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RESEARCH ARTICLE

Concentration or dispersal of research funding?

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ABSTRACT

The relationship between the distribution of research funding and scientific performance is a major discussion point in many science policy contexts. Do high shares of funding handed out to a limited number of elite scientists yield the most value for money, or is scientific progress better supported by allocating resources in smaller portions to more teams and individuals? In this review article, we seek to qualify discussions on the benefits and drawbacks of concentrating research funds on fewer individuals and groups. Based on an initial screening of 3,567 articles and a thorough examination of 92 papers, we present a condensation of central arguments. Further, we juxtapose key findings from 20 years of empirical research on the relation between the size of research grants and scientific performance. Overall, the review demonstrates a strong inclination toward arguments in favor of increased dispersal. A substantial body of empirical research also exhibits stagnant or diminishing returns to scale for the relationship between grant size and research performance. The findings question the rationale behind current funding trends and point toward more efficient ways to allocate resources. In addition, they highlight the need for more research on the interplay between science-internal mechanisms and policy priorities in accelerating concentration of funding.

1. INTRODUCTION

Maximizing the returns of research funding investments is a major concern among science policy-makers and stakeholders. A key issue in current debates concerns the relationship between the size and concentration of research grants and scientific performance. Are scientific discovery and productivity best supported by concentrating funding in the hands of a limited number of PIs or by spreading out funding on many small and medium-sized teams? Discussions on this question have recently been bolstered by research reporting accelerating trends toward funding concentration at different levels in the science system, notably at the individual and group level. For instance, Bloch and Sorensen (2015) report a generic trend toward funding concentration at the individual and group level across a broad range of countries, whereas Katz and Matter (2017) find that funding inequalities in the US National Institutes of Health have increased considerably between 1985 and 2015, with a small segment of investigators and institutes accumulating an increasing proportion of funds. Two Canadian studies (Larivière et al., 2010; Mongeon et al., 2016) also report a tendency toward resource concentration on fewer individuals and groups across a broad range of fields, whereas Ma et al. (2015) show similar patterns for the engineering and physical sciences in the UK. However, the evidence is still scattered and trends toward concentration are likely to play out differently across countries, institutions, fields and specialties.

In this paper, we seek to qualify current policy discussions on the benefits and drawbacks of the shift toward an increase in grant size and/or an intensification in the accumulation of grants at the individual and group level. We do this by carrying out the first systematic review of a steadily growing literature on the effects of funding concentration.

By limiting our focus to the individual and group levels, we leave out a substantial literature on funding concentration at the national, regional, institutional, disciplinary, faculty and department level. Although this literature is key to understanding broader patterns of concentration and social stratification in the contemporary science system, our main objective with this review is to examine the possible consequences of concentrating research funding at the micro-level. In the remainder of the paper, we use "funding concentration" to refer to the trend toward allocating larger shares of funding to fewer individuals and groups, and "funding dispersal" as a reference to the distribution of smaller shares to more individuals and groups.

Our paper makes several important contributions. To our knowledge, this is the first systematic review of the literature concerned with the benefits and drawbacks of concentrating research funding at the individual and group level. We examine developments in the literature on funding concentration from the 1980s and demonstrate a rapid increase in both opinion-based and empirical studies on the topic, especially over the past 10 years. We map geographical and disciplinary variations in the scholarly attention to issues of concentration and dispersal, and show a clear North American bias and an overrepresentation of studies focusing on the biomedical sciences. We further present a condensation of main arguments for and against concentration or dispersal of research funding, and find that the vast majority of the literature leans toward arguments in favor of dispersal. Finally, we summarize extant empirical research on the relation between funding size and research performance, and find little compelling evidence that bigger is necessarily better. Most empirical studies demonstrate stagnant or diminishing returns to investment for grant sizes above a certain threshold, although this threshold appears to vary depending on field- and country-specific characteristics. Finally, we assess the reviewed literature as a whole and identify limitations, gaps and promising avenues for further investigation.

The policy implications of these findings are important because they question the rationale behind current funding trends and may point toward more efficient ways to allocate resources. However, to remedy some of the shortcomings in the funding system it is necessary to understand the interplay between science-internal mechanisms and the policy factors which may drive trends toward increased concentration. These issues are discussed at the end of the paper.

The paper proceeds as follows: First, we detail the search strategy and selection criteria used to survey the literature. Second, we present a descriptive analysis of the selected corpus of eligible articles. Third, we outline the main arguments in favor of concentration and dispersal. Fourth, we examine empirical research on the relation between funding size and research performance. Finally, we discuss the main findings, draw conclusions, highlight caveats of the literature, and propose directions for further enquiry.

2. MATERIALS AND METHODS

The literature on concentration and dispersal of research funding is still in its infancy and hence characterized by wide variations in terminology. These characteristics do not only reduce the value and usefulness of the available evidence, they also challenge systematic, semiautomated searches in the large bibliographic databases at the outset of a review process. Therefore, we initiated the literature search by collecting 11 papers that we, based on our knowledge of the field, considered to be core publications on the topic. From this outset a problem-driven search was carried out by tracking the citations of each relevant article from this core collection with the aim of covering the full gamut of the existing literature, including blog posts and reports from funding agencies, editorials, comments, and opinion pieces. This screening process resulted in 36 (including the original 11) sources that met the following criteria for inclusion: The papers should have a key focus on concentration or dispersal of research funding at the grant, unit, group, lab, or individual level. Papers focusing on national, regional, institutional, subdisciplinary, faculty, and department-level trends in funding concentration were not included. However, papers on these matters have informed our discussions. Further, we excluded papers primarily focusing on differences between public and private funding schemes, differences between competitive grants and block grants, issues related to gender, age, and race diversity in funding, knowledge spillover effects of funding, and arguments pertaining to agglomeration effects.[1] Although issues concerning concentration at the individual and group level are often touched upon in papers addressing the abovementioned dimensions, these discussions are in most cases of secondary concern.

Next, systematic semiautomated searches in Web of Science (WoS) and Scopus were carried out. Based on the search strings presented in Tables A1 and A2, 3,567 potentially relevant papers were retrieved from WoS and Scopus (Figure 1). Of these, 840 were excluded due to overlap between the databases. An additional 2,679 papers were excluded after reviewing titles, abstracts, and (in instances of doubt) full texts.

The final sample consists of 92 papers (see Appendix for the full list). Of these, 24 are publications with empirical data examining the association between funding size and research performance, 30 are empirical publications without such a perspective, 10 are theoretical, conceptual, review, or discussion-based papers, and 28 are opinion-based short papers, editorial materials, comments, and blog posts, many of which come from NIH and other funding organs.

3. DESCRIPTIVE ANALYSIS

In the following section, we detail temporal developments in the literature and map out variations in the geographic and disciplinary orientation of the sampled articles.

3.1. Temporal Developments in the Literature

As visible in Figure 2, research on the concentration of research funding at the micro-level is still an emerging strand of scientific inquiry. The number of publications explicitly targeting this issue did not really take off before 2009, so far peaking in 2017 with 16 contributions. Hence, 73 out of 92 papers (79%) were published in the past 10-year period. A similar temporal trend becomes apparent when zeroing in on the narrow set of empirical studies examining the relation between funding size and the research performance of groups and individuals (Figure 3). Here, 22 out of 24 identified studies (92%) were published in the period from 2010 and onwards. This rapidly increasing interest in the topic is likely sparked by policy trends reshaping the funding and reward system in the new millennium, including funding cuts in the wake of the financial crisis (Alberts et al., 2014; Lepori et al., 2007), an intensified focus on excellence (Moore et al., 2017), an oversupply of junior researchers in temporary positions

[1] Agglomeration effects are here understood as geographical concentration of research capacities in science areas, regions, districts, clusters, and hubs with the aim to enhance scientific productivity (see Bonaccorsi & Daraio, 2005; Hellström et al., 2017).

