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? Discussions on this question have recently been bolstered by research reporting accelerating trends towards funding concentration at the individual and group level. In this review article, we seek to qualify current 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 91 papers identified through systematic searches in Web of Science and Scopus, we present a condensation of central arguments for and against concentration or dispersal of research funding. Further, we juxtapose key findings from 20 years of empirical research on the relation between the size of research grants and scientific performance. Our review demonstrates a rather strong inclination in the literature towards arguments in favor of increased dispersal of research funding. A substantial body of empirical research also exhibits stagnant or diminishing returns to scale for the relationship between grant size and research performance. The policy implications of these findings are important as they question the rationale behind current funding trends and may point towards more efficient ways to allocate resources. The review highlights the need for more research on the interplay between science-internal mechanisms and policy priorities in accelerating the concentration of funding on fewer individuals and groups.

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. Is 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 towards 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 towards funding concentration at the individual and group level across a broad range of countries, while 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 (Lariviere 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, while 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 article, we seek to qualify current policy discussions on the benefits and drawbacks of the shift towards 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 level, we leave out a substantial literature on funding concentration at the national, regional, institutional, disciplinary, faculty and department level. While 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 towards 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 towards 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. We juxtapose these findings with ample evidence from the broader scholarship on team size and scientific performance and reach similar conclusions: the majority of existing studies either report no notable association between team size and scientific performance, or diminishing returns to scale with an increase in the size of groups. Finally, we assess the reviewed literature as a whole and identify limitations, gaps and fruitful avenues for further investigation.

The policy implications of these findings are important as they question the rationale behind current funding trends and may point towards 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 article.

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. Methods and materials

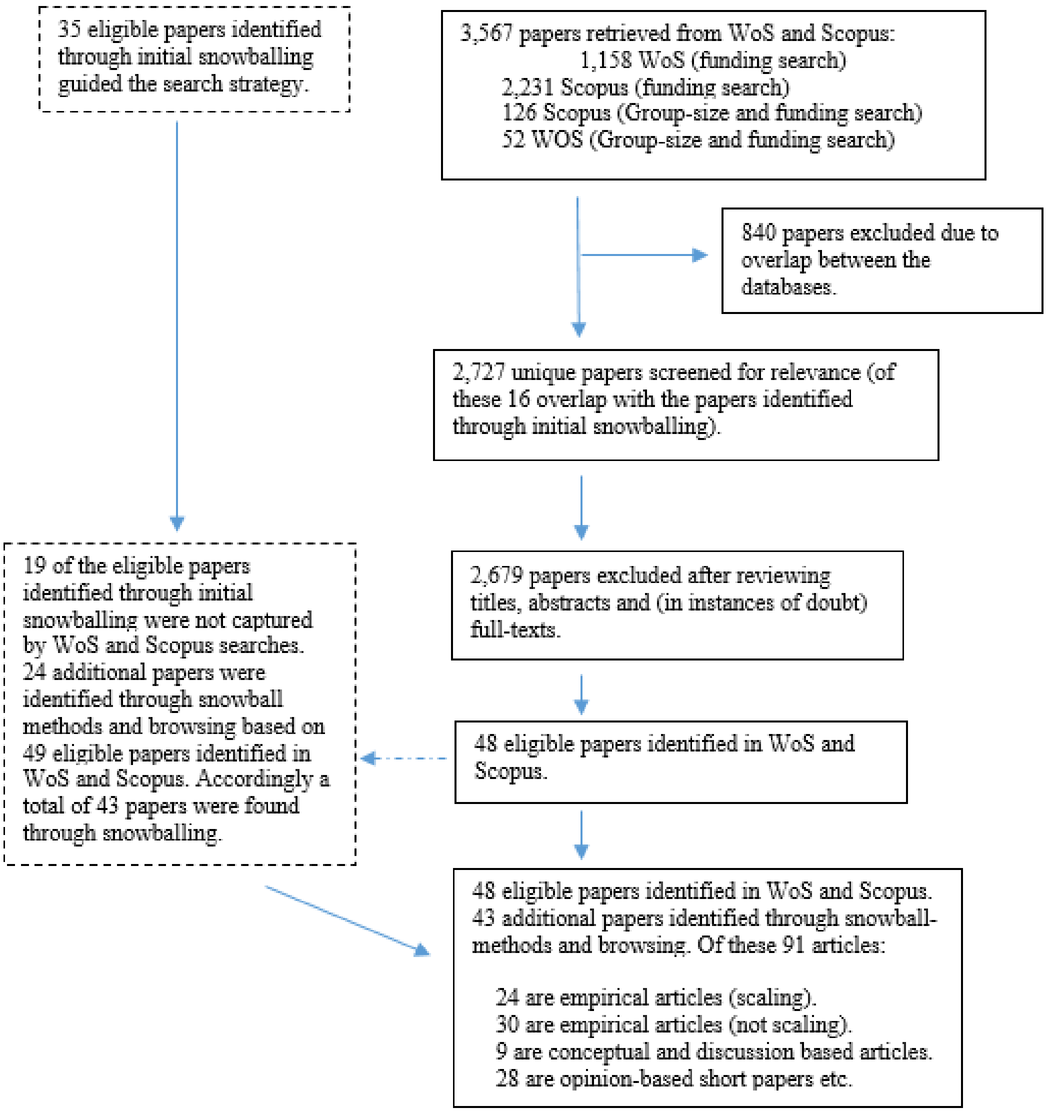
The literature on concentration and dispersal of research funding is still in its infancy and hence characterized by wide variations in terminology. These characteristics do not only reduce the value and usefulness of the available evidence, they also challenge systematic, semi-automated searches in 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 35 (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, sub-disciplinary, 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 spill-over effects of funding, and arguments pertaining to agglomeration effects[1]. While issues concerning concentration at the individual and group level are often touched upon in papers addressing the above-mentioned dimensions, these discussions are in most cases of secondary concern.

