more systematically, which would require data on the number of researchers and success rates as well as the growth in research funding in a larger number of countries.

Second, to the extent that larger research grants aim to promote excellence, it is important to be clear about what is meant by 'excellence' (high quality research in general or breakthroughs) and to what extent the funding program encourages risk taking and the pursuit of bold ideas. Furthermore, many funding programs lack clarity on the goals of their funding programs and how these goals will be met (mechanisms). The design of funding programs, including the peer review and awarding process, grant size and subsequent evaluation, may affect both the character of proposals submitted and the ambitions and risk taking behavior of applicants. Careful examination is needed to assess how grants promote excellence in research. For example, are small grants such as the NSF's Early-concept Grants for Exploratory Research (EAGER)¹⁰ best suited to support high-risk research, or can large grants, such as centers be designed in such a way that it allows research to take chances, and fail?

Third, when assessing the merits of large funding initiatives, it is important to take the adverse effects on equity into account. This is important both from a moral values standpoint, but also in terms of scientific performance. It remains to be shown that a greater concentration of funding

¹⁰ http://www.nsf.gov/pubs/policydocs/pappguide/nsf09_1/gpg_2.jsp

among a select group of top researchers improves scientific performance. There are a number of issues that deserve careful attention to ensure that a program that focuses on excellence is able to achieve its objective. For example, the results above point to the importance of small grants as seed money that can act as a catalyst to greater research productivity. A greater concentration of resources directs funds away from this channel, so that less equity can potentially risk leading to less excellence.

An additional factor is diversity. Do large centers or a concentration of funding in general lead to a reduction in the diversity of research areas and would a potential decline in diversity slow development of the research field as a whole? Equity is also conceived in terms of regions or distribution across universities. Despite a lower overall productivity, weaker regions or universities may still be a source of individual excellence. A greater allocation of resources away from these areas may greatly hinder their capacity to spawn top research results and talent.

As we have shown above, supporting Centers of Excellence and other large research projects partly at the expense of support for smaller, individual projects can present problems concerning the gender balance in academia, if the large majority of new centers and programs are led by men. As we showed above, share of centers led by women are typically much lower than for individual research grants or professorships. The gender balance in academia has thus been worsened by introducing these new programs and schemes of excellence. This is in itself a serious democratic problem that works against stated goals of improving gender balance in research. But it may also be detrimental to goals of excellence and genuine scientific breakthroughs to have such an uneven distribution of research funds between genders (Schiebinger and Schraudner 2011).

Finally, a distinction between ex post and ex ante assessment of scientific performance is important here. The top performing researchers of the past (or present) may not be the best performers in the future. A greater concentration of funding, to the extent that it focuses solely on assessments of past performance, can have important implications by reducing the availability of funding for new talents.

We have seen above that existing evidence on the impacts of larger project grants and centers is fairly limited. Given the amount of resources that are devoted to R&D and its importance for growth and prosperity, a much better understanding is needed on how funding impacts research performance. We outline here four suggestions for future work in this area.

First, more analysis is needed on the role of size for the impacts of grants. Furthermore, analysis needs to account for impacts not just for the PI but for all participants in the funded project. Second, given that scientific excellence is an important goal of the concentration of funding, it would be very instructive to look directly at incidences of path breaking research and examine under what types of conditions and environments the path breaking research results were produced. Ie. what types of environments, grants, etc., are most conducive to novel research?

Third, research should place greater focus on the productivity of centers as a specific funding instrument, both examining impacts on the productivity of participants, but also examining eventual consequences for those that were not successful in winning a center grant. In addition, it would also be interesting to examine how large centers have impacted the overall development of their specific research fields.

Finally, and as noted above, more international data and statistics are needed on types of external funding. This includes the distribution of funds among different types of instruments, average size, gender balance, and success rates. Important work is already being conducted through a project on funding schemes that has developed statistics and typologies of the overall funding structure of individual countries (Lepori et al. 2007). Continued work in this direction would be valuable in helping to see trends in types of funding and the eventual impacts.

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