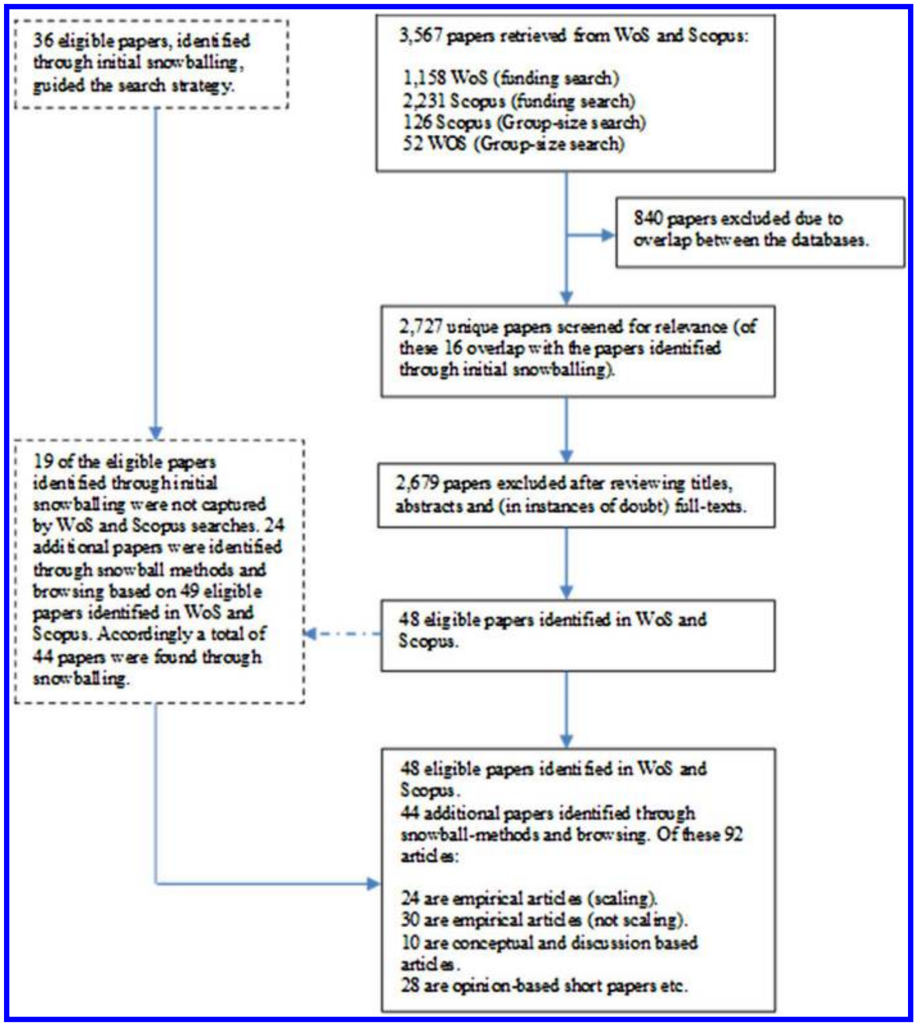

Figure 1. Flowchart of article inclusion and exclusion in the literature survey.

(e.g., Cyranoski et al., 2011; Powell, 2015), and the increasing use of competition-based funding schemes (Aagaard, 2017; Heinze, 2008). In comparison, earlier scholarly debates appear to have been more concerned with the consequences of science-internal drivers of concentration. For instance Ziman (1994) argued that powerful forces based on excellence were "endogenous to science" and would lead to greater concentration over time. Also Merton's (1968) theory of "cumulative advantage" provided a predominantly science-internal prediction model for intensified levels of concentration.

3.2. Geographic and Disciplinary Orientation

Although rapidly growing, the literature on the effects of funding concentration is by no means covering the science system as a whole, neither from a geographic nor a disciplinary perspective. The literature is heavily dominated by a North American orientation and a predominance of contributions, with a primary emphasis on biomedicine. As depicted on the global map in Figure 4, the largest bulk of contributions (deep blue) originate from the United States (38), of which many are dealing with the practices of the NIH. In general, more than half of the studies

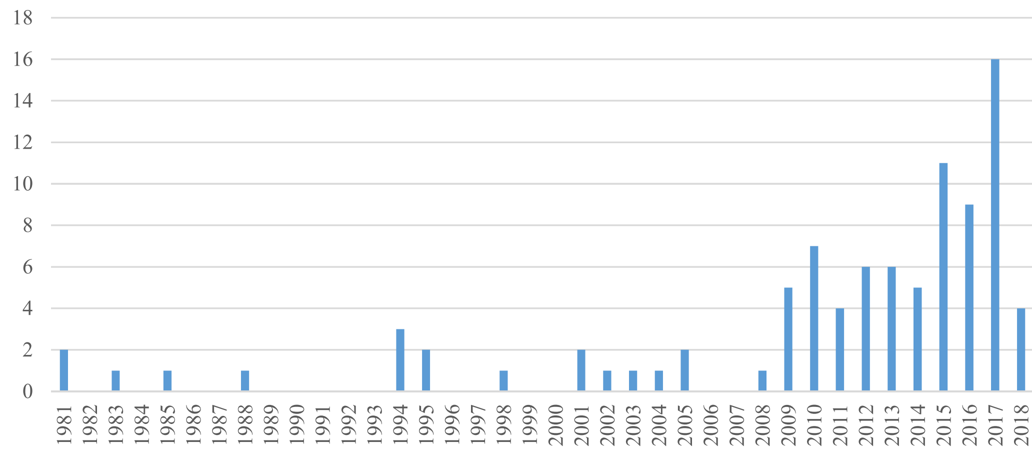

Figure 2. General overview of temporal developments in research on the effects of funding concentration at individual and group levels.
Note: *N* = 92. Our literature search was carried out in March 2018. Hence, the number of publications reported for 2018 is not representative for the full year.

focus on the US and Canadian science contexts. Further, approximately one fourth of the papers (18) focus on European countries, of which nine examine the UK context. Other geographic regions are scarcely represented.

Likewise, the 92 studies cover a variety of disciplinary fields, but also here the representation is highly skewed. There is a clear predominance of contributions with a focus on the medical sciences (biomedicine in particular). This main field is covered by 44 studies (48% of the total set), which either have the medical sciences as the sole focus or cover this field as part of a focus on several main areas. Along the same lines, the natural sciences are covered by 32 studies (35%), the technical sciences by 29 studies (32%), and the social sciences and humanities by 13 studies (14%). Finally, 25 studies (27%) do not have a specific disciplinary orientation.

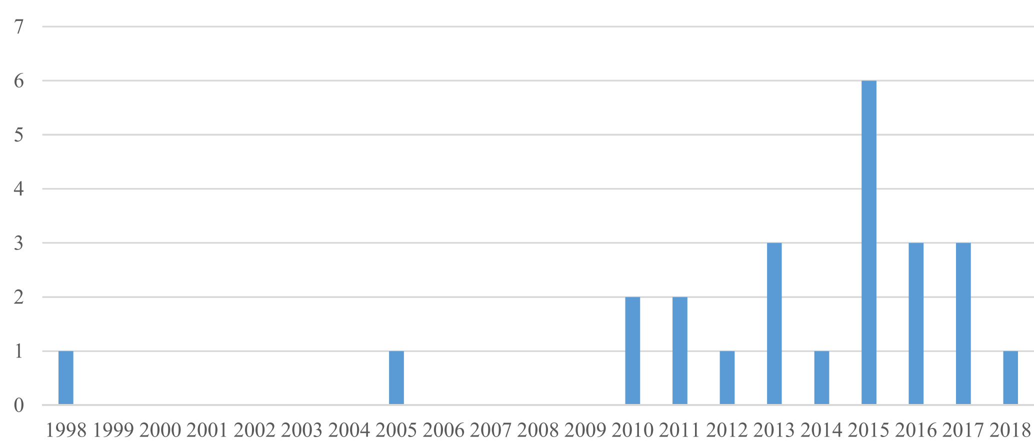

Figure 3. Developments in empirical research focusing on the relation between funding size and the research performance of groups and individuals.
Note: *N* = 24. Our literature search was carried out in March 2018. Hence, the number of publications reported for 2018 is not representative for the full year.