Next, systematic semi-automated searches in Web of Science (WOS) and Scopus were carried out. Based on the search strings presented in Tables A1 and A2 (Online Appendix), 3,567 potentially relevant papers were retrieved from Web of Science 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 91 papers (see Online 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, nine are theoretical, conceptual, review or discussion-based papers, and 28 are opinion-based short-papers, editorial materials, comments and blog posts from NIH and other funding organs.

[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 and Daraio 2005; Hellström and Jabrane 2017).

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



3. Descriptive analysis

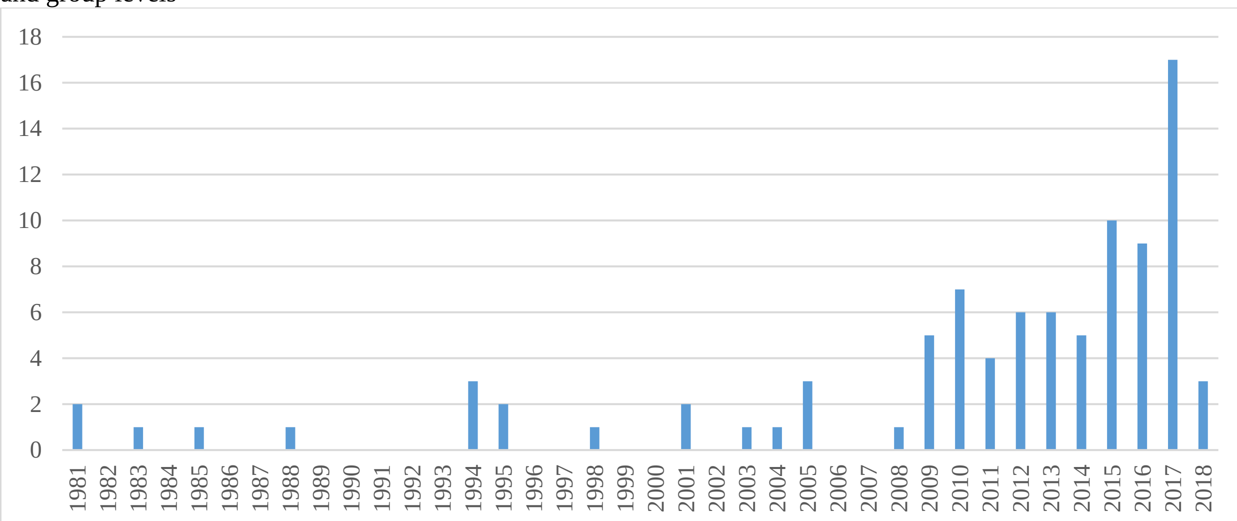
In the following section we detail temporal developments in the literature and map out variations in the geographic and disciplinary orientation of the sampled articles.

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 a total of 17 contributions. Hence, 72 out of 91 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 %)

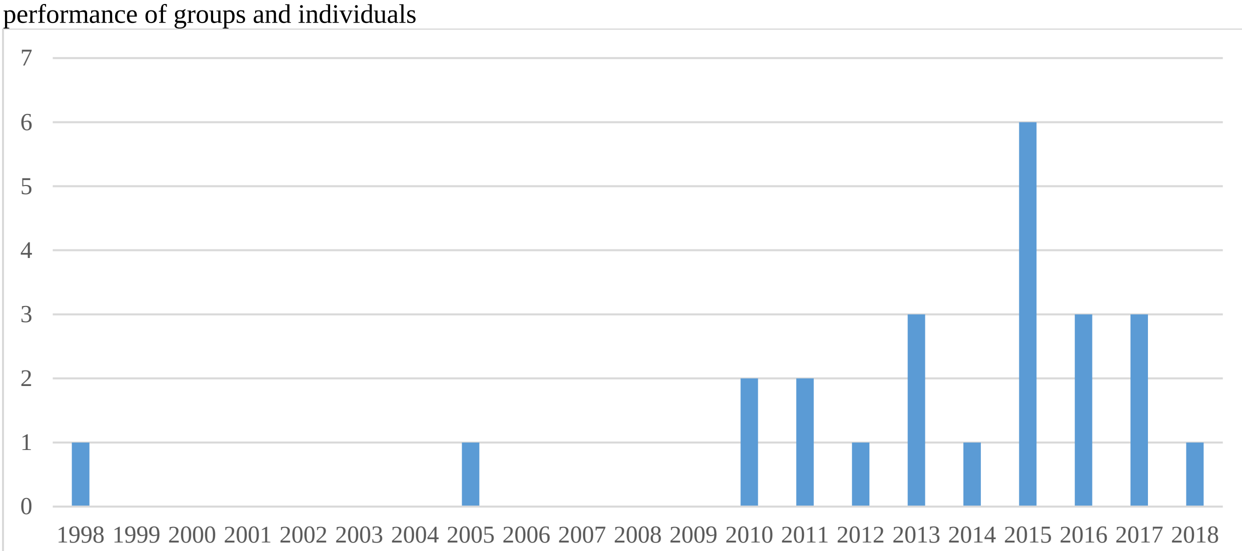
were published in the period from 2010 and onwards. This rapidly increasing interest in the topic is likely sparked by policy trends reshaping the funding and reward system in the new millennium, including funding cuts in the wake of the financial crisis (Alberts et al. 2014; Lepori et al. 2007), an intensified focus on excellence (Moore et al. 2017), an oversupply of junior researchers in temporary positions (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.

Figure 2: General overview of temporal developments in research on the effects of funding concentration at individual and group levels



Note: N= 91.

Figure 3: Developments in empirical research focusing on the relation between funding size and the research performance of groups and individuals