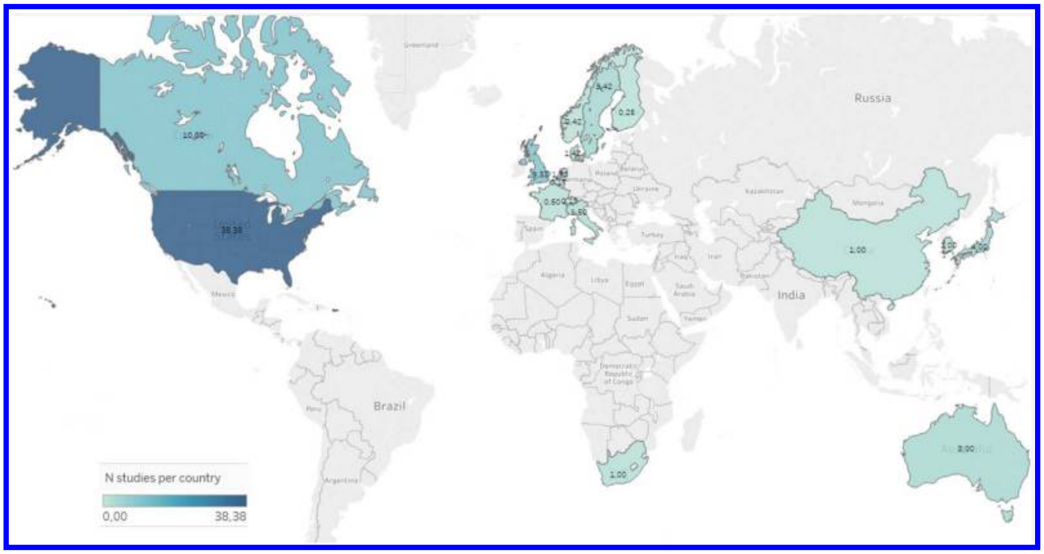

Figure 4. Geographical distribution of the literature.
Note: The country-specific numbers presented on the map are based on a fractional counting. For instance, if a study focuses on three countries, the value 0.33 is assigned to each country. Thirteen studies in the dataset do not provide specifications on national context. Three focus on EU countries as a whole. These 16 studies are not included in the figure.

4. A CONDENSATION OF MAIN ARGUMENTS IN THE LITERATURE

Despite geographical and disciplinary gaps in the literature, the selected set of 92 articles allows us to synthesize a number of key arguments in favor of concentration and dispersal. In the following, we first highlight the main arguments in favor of concentration of research funding, followed by a section presenting the central arguments in favor of resource dispersion.

4.1. Key Arguments in Favor of Concentration of Research Funding

The literature offers surprisingly few unambiguous arguments in favor of a strong concentration of research funding. Most contributions in which arguments in favor of concentration are presented seem to include them to offer a balanced discussion of both "pros" and "cons." As illustrated in Table 1, the arguments in favor of concentration can broadly be placed under one of the following three main categories: (1) efficiency-related arguments, (2) arguments related to epistemic effects, and finally (3) arguments concerning organizational issues. For purposes of clarification, these categories are presented as analytically separate. However, in reality the arguments are often closely intertwined and difficult to disentangle.

4.1.1. Efficiency

The efficiency-related arguments are predominantly framed in economic terms and mostly center on concepts such as critical mass and economies of scale. Following the rationale of this type of argument, concentration of funding allows for the creation of critical mass in terms of human resources, equipment, and infrastructure and for pooling of resources and expertise for large-scale research projects that would otherwise be impossible to carry out (Bloch & Sorensen, 2015; Bonaccorsi & Daraio, 2005; Breschi & Malerba, 2011). According to this strand of argumentation, concentration is also promoted as a means to avoid the dilution of resources and as a necessary precondition for efficiency in terms of larger scientific outputs (Hicks & Katz, 2011; Johnston, 1994; Johnston et al., 1995; Vaesen & Katzav, 2017; von Tunzelmann et al.,

Table 1. Arguments in favor of concentration

Type of argument	Argument	Selected references
Efficiency	Need for critical mass/Risk of dilution of resources	Hellström et al. (2017); Bonaccorsi & Daraio (2005); Johnston et al. (1995); Hicks & Katz (2011); Vaesen & Katzav (2017; Kenna & Berche (2011)
	Concentration leads to economies of scale	Hellström et al. (2017); Ida & Fukuzawa (2013); Bloch et al. (2016)
	Fewer grants lead to smaller administrative burden	Berg (2012); Johnston (1994)
Epistemic effects	Achievement of scientific excellence	Hellström et al. (2017); Bloch et al. (2016); Hicks & Katz (2011); Breschi & Malerba (2011); Bloch & Sorensen (2015)
	Concentration as natural effect of merit-based funding system	Hicks and Katz (2011); Berg (2012)
Organizational conditions	Stable funding flows allow for flexible use of resources	Hellström et al. (2017); Bonaccorsi & Daraio (2005)
	Enables expansion of collaborative ties	Hellström et al. (2017); Bloch et al. (2016); Bonaccorsi & Daraio (2005); Johnston (1994)
	Positive spillover effects of concentration	Bonaccorsi & Daraio (2005)
	Facilitated recruitment	Hellström et al. (2017); Bloch et al. (2016); Bonaccorsi & Daraio (2005); Johnston (1994)
	Availability of critical research infrastructure and equipment	Bonaccorsi & Daraio (2005); Gallo et al. (2014); Johnston (1994)

2003). Others point at issues related to efficiency in terms of smaller administrative burdens when funding is distributed in fewer and larger grant portions (Johnston, 1994). For instance, Berg (2012) describes how a policy aimed at reducing concentration at the U.S. National Institutes of Health was criticized for increasing the administrative burden. According to the critique, the allocation of funding in smaller grants would require extra scrutiny and additional resources for lengthy peer-review evaluation procedures.

4.1.2. Epistemic factors

Another line of argumentation is more explicitly concerned with epistemic factors or other quality-related concepts, such as merit and excellence. Here, the dominant argument is that concentration of funding, and more generally selectivity in the distribution of resources, will ensure that the most capable and productive scientists with the greatest potential to produce world-class and path-breaking research results are rewarded according to their abilities (Bloch & Sorensen, 2015; Hicks & Katz, 2011; Johnston et al., 1995). The underlying assumption is that funding concentration is a necessary precondition for the creation and maintenance of scientific excellence—in particular in an increasingly competitive and globalized science system, where research environments need to achieve or sustain a competitive edge (Bloch &