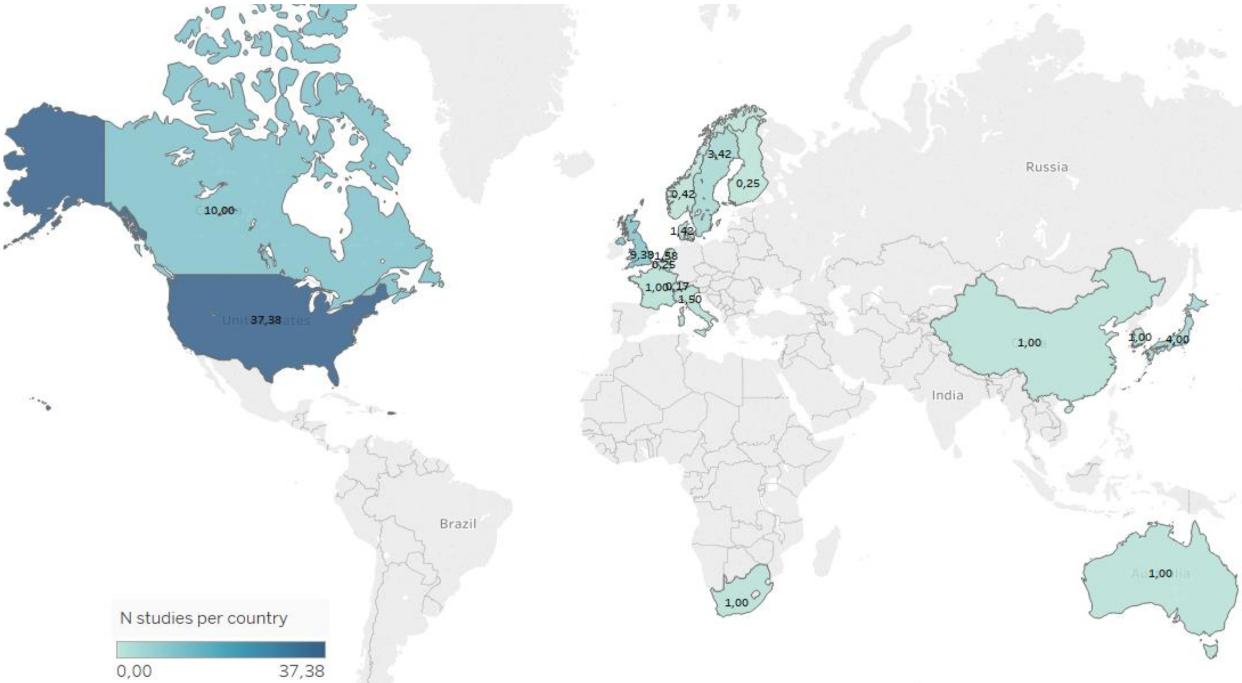


Note: N= 24.

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 USA (37) of which many are dealing with the practices of NIH. In general, more than half of the studies focus on the US and Canadian science contexts. Further, approximately one fourth of the papers focus on European countries, of which 9 examine the UK context. Other geographic regions are scarcely represented.

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. Eleven studies in the dataset do not provide specifications on national context. Three focus on EU countries as a whole. These 14 studies are not included in the figure.

Likewise, the 91 studies cover a variety of disciplinary fields, but also here the representation is highly skewed. There is a clear predominance of contributions with a main focus on the medical sciences (32), biomedicine (15) in particular. In addition, seven of the papers are concerned with the natural sciences, notably biology (5), while four studies examine the technical sciences. Further, there is an absence of contributions with a specific emphasis on the humanities and the social sciences. Finally, 23 of the studies do not have a specific disciplinary orientation, whereas 25 of the studies cover several main areas.

4. A condensation of main arguments in the literature

Despite geographical and disciplinary gaps in the literature, the selected set of 91 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.

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 manpower, equipment, infrastructure and for pooling of resources and expertise for large-scale research projects that would otherwise be impossible to carry out (Bloch and Sorensen 2015; Bonaccorsi and Daraio 2005; Breschi and 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 and Katz 2011; Johnston 1994; Johnston et al. 1995; Vaesen and Katzav 2017; von Tunzelmann 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.

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 and Sorensen 2015; Hicks and 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 and 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 and 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 unanimous support for stronger concentration. The authors argue that R&D funding – due to a purported inequality aversion inherent in the funding system and among policy makers – 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).

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 and 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 and Daraio 2005; Hellström et al. 2017). In particular, the shift from individual towards collective modes of research (from small science to big science) is seen as a development which 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 and 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 and Daraio 2005; Hellström et al. 2017; Hicks and Katz 2011).

Table 1: Arguments in favor of concentration

Type of argument	Argument	Selected references
Efficiency	Critical mass/avoiding dilution of resources	Hellström et al. (2017); Bonaccorsi and Daraio (2005); Johnston et al. (1995); Hicks and Katz (2011); Vaesen and Katz (2017); Kenna and Berche (2011)
	Economies of scale	Hellström et al. (2017); Ida and Fukuzawa (2013); Bloch et al. (2016)
	Smaller administrative burden	Berg (2012); Johnston (1994)
Epistemic effects	Scientific excellence	Hellström et al. (2017); Bloch et al. (2016); Hicks and Katz (2011); Breschi and Malerba (2011); Hellström et al. (2017); Bloch and Sorensen 2015
	Merit-based funding system	Hicks and Katz 2011; Berg (2012)
Organizational conditions	Stability/flexibility	Hellström et al. (2017); Bonaccorsi and Daraio (2005)
	Collaboration	Hellström et al. (2017); Bloch et al. (2016); Bonaccorsi and Daraio (2005); Johnston (1994)
	Spillover effects	Bonaccorsi and Daraio (2005)
	Recruitment	Hellström et al. (2017); Bloch et al. (2016); Bonaccorsi and Daraio (2005); Johnston (1994)
	Equipment/infrastructure	Bonaccorsi and Daraio (2005); Gallo et al. (2014); Johnston (1994)

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. Here the arguments can 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.

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 and Daraio 2005; Johnston et al. 1995; Nag et al. 2013; von Tunzelmann 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 and Daraio 2005; von Tunzelmann 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 and 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 5-8 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 and 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' that spend nearly full 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 and Sorensen 2015; Hicks and Katz 2011; Sousa 2008).

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 and 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 and 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 and 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 and Sorensen 2015; Fortin and 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 2015, Peifer 2017).

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 increases the diversity of fields and specialties of research as well as the range of opportunities available to students at both the institutional and the systemic level (Fortin and Currie 2013; Lauer 2014; Vaesen and Katzav 2017). Thus, a higher degree of dispersal of grant funding will serve to keep more students and scientists active in research (Fortin and 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 and 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 and 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 are provided for researchers within smaller research fields allowing pockets of excellence to grow outside of prioritized areas (Bloch and Sorensen 2015). Finally, it is suggested that increased dispersal of funding will reduce trends towards hypercompetition and serve to curb the Matthew Effects and mechanisms of cumulative advantage already inherent in the science system (Fang and Casadevall 2016). In addition, it is argued 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 (Johnston 1994).

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 that this process is unreliable and subject to a number of biases (Fang and Casadevall 2016; Gordon and Poulin 2009; Kimble et al. 2015; Vaesen and Katzav 2017). Likewise, it is suggested that low success rates induce conservative, short-term thinking among applicants, reviewers, and funders. The system, it is argued, now favors those who can guarantee results rather than those with innovative and potentially path-breaking ideas that, by definition, cannot promise success (Gordon and Poulin 2009). In addition, Berg (2012) points out 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 and Sorensen 2015). As a result many meritorious projects remain unfunded and undone (Fang and Casadevall 2016; Gordon and Poulin 2009). 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 and Casadevall 2016; Fortin and Currie 2013; Gordon and Poulin 2009; Vaesen and Katz 2017).

Table 2: Arguments in favor of dispersal

Type of argument	Argument	Selected references
	Diseconomies of scale	Berg (2012); Cook et al. (2015); Lorsch (2015); Mongeon et al. (2016); Lauer et al. (2015); Peifer (2017); Fortin and Currie (2013); Bloch and Sorensen (2015); Breschi and Malerba (2011); Alberts (1985, 2012); Bonaccorsi and Daraio (2005)

Efficiency	Diminishing marginal returns	Mongeon et al. (2016); Breschi and Malerba (2011); Lorsch (2015); Fortin and 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 and Katzav (2017); von Tunzelmann et al. (2003); Johnston (1994); Bloch et al. (2016); Bloch and Sorensen (2015); Alberts (1985)
	Excess size leads to fragmentation, inertia and inefficiencies	Alberts (1985); Breschi and Malerba (2011); Bloch and Sorensen (2016); Mongeon et al. (2016); Fortin and Currie (2013); Vaesen and Katzav (2017); Johnston (1994)
	Innovative researchers are turned into fundraisers and managers	Kimble et al. (2015); Bloch and Sorensen (2014); Alberts (1985)
	Allocative and economic inefficiencies	Nag et al. (2013); Bloch and Sorensen (2015); Hicks and Katz (2001); Sousa (2008); Mongeon et al. (2016)
Epistemic effects	Diversification spreads risk and increases chances of breakthroughs	Fortin and Currie (2013), Lorsch (2015); Lauer (2014); Fang and Casadevall (2016); Peifer (2017); Ioannidis (2011); Vaesen and Katzav (2017); Berg (2012); Mongeon et al. (2016); Fang and Casadevall (2016)
	Dispersal of funding as means to avoid mainstream, risk-averse research	von Tunzelmann et al. (2003); Kimble (2015); Peifer (2017); Bloch and Sorensen (2015)
Organizational issues / system level issues	Dispersal keeps researchers and students active with research	Fortin and Currie (2013); Lauer (2014); Vaesen and Katzav (2017)
	Securing a strong growth layer of early and mid-career researchers	Peifer (2017); Fang and Casadevall (2016); Berg (2012); Alberts (1985)
	Broader knowledge pool and greater research breadth + Pockets of excellence	Fortin and Currie (2013); Vaesen and Katzav (2017); Bloch and Sorensen (2014); Kimble et al. (2015); Katz and Matter (2017); Lauer (2014)
	Avoid Matthew Effects/ cumulative advantages and hypercompetition	Berg (2012); Fang and Casadevall (2016); Bloch et al. (2016); Bol et al. (2018)
Problems with peer review and allocation procedures	Problems with peer review	Vaesen and Katz (2017); Kimble et al. (2015); Fang and Casadevall (2016); Lorsch (2015); Katz and Matter (2017); Gordon and Poulin (2009);
	Egalitarian distribution of funding	Fortin and Currie (2013); Gordon and Poulin (2009); Ioannidis (2011); Vaesen and Katzav (2017)