Table 2. Arguments in favor of dispersal

Type of argument	Argument	Selected references
Efficiency	Concentration leads to diseconomies of scale	Berg (2012); Cook et al. (2015); Lorsch (2015); Mongeon et al. (2016); Lauer et al. (2015); Peifer (2017); Fortin & Currie (2013); Bloch & Sorensen (2015); Breschi & Malerba (2011); Alberts (1985, 2012); Bonaccorsi & Daraio (2005)
	Diminishing marginal returns as a result of concentration	Mongeon et al. (2016); Breschi & Malerba (2011); Lorsch (2015); Fortin & Currie (2013); Cook et al. (2015); Berg (2010b, 2012); Peifer (2017); Alberts (2012)
	Small and medium-sized research groups are more productive	Cook et al. (2015); Vaesen & Katzav (2017); von Tunzelmann et al. (2003); Johnston (1994); Bloch et al. (2016); Bloch & Sorensen (2015); Alberts (1985)
	Excess size leads to fragmentation, inertia, and inefficiencies	Alberts (1985); Breschi & Malerba (2011); Bloch & Sorensen (2015); Mongeon et al. (2016); Fortin & Currie (2013); Vaesen & Katzav (2017); Johnston (1994)
	Innovative researchers are turned into fundraisers and managers	Kimble et al. (2015); Bloch & Sorensen (2015); Alberts (1985)
	Concentration leads to allocative and economic inefficiencies	Nag et al. (2013); Bloch & Sorensen (2015); Hicks & Katz (2011); Sousa (2008); Mongeon et al. (2016)
Epistemic effects	Diversification spreads risk and increases chances of breakthroughs	Fortin & Currie (2013), Lorsch (2015); Lauer (2014); Fang & Casadevall (2016); Peifer (2017); Ioannidis (2011); Vaesen & Katzav (2017); Berg (2012); Mongeon et al. (2016); Fang & Casadevall (2016)
	Dispersal of funding as means to avoid mainstream, risk-averse research	von Tunzelmann et al. (2003); Kimble et al. (2015); Peifer (2017); Bloch & Sorensen (2015); Alberts et al. (2014)
Organizational issues/ system level issues	Dispersal keeps researchers and students active with research	Fortin & Currie (2013); Lauer (2014); Vaesen & Katzav (2017)
	Dispersal secures a strong growth layer of early and mid-career researchers	Peifer (2017); Fang & Casadevall (2016); Berg (2012); Alberts (1985)
	Dispersal leads to a broader knowledge pool and greater research breadth + pockets of excellence	Fortin & Currie (2013); Vaesen & Katzav (2017); Bloch & Sorensen (2015); Kimble et al. (2015); Katz & Matter (2017); Lauer (2014)
	Dispersal reduces Matthew Effects/ cumulative advantages and hypercompetition	Berg (2012); Fang & Casadevall (2016); Bloch et al. (2016); Bol et al. (2018)

Table 2. (*continued*)

Type of argument	Argument	Selected references
Problems with grant peer review and allocation procedures	Peer reviewers unable to identify the most promising projects	Vaesen & Katzav (2017); Kimble et al. (2015); Fang & Casadevall (2016); Lorsch (2015); Katz & Matter (2017); Gordon & Poulin (2009a, 2009b); Alberts et al. (2014)
	More egalitarian distribution of funding is possible without dilution	Fortin & Currie (2013); Gordon & Poulin (2009a, b); Ioannidis (2011); Vaesen & Katzav (2017)

Sorensen, 2015; Johnston et al., 1995). Other studies that focus on Centers of Excellence (CoE) arrive at similar conclusions and generally find positive epistemic effects of resource concentration in large units (Bloch et al., 2016; Hellström et al., 2017; Ida & Fukuzawa, 2013). With regard to the merit-based arguments, the work by Hicks and Katz (2011) stands out among the selected articles with the most unambiguous support for stronger concentration. The authors argue that R&D funding—due to a purported inequality aversion inherent in the funding system and among policymakers—tends to be more equally distributed than would be justified by differences in output measures such as publications and citations. Hence, Hicks and Katz (2011) see concentration as a natural and desirable consequence of a merit-based funding system that follows a power-law distribution of productivity and resources (Lotka, 1926).

4.1.3. Organizational conditions

A third group of arguments in favor of concentration places explicit emphasis on organizational conditions. Here the main assumption is that large grants and the concentration of investments in large research units give researchers the necessary resource availability and flexibility to conduct innovative, high-risk, and high-impact research (Bonaccorsi & Daraio, 2005; Hellström et al., 2017). In essence, the combination of funding stability and flexibility is perceived to facilitate autonomy, availability of cooperative partners, and concomitant collaboration (Bloch et al., 2016; Bonaccorsi & Daraio, 2005; Hellström et al., 2017). In particular, the shift from individual toward collective modes of research (from small science to big science) is seen as a development that is dependent on selectivity and concentration in the allocation of research funding (Johnston, 1994). This argument also emphasizes growth in expenditures for equipment and infrastructure. Hence, access to expensive physical infrastructure is also part of the call for critical mass and concentration of resources in large units (Bonaccorsi & Daraio, 2005; Gallo et al., 2014; Johnston, 1994). Finally, the presence of funding concentration is also expected to increase international visibility and attractiveness in the sense that stable financial conditions can attract top-quality researchers and talents and may support organizational robustness (good governance and professional academic leadership; Bloch et al., 2016; Bonaccorsi & Daraio, 2005; Hellström et al., 2017; Hicks & Katz, 2011).

4.2. Key Arguments in Favor of Dispersal of Research Funding

The vast majority of the identified articles, whether empirical, conceptual/theoretical, editorials, or comments, lean toward arguments in favor of dispersal of funding. As shown in Table 2, the arguments can here also be subsumed under the same three categories: (1) efficiency, (2) epistemic effects, and (3) organizational issues (although in this third category we also include arguments explicitly targeting the systemic level). In addition, we include a fourth category concerned with problems pertaining to peer review and allocation procedures. Hence, most of the arguments presented here can be seen as the flipside of the arguments in favor of concentration.

4.2.1. Efficiency

Under the broad heading of efficiency, we find a substantial number of contributions highlighting that concentration of research funding may in fact lead to diseconomies of scale (Bloch et al., 2016; Bonaccorsi & Daraio, 2005; Johnston et al., 1995; Nag et al., 2013; von Tunzelmann et al., 2003). As we describe in section 5, the majority of extant empirical research finds little or no convincing evidence to justify funding policies aimed at concentrating resources to achieve economic efficiency (Bonaccorsi & Daraio, 2005; von Tunzelmann et al., 2003). These studies show that concentration of funding, on average, leads to decreasing marginal returns (measured by the number of citations and impact factors) above a certain threshold (Cook et al., 2015; Fortin & Currie, 2013; Lorsch, 2015). Correspondingly, numerous empirical studies suggest that research productivity can be increased by spreading out funding on many small and medium-sized research teams, averaging from around five to eight group members (Bloch et al., 2016; Johnston, 1994; Johnston et al., 1995; von Tunzelmann et al., 2003). For further discussion of the available empirical evidence, see section 5.

Another central efficiency-related argument in favor of resource dispersal is that the excess size of research projects, consortia, groups, and grants can lead to fragmentation within groups and cumbersome levels of administration (Alberts, 1985; Breschi & Malerba, 2011; Nag et al., 2013). Similarly, Alberts (1985) early on pointed out that concentration of funding may turn group leaders in big research teams into "science managers" who spend nearly all their time on grant writing, science administration, and organizational matters, leaving little time for doing actual research and mentoring students and junior staff (see also Kimble et al., 2015). Finally, several authors allude to what they claim to be allocative and economic inefficiencies in the funding and reward system of science, as scientists who have already secured funding are incentivized to apply for and obtain resources over and above what they can productively spend (Bloch & Sorensen, 2015; Hicks & Katz, 2011; Sousa, 2008).

4.2.2. Epistemic effects

Arguments related to epistemic effects figure even more prominently in the literature advocating for dispersal. Here, a key claim is that spreading out grants among many researchers and supporting a greater number of investigators at moderate funding levels is a better investment strategy that yields higher research outputs with stronger impact than concentrating large amounts of resources on fewer scientists (Fortin & Currie, 2013; Gallo et al., 2014; Lauer, 2014; Lorsch, 2015). According to proponents of this funding strategy, diversity in research investments spreads risk and thereby increases the chances of scientific breakthroughs (Fang & Casadevall, 2016; Lorsch, 2015; Peifer, 2017). Along the lines of this argument, each grant recipient is seen as an experiment, meaning that a larger number of grantees will increase the number of experiments (Fortin & Currie, 2013). On the other hand, the so-called "few big" strategy is perceived as risky because it reduces the number of experiments by concentrating funding on selected research areas, and by supporting investigators or research projects that might not necessarily have the greatest scientific potential (Bloch & Sorensen, 2015; Fortin & Currie, 2013). Conversely, the essence of the "many small" strategy is that support for a wide web of research will increase the chances of making important discoveries, as diversity offers varying perspectives, interpretations, heuristics, and prediction models (Lorsch, 2015).

Dispersal of funding is here seen as a way to foster resilience in a system that constantly shifts and adapts (von Tunzelmann et al., 2003). Increased concentration of funding, on the other hand, is argued to lead to both stasis and closure, resulting in a system less capable of adaption and to a suppression of both creativeness and risk-taking. Therefore, to avoid mainstream, risk-averse, and less imaginative research, it is argued that it is desirable to provide funding for many different types of research and thereby allow for a variety of competing approaches (Kimble et al., 2015; Peifer, 2017).

4.2.3. Organizational (and systemic) issues

The articles in favor of dispersal and diversity also point to a number of arguments tied to organizational and systemic issues. Most notably, it is highlighted that funding more scientists creates a more diverse research ecology and provides students with a larger range of opportunities (Fortin & Currie, 2013; Lauer, 2014; Vaesen & Katzav, 2017). Thus, a higher degree of dispersal of grant funding will serve to keep more students and scientists active in research (Fortin & Currie, 2013) and contribute to secure a strong growth layer of early and mid-career researchers, which is seen as a prerequisite for maintaining viable institutions and a healthy overall scientific ecosystem (Berg, 2012; Fang & Casadevall, 2016). Concentration of funding, on the contrary, is here seen to endanger the next generation of scientists, who cannot compete with the track records, the amount of resources, and availability of scientific staff of their senior colleagues (Kimble et al., 2015; Peifer, 2017). Furthermore, disproportionate financial support for highly specialized research areas within narrowly defined disciplinary boundaries results in a lack of diversity of disciplinary fields and scientific approaches and might come at the expense of advancement within other equally or potentially more promising research areas (Bloch & Sorensen, 2015). By comparison, policies aimed at targeting diversity are perceived to secure a broader knowledge pool and a greater research breadth where seed money is provided for researchers within smaller research fields, allowing pockets of excellence to grow outside of prioritized areas (Bloch & Sorensen, 2015). Finally, it is suggested that increased dispersal of funding will reduce trends toward hypercompetition and serve to curb the Matthew Effects and mechanisms of cumulative advantage already inherent in the science system (Fang & Casadevall, 2016). In addition, Johnston (1994) recounts Lowe's (1991) argument that concentration of funding creates units that become self-perpetuating "…thereby reducing the capacity of the research funding system to respond flexibly to changing priorities" (Lowe, 1991: 187 in Johnston, 1994: 28).

4.2.4. Problems with grant peer review and allocation procedures

The fourth and final group of arguments questions the functioning of existing review and allocation procedures, and the assumption that the best researchers are rewarded according to their abilities. Hence, these arguments both relate to discussions of efficiency and epistemic effects. Here, it is highlighted that grant peer review is not only an expensive and resource-demanding process, but also unreliable and subject to a number of biases (Fang & Casadevall, 2016; Gordon & Poulin, 2009a; Kimble et al., 2015; Vaesen & Katzav, 2017). Likewise, it is suggested that low success rates induce conservative, short-term thinking among applicants, reviewers, and funders (Alberts et al., 2014). As pointed out by Alberts et al. (2014) "[t]he system now favors those who can guarantee results rather than those with potentially path-breaking ideas that, by definition, cannot promise success" (p. 5774). In addition, Berg (2012) highlights that although many funding bodies try to avoid overlaps between new and already funded projects, reviewers often do not have access to portfolio data on which they can take informed funding decisions. Instead, reviewers tend to reward past performers and disadvantage applicants with a poorer track record at the expense of potentially promising research projects (Bloch & Sorensen, 2015). As a result many meritorious projects remain unfunded and undone (Fang & Casadevall, 2016; Gordon & Poulin, 2009a). Hence, a number of authors call for a reform of the current system and some even for a replacement of grant peer review with a more egalitarian distribution of funding (Fang & Casadevall, 2016; Fortin & Currie, 2013; Gordon & Poulin, 2009a, b; Vaesen & Katzav, 2017).

5. EMPIRICAL STUDIES EXAMINING EFFECTS OF FUNDING SIZE ON RESEARCH PERFORMANCE

As should be clear from the preceding sections, a large bulk of the literature on concentration and dispersal of research funding is dominated by theoretical and opinion-based arguments. However, a subset of empirical studies also attempts to examine the direct effects of funding size on the research performance of groups and individuals. We identified 24 articles addressing this particular issue (Table 3). Some parts of this literature are characterized by conflicting and inconsistent results, which may be explained by differences in research design, dissimilarities in how "research performance" and "funding size" are conceptualized and measured, and variations in funding mechanisms across geographical, institutional and disciplinary contexts. Nonetheless, by far most studies exhibit stagnant or decreasing returns to scale for the relationship between funding size and research performance.

In line with the broader literature, studies based on data from the United States and Canada are overrepresented in this subset. Twelve studies focus on a North American science context, six are based on European data, four focus on Asian countries, one focuses on South Africa, and one employs a global perspective. Twenty-two of the studies are based on observation data and two use cross-sectional survey data. Ten of the 24 studies are based on bivariate correlations between input and output measures, and 14 employ multivariate statistical analysis, matching techniques, and difference-in-differences estimations to adjust for possible confounders. Performance is in most cases measured by research output (i.e., number of publications; $N = 16$) or citation impact ($N = 12$), and to a lesser extent by journal impact factors ($N = 4$), journal rankings ($N = 1$), and patents ($N = 1$).

Nineteen studies examine correlations between the size of research grants and scientific performance. Of these, 17 demonstrate either a negative association, no discernible effect, or stagnant or diminishing returns to investment for grant sizes above a certain threshold (Arora et al., 1998; Asonuma & Urata, 2015; Berg, 2010a, b; Bloch et al., 2016; Breschi & Malerba, 2011; Danthi et al., 2015; Doyle et al., 2015; Fedderke & Goldschmidt, 2015; Fortin & Currie, 2013; Gallo et al., 2014; Jung et al., 2017; Lauer et al., 2015, 2017; Mongeon et al., 2016; Nag et al., 2013; Spanos & Vonortas, 2012). This threshold appears to vary considerably depending on field- and country-specific characteristics. For instance, using data on 2,938 grants from the U.S. National Institute of General Medical Sciences, Berg (2010a, b) shows that the research output and average journal impact factor per lab decreases with funding above ~\$750,000, and that funding above ~\$250,000–300,000 is associated with only modest increases in research performance. In comparison, Doyle and colleagues exhibit diminishing returns to investment for basic research with grant sizes above ~\$4.5 million in a sample of 1,755 R01 projects funded by the U.S. National Institute of Mental Health.

The remaining two studies on grant size and scientific performance report positive effects, but none of these look into possible inflection points for diminishing marginal returns (Katz & Matter, 2017; Yan et al., 2018).

Table 3. Empirical studies on the relation between funding size and scientific performance

Reference	Study type	Study population/sample	Country	Time period	Focus	Results
Arora et al. (1998)	Observation	797 research units applying to a research program in biotechnology and bioinstrumentation funded by the National Research Council in Italy	Italy	1989–1993	Link between size of units/size of research funds and research output	Adjusting for multiple potential confounders, the study finds that unit size does not affect research output. The study, however, finds that "a more unequal distribution of research funds would increase research output in the short-run"
Asonuma & Urata (2015)	Observation	Competitive and Basic research funds for Japanese researchers in 1992 and 2007	Japan	NS	Link between amount of funding and research output	Finds diminishing returns in terms of research output per researcher with increasing amounts of funding
Berg (2010a, b)	Observation	2,938 investigators/labs receiving grants from the National Institute of General Medical Sciences in 2006	USA	2007–2010	Link between grant size and research output/average journal impact factor	Finds that research output and the average journal impact factor per lab decrease with funding above ~$750,000. Research output and the average journal impact factor per lab increased modestly with funding above ~$250,000–300,000).
Bloch et al. (2016)	Observation	57 Centers of excellence (CoE) funded by the Danish National Research Foundation	Denmark	1993–2011	Link between grant size and research output and citation impact	Finds that larger CoEs have higher average citation impact and more top-cited papers. However panel data indicate that the citation performance on both metrics decrease over the course of the granting period for the largest CoE, while increasing for the smallest 50%. The authors estimate that the optimal annual grant size is €1.45 million. Similarly, they estimate that the average citation impact of CoEs peaks at 6.7 grant years
Breschi & Malerba (2011)	Observation	734 European Commission FP6 projects funded by	Europe	NS	Link between project size,	In negative binomial regression models, a slight positive

Table 3. (*continued*)

Reference	Study type	Study population/sample	Country	Time period	Focus	Results
		the Information Society and Media Directorate			grant size, and research output	association is found between the proportion of university-based project partners and research output and between average grant size per partner and scientific output. Further, the study shows diminishing returns of the number of project participants on research output with an estimated inflection point at 52 participants. The log of total funding per project also indicates diminishing returns of increasing grant sizes
Danthi et al. (2015)	Observation	623 *de novo* R01 grants funded by the National Heart, Lung, and Blood Institute in 2009 distributed on 458 payline grants and 165 ARRA grants	USA	2009–2014	Link between grant size and field-normalized citation impact (comparing the citation impact of payline grants (median funding: ($1.87 million) vs. ARRA grants (median funding: $1.03 million)	Adjusting for potential confounders, the study finds that ARRA and payline grants have similar normalized citation impact per $1 million spent
Doyle et al. (2015)	Observation	1,755 *de novo* investigator-initiated R01 grants funded for at least 2 years by the National Institute of Mental Health between 2000 and 2009	USA	2000–2009	Link between grant size and citation impact	Finds an association between total award-dollars per grant and normalized citation impact, but with diminishing marginal returns. Using forest regressions, the study finds decreasing grant size to be one of the three most important predictors of returns to investment on citation impact per $ million spent
Fedderke & Goldschmidt (2015)	Observation	76 research chairs awarded by the National Research Foundation (NRF) of South Africa. 67	South Africa	2009–2012	Link between grant success and research output	Finds that funding success is associated with moderate gains in publication and citation rates compared to

		A-rated researchers without NRF chairs. 157 B-rated researchers without NRF chairs				researchers at equivalent standing without chairs. A comparison of high-performing researchers with and without chairs (based on propensity-score matching) indicates that the costs of each additional publication for funding recipients is 22 times as high as for equivalent researchers without funding. Further, the additional cost per citation is 32 times as high.
Fortin & Currie (2013)	Observation	374 individual researchers in three biology, chemistry and ecology disciplines funded by the Natural Sciences and Engineering Research Council of Canada in 2002	Canada	2002–2007	Link between grant size and research output and citation impact	Funding size “accounts for between R-square = 0.03 to R-square = 0.28 of the among-researcher variation in impact” (i.e., citation impact). Average scientific impact generally decreased with funding size. Receiving additional funds other federal granting councils did not result in higher scientific impact
Gallo et al. (2014)	Observation	227 projects funded by the American Institute of Biological Sciences	USA	2004–2011	Link between grant size and total-relative citation impact (TRC)	The study created nine levels of funding in $400,000 increments, comparing the average TRC per winning application for each level. The study found no statistically significant difference in TRC across the funding levels. The total annual TRC correlated moderately with the number of funded applications, but not with the total annual programmatic budget.
Gaughan & Bozeman (2002)	Observation	436 PhD level scientists and engineers in biotechnology and microelectronics-related with funding grants. Of these 177 are recipients of NSF center grants	USA	NS	How center funding influences individual researchers’ research output	Adjusting for potential confounders, the study finds no association between center funding and research output. However, having another type of government or foundation grant is associated with increasing research output, but the effect is small. In general, grant volume slightly (i.e., number of grants) improves performance.

Table 3. (*continued*)

Reference	Study type	Study population/sample	Country	Time period	Focus	Results
Gök et al. (2016)	Observation	All researchers from BE, DK, NL, NO, CH, and SE with publications in WoS in the period 2009–2011 (242,406 articles)	Europe	2009–2011	Link between funding intensity/funding variety and citation impact per paper	In per-country logistic regressions adjusting for country of coauthors, broad subject categories, number of authors, and publication year the study finds a negative association between funding intensity (i.e., the number of funding sources acknowledged in a paper/ number of authors) and per-paper citation rates. A positive association is shown between funding variety (i.e., "number of funders/the number of unique funders per each paper") and citation impact
Ida & Fukuzawa (2013)	Observation	374 Japanese research teams, of which some were funded as Centers of Excellence	Japan	1997–2008	Comparing the impact of CoE funding on research output and citation impact	Comparing the citation and publication rates of CoE participants before and after funding (difference in difference) with the performance a control group, the study finds a positive association between CoE funding and research output in four out of eight scientific fields. Further, it shows a positive association between CoE funding and citation impact in three out of eight fields. In the remaining fields no statistically significant association between CoE funding and research output and impact is demonstrated, with one exception: the study shows a negative association between CoE funding and citation impact in mathematics and physics
Jung et al. (2017)	Observation	Researchers receiving grants from South Korea's National Research Foundation between	South Korea	NS	Link between amount of funding and journal impact factor and journal ranking	In regressions adjusting for multiple confounders, the study finds that funding size correlates slightly negatively with journal

		2003 and 2009. Analysis was based on 3228 published paper				impact factor per paper and journal ranking per paper
Katz & Matter (2017)	Observation	Recipients of NIH R grants in the period 2005–2010. *N* is not specified for the given period of analysis, but the data are taken from a larger sample of nearly 90,000 NIH-funded projects between 1985 and 2015	USA	2005–2010	Link between distribution of funding and scientific output	Finds that the most highly funded R-grant recipients have a considerably larger number of publications than less funded recipients, accumulate a larger number of citations, and have more publications in the most prestigious journals. The study does not look into possible inflection points for diminishing marginal returns
Langfeldt et al. (2015)	Observation	12 Scandinavian Centers of Excellence. Performance is measured 5 years prior to and after the establishment of the CoEs	Scandinavia	NA	Link between CoE grants and research output, normalized journal impact, and normalized citation impact	Based on descriptive analysis, it is concluded that “CoE grants seem to have limited impact for some already high-performing and distinguished groups (…) [T]he status and opportunities offered by the CoE grant add less to the situation of some of the highest performing groups, than for less recognized groups”
Lauer et al. (2015)	Observation	6873 *de novo* cardiovascular R01 grants funded by the National Heart, Lung, and Blood Institute between 1980 and 2011	USA	1980–2011	Link between grant size and citation impact (in terms of top 10% most cited papers)	Finds an association between annual total budget per project and citation impact in terms of field-normalized top 10% most cited papers, but with varying marginal returns depending on funding size. Finds an association between total grant budget and top 10% most cited paper rates but with diminishing returns on investment
Lauer et al. (2017)	Observation	71,936 researchers funded by the NIH between 1996 and 2014	USA	1996–2014	Link between grant size and citation impact (measured by three metrics)	Finds diminishing returns in terms of citation impact with increasing grant sizes

Table 3. *(continued)*

Reference	Study type	Study population/sample	Country	Time period	Focus	Results
Mongeon et al. (2016)	Observation	12,720 unique funding recipients in Quebec between 1998 and 2012	Canada	2000–2013	Link between grant size and research output and citation impact	Finds that increasing research funding yields decreasing marginal returns with respect to research output and citation impact (including top 10% most cited) in health research, science and engineering research, and social science research. The study concludes that researchers receiving a moderate amount of funding provide the best returns in terms of research output and citation impact per dollar
Nag et al. (2013)	Cross-sectional survey	720 bioscientists performing agriculturally related molecular or cellular level research (total sample 1,441)	USA	2003–2006	Link between financial support/lab size and research output	Adjusting for multiple potential confounders, the study finds that that the mean bioscience laboratory "is too large to make efficient use of its resources." A 10% boost in laboratory budget results in a 7.5% increase in article output

Shibayama (2011)	Observation	Projects supported by the Japanese Grants-in-Aid since 1965, (i.e., approx. 600,000 grants and 210,000 funded university researchers)	Japan	2001–2005	Efficiency of funding distribution in terms of research output	Finds inequality in research funding (calculated by the Gini-coefficient) to be larger than the inequality in research output (calculated by the Gini-coefficient) at the institutional level (0.845 vs 0.919) and at the level of the individual researcher (0.592 vs. 0.685).
Spanos & Vonortas (2012)	Cross-sectional survey	Randomly selected sample of 54,492 participating organizations funded through the European Framework Programme 5 and 6. Final sample employed in the analysis: 583/586 organizations	Europe	2006	Link between funding size/*N* project partners and research output/ technological output (patents)	Adjusting for multiple project-level controls, the study does not find a statistically significant relationship between funding size and research output or technological output and number of project partners and research output or technologic output
Yan et al. (2018)	Observation	Five core journals from seven STEMM disciplines	International	2010–2016	Link between funding size and citation impact	Funding size is found to increase citation impact considerably. Number of funding sources is a weak predictor of citation impact

Three of the abovementioned studies also analyze associations between the size of funded projects (in terms of number of people) and research performance. Of these, one study reports a statistically insignificant effect (Arora et al., 1998), and two show diminishing returns to scale as the number of project partners and participants increases (Breschi & Malerba, 2011; Nag et al., 2013).

One study reports a slight positive association between per-researcher "grant volume" (i.e., number of grants per researcher) and research output (Gaughan & Bozeman, 2002), and another exhibits a negative association between per-paper funding intensity (i.e., number of funding sources acknowledged in an article divided by the number of authors) and citation impact, and a positive association between per-paper funding variety (i.e., the proportion of unique funders acknowledged in an article) and citation impact (Gök et al., 2016).

Two studies analyze how large-scale grants funded through Centers of Excellence (CoE) influence research performance. One of them exhibits a positive association between CoE funding and research output in four out of eight scientific fields (Ida & Fukuzawa, 2013); the other finds that already successful research groups are less likely to see benefits of CoE grants (in terms of performance) than less recognized research groups (Langfeldt et al., 2015).

Finally, one study analyzes publication and funding data for a large sample of university researchers and finds that researcher inequality in funding is significantly larger than researcher inequality in publication output (Shibayama, 2011).

In summary, our systematic survey of existing empirical research exhibits little compelling evidence of increasing returns to investment. A few studies demonstrate a positive association between grant size and project size on the one hand, and bibliometric indices of scientific performance on the other. However, none of these studies look into possible inflection points for increasing or diminishing marginal returns. In comparison, a substantial part of the literature exhibits tangible evidence of stagnant or decreasing returns on research output and impact for grant sizes above a certain threshold, although this threshold appears to vary considerably, depending on field- and country-specific characteristics. Consequently, both "too small" and "too large" research grants seem unfavorable if "returns to scale" are measured based on traditional, bibliometric approaches to science evaluation.

6. DISCUSSION AND CONCLUSION

Concerns about the implications of funding concentration are not new to the science-policy literature. Already in 1994, Johnston observed that "the widespread introduction of policies of resource concentration around the world [was] found to have been based on little examined assumptions and in operation to be at times counter-productive" (p. 25). As shown in sections 3 and 4, such criticisms have become increasingly prevalent in the literature, especially in light of the recent transformations in the science-policy landscape. Although our knowledge of the exact extent of trends toward funding concentration within the science system remains incomplete, a thorough examination of the potential consequences of this development seems timely and warranted.

To our knowledge, no attempts have thus far been made to thoroughly examine the full body of empirical and theoretically driven arguments concerning the implications of funding concentration at the group and individual level. With the objective to provide more tangible guidance for policy, our review targets this gap in knowledge by presenting the first systematic survey of the literature on the effects of funding concentration.

6.1. Overall Findings

Taken together, extant research on this topic is characterized by a rather strong inclination toward arguments in favor of increased dispersal of funding. Conversely, limited support is found for arguments of economies of scale related to high levels of funding concentration. Further, the presumed positive epistemic effects of high degrees of funding selectivity are contested, and the expected organizational benefits do not as a general rule appear to outweigh the suggested drawbacks.

Although many of the arguments for and against funding concentration are opinion-based, a substantial number of empirical studies also indicate that spreading out funding on smaller grants, on average, yields better performance than distributing funding in fewer and larger grant portions. Here, it is worth noting that the empirical research on the relation between funding size and research performance primarily measures scientific output by way of standard bibliometric indicators of impact (i.e., citation indicators, journal impact factors, and journal rankings). Hence, there is reason to believe that the suggested benefits of dispersal draw a conservative picture, because the abovementioned indicators may suppress cognitive diversity and be biased against scientific novelty (Yegros-Yegros et al., 2015; Wang et al., 2017). Further, bibliometric data provide a narrow understanding of research performance. Fully capturing the benefits and drawbacks of funding concentration would require more careful attention to the potential implications for the research questions raised, the topics addressed and methods employed in scientific knowledge-making, as well as the ability of the scientific enterprise to address prevalent societal needs and expectations. It should also be kept in mind that our knowledge of these issues primarily comes from the North American region and the biomedical field. Nonetheless, with caution, many of the general lessons derived from this paper appear to be of relevance across fields and national contexts.

However, reducing the issue of funding size to a simple question of evidence for or against concentration would be to oversimplify a complex and multifaceted problem. The "proper" balance between concentration and dispersal of research funding may be more accurately described as a matter of degree: Both too small and too large grant sizes appear to be inefficient in both economic and epistemic terms. Notwithstanding, the available research suggest that the funding levels needed to achieve a "critical mass" may not necessarily be very high. Hence, a key question concerns where the "sweet spot" (or preferred region) in the balance between concentration and dispersal is to be found (Page, 2014). Given the presumed benefits of funding dispersal with respect to diversity, there is an urgent need for more thorough and systematic examinations of how much diversity and which forms of diversity that could accommodate a more robust, innovative, and forward-moving scientific system (Page, 2014). The optimal balances are, however, likely to be dependent on both field-specific characteristics and factors related to the overall configuration of national funding systems.

6.2. Lack of Consistency, Cross-referencing and Theoretical Elaboration

Although the reviewed literature presents a fairly strong case against funding concentration, it is critical to emphasize the limitations of the available knowledge. As demonstrated, the literature is fragmented and characterized by conceptual, terminological, and methodological inconsistencies and shortcomings.

As described in section 5 (and above in relation to the bibliometric output measures), part of the problem can be linked to differences (and weaknesses) in research designs and dissimilarities in how "research performance" and "funding size" are conceptualized and measured.

Although there is certainly room for improvement with respect to these issues, the key limitation of the literature concerns its lack of consistency, cross-referencing, and theoretical elaboration. Although variations in funding and governance mechanisms across geographical, institutional, and disciplinary contexts naturally lead to different ways of approaching and addressing the issues at stake, the differing contexts are no excuse for not consulting the relevant, more generic science-policy and funding literature. Unfortunately most of the reviewed articles fall into this trap. They do not as a general rule attempt to engage with the broader science-policy literature, nor existing research on funding concentration. This limitation is further amplified by the fact that the included opinion pieces, editorials, and comments all can be situated somewhat at the outskirts of more traditional scholarly debates, and are thus easily overlooked in systematic searches. As a consequence, we find limited progress in academic discussions of funding concentration, which in most cases only sparsely build on previous contributions. Further, we observe a lack of agreement on key terms and hence a general fragmentation of the available knowledge. These limitations are also visible when studying developments in the literature over time. There are relatively few common references across contributions—and the ones we find are often quite old and perfunctory, such as classical sociology of science contributions by Merton (1968) and Cole and Cole (1973). Accordingly, another limitation concerns the relatively weak theoretical grounding and elaboration of most existing contributions. This limitation is particularly evident in discussions of the causes of the observed developments and in discussions of potential remedies. Our final section highlights key theoretical issues that deserve greater consideration in future studies.

6.3. Attention to Factors Influencing Degrees of Concentration

The results presented in this review provide compelling reasons to discuss whether and to what extent the current funding system needs to be adjusted to mitigate further trends toward concentration. We argue that the need for more thorough investigations of how to balance concentration and dispersal of research funding should be accompanied by a more nuanced understanding of how different types of competition interact to shape allocation patterns and eventually research practices. An accurate understanding of these mechanisms is a prerequisite for effective policy interventions.

The accelerating concentration of funding is not merely the result of conscious and explicit policy decisions (e.g., to allocate funding in fewer and larger portions, or to increase the level of funding allocated in competition). It may also be driven by internal Matthew Effects in the reward system of science. Further, growing concentration may be an inadvertent consequence of uncoordinated grant decisions made in isolation across a wide variety of funding organizations. Unintended funding concentration will be particularly likely to occur when different funding agencies operate with relatively uniform excellence criteria, and when they lack oversight of allocation decisions made elsewhere in the system. Both conditions appear to be widespread in most funding systems.

In other words, aggregated allocation patterns are shaped by multiple interconnected, science-internal and science-external factors that produce intended as well as unintended effects. The complex interplay between all these factors needs to be taken into consideration when suggestions for adjustments to the overall system are discussed. Securing a well-balanced and sustainable science system will not be possible before these broader considerations are factored into the funding equation.

Ultimately, striking the right balance between concentration and dispersal will require real-world experimentation across different funding contexts and disciplines. Although such balances cannot be inferred directly from this literature, there are indications that most countries and most fields are in need of initiatives leading to less, not more, concentration. Although policymakers obviously worry about spreading out the available funding too thinly, and although some degree of selectivity certainly is justified due to differences in talent and originality across populations of researchers, there are reasons to believe that most systems currently have moved too far toward concentration—and that this may harm the progress of science. As made clear by historians, philosophers, and sociologists of science, scientific advancement is best promoted by ensuring competition between ideas, paradigms, theories, methods, and approaches. A prerequisite for advances is therefore systemic underpinning of diversity, originality, and risk-taking. Dispersal of funding among more individuals and groups is one way to secure this.

AUTHOR CONTRIBUTIONS

The article has been developed as a fully collaborative project with all three authors, Kaare Aagaard (KA), Mathias W. Nielsen (MWN), and Alexander Kladakis (AK) contributing equally to all tasks.

Kaare Aagaard: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Software; Validation; Visualization; Writing—original draft; Writing—review & editing. Mathias W. Nielsen: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Validation; Visualization; Writing—original draft; Writing—review & editing. Alexander Kladakis: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Validation; Visualization; Writing—original draft; Writing—review & editing.

COMPETING INTERESTS

The authors have no competing interests.

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APPENDIX

Table A1. Search strings used in funding-focused searches in Web of Science and Scopus

<u>Web of Science:</u>

TS=("R01 grant*" OR "baseline grant*" OR "funding mechanism*" OR "Research fund*" OR "Science fund*" OR "funding instrument*" OR" funding scheme*" OR "federal funding" OR "well-funded scien*" OR "well-funded research*" OR "well-funded investigat*" OR "grant portfolio*" OR "investment portfolio" OR "research grant*" OR "research investment*" OR "investment* in research" OR "science grant*") AND TS=("research productivity" OR "scientific productivity" OR "scientific performance" OR "research performance" OR "research impact" OR "technological performance" OR "grant size*" OR "scientific impact*" OR "citation impact" OR "scientific quality" OR "scholarly impact" OR "scientific output*" OR "critical mass" OR "centers of excellence" OR "centres of excellence" OR "grant size*" OR "funding size*" OR "epistemic effect*" OR "research excellence" OR "scientific excellence" OR "distributional equit*" OR "allocation of funding" OR "distribution of funding" OR "research allocation*" OR "funding allocation*" OR "funding distribution*" OR "size of research funding" OR "concentrat*" OR diversity OR diversifying OR diversification* OR dispersion OR dispersal OR "increasing marginal return*" OR "decreasing marginal return*" OR "large-scale" OR "small-scale" OR "small science" OR "big science" OR "funding cap" OR "project size" OR "peer-review system" OR "strategic funding" OR "research agenda" OR "ground-breaking research" OR "scientific breakthrough*" OR concentration*)

Timespan: no limitation

Index: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.

Document types: Article, Book, Book Chapter, Discussion or Letter.

Language: English

N publications retrieved: 1,158

<u>Scopus:</u>

TITLE-ABS-KEY ("R01 grant" OR "baseline grant*" OR "funding mechanism*" OR "Research fund*" OR "Science fund*" OR "funding instrument*" OR " funding scheme*" OR "federal funding" OR "well-funded scien*" OR "well-funded research*" OR "well-funded investigat*" OR "grant portfolio*" OR "investment portfolio" OR "research grant*" OR "research investment*" OR "investment* in research" OR "science grant*") TITLE-ABS-KEY ("research productivity" OR "scientific productivity" OR "scientific performance" OR "research performance" OR "research impact" OR "technological performance" OR "grant size*" OR "scientific impact*" OR "citation impact" OR "scientific quality" OR "scholarly impact" OR "scientific output*" OR "critical mass" OR "centers of excellence" OR "centres of excellence" OR "grant size*" OR "funding size*" OR "epistemic effect*" OR "research excellence" OR "scientific excellence" OR "distributional equit*" OR "allocation of funding" OR "distribution of funding" OR "research allocation*" OR "funding allocation*" OR "funding distribution*" OR "size of research funding" OR "concentrat*" OR diversity OR diversifying OR diversification* OR dispersion OR dispersal OR "increasing marginal return*" OR "decreasing marginal return*" OR "large-scale" OR "small-scale" OR "small science" OR "big science" OR "funding cap" OR "project size" OR "peer-review system" OR "strategic funding" OR "research agenda" OR "ground-breaking research" OR "scientific breakthrough*" OR concentration*)*

Timespan: no limitation

Document types: no limitation

Language: no limitation

N publications retrieved: 2,231

Table A2. Search strings used in searches combining a focus on funding and group size in Web of Science and Scopus

Web of Science:

TS = ("funding structure*" OR "grant award*" OR "research council" OR "funding agency" OR "science agency" OR "centers of excellence" OR "centres of excellence" OR "R01 grant*" OR "baseline grant*" OR "funding mechanism*" OR "Research fund*" OR "Science fund*" OR "funding instrument*" OR "funding scheme*" OR "federal funding" OR "well-funded scien*" OR "well-funded research*" OR "well-funded investigat*" OR "grant portfolio*" OR "investment portfolio" OR "research grant*" OR "research investment*" OR "investment* in research" OR "science grant*") AND TS = ("lab size*" OR "group size*" OR "big group*" OR "small group*" OR "team siz*" OR "big team*" or "small team*")

Timespan: no limitation

Index: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.

Document types: Article, Book, Book Chapter, Discussion or Letter.

Language: English

N publications retrieved: 52

Scopus:

TITLE-ABS-KEY ("funding structure" OR "grant award*" OR "research council" OR "funding agency" OR "science agency" OR "centers of excellence" OR "centres of excellence" OR "R01 grant*" OR "baseline grant*" OR "funding mechanism*" OR "Research fund*" OR "Science fund*" OR "funding instrument*" OR "funding scheme*" OR "federal funding" OR "well-funded scien*" OR "well-funded research*" OR "well-funded investigat*" OR "grant portfolio*" OR "investment portfolio" OR "research grant*" OR "research investment*" OR "investment* in research" OR "science grant*") TITLE-ABS-KEY ("lab size*" OR "group size*" OR "big group*" OR "small group*" OR "team siz*" OR "big team*" OR "small team*")*

Timespan: no limitation

Document types: no limitation

Language: no limitation

N publications retrieved: 126

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