5. Empirical studies examining effects of funding size on research performance

As should be clear from the preceding sections, the 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 such articles (Table A3). 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 U.S. and Canada are overrepresented in this subset. Twenty-one of the studies are based on observation data and two use cross-sectional survey data. Nine of the 23 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), citation impact (N= 12), and to a lesser extent by journal impact factors (N= 4), journal rankings (N= 1) and patents (N= 1).

Eighteen studies examine correlations between the size of research grants and scientific performance. Of these, 16 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 and Urata 2015; Berg 2010a; Berg 2010b; Bloch et al. 2016; Breschi and Malerba 2011; Danthi et al. 2016; Doyle et al. 2016; Fortin and Currie 2013; Gallo et al. 2014; Jung et al. 2017; Lauer et al. 2015; Lauer et al. 2017; Mongeon et al. 2016; Nag et al. 2013; Spanos and 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 National Institute of General Medical Sciences, Berg (2010a; 2010b) 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. The remaining two studies examining associations between grant size and scientific performance report positive effects, but none of these look into possible inflection points for diminishing-marginal returns (Katz and Matter 2017; Yan et al. 2018). Further details on the empirical studies included in the review are presented in Table A3 (in the online appendix).

In summary, our comprehensive survey of extant empirical research exhibits little compelling evidence of increasing returns to investment. A few studies demonstrate positive associations between grant size and project size on the one hand, and bibliometric indices of scientific performance on the other. However, none of these studies examine 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 investment with respect to research output and impact for grant-sizes above a certain threshold. 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.

To test the robustness of these findings, we juxtaposed our analysis with evidence from the scholarship on team size and scientific performance. In line with the results presented above, our survey of this literature demonstrates either no association between team size and research performance or decreasing returns to scale with increasing group sizes. A majority of the reviewed studies suggest that small- and medium-sized research teams perform better than large ones, although reports on the optimal team size vary considerably, depending on discipline and type of research. Search methods for the survey of team size and performance are specified in the Online Appendix, Table A4, Figure A1. Table A5 (in the Online Appendix) summarizes the main results of each study included in this part of the review and offers specification on methodology and national context.

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 towards 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 towards 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 benefits of dispersal suggested in the empirical literature draw a conservative picture, since 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 do 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. Need for a more integrated and forward moving scholarly effort

While the reviewed literature presents a fairly strong case against funding concentration, it is critical to emphasize the limitations of the available knowledge. As the review demonstrates, the existing 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. However, while there is certainly room for improvement with respect to these issues, the key limitation of the literature concerns its lack of coherence, cross-referencing and theoretical elaboration. While 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. However, as we have shown, most of the reviewed articles, which in most cases limit their focus to specific disciplinary and/or national contexts, unfortunately 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 thus are 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 – e.g. classical sociology of science contributions by Merton (1968) and Cole and Cole (1974). Accordingly, another limitation concerns the relatively weak theoretical basis of most existing contributions. This limitation is particularly evident in discussions of the causes of the observed developments and in the discussion of potential remedies. Our final section points towards some of these more theoretical issues which deserve further attention in future studies.

6.3. Attention to factors influencing degrees of concentration

In spite of the limitations outlined above, the results presented in this review still provide compelling reasons to discuss whether and to what extent the current science funding system needs to be adjusted in order to reduce trends towards further concentration. Hence, the need for more thorough investigations of how to efficiently balance concentration and dispersal of research funding must be accompanied by more nuanced understandings of the way in which (combinations of) different types of competition shape allocation patterns and eventually research practices. An accurate understanding of these mechanisms is a prerequisite for effective policy interventions.

It is hence important to acknowledge that rising concentration of funding is not merely the result of conscious and explicit research policy decisions (for example to allocate funding in fewer and larger portions or to increase the degree of funding allocated in competition), but may also be and effect of (or amplified by) internal Mathew Effects in the reward system of science. Furthermore, concentration of research funding may also be an unintended consequence of uncoordinated grant decisions made in isolation across a wide variety of funding organizations. Hence, aggregated funding patterns are not only the result of strategic decisions at the policy level, but may also be the sum of a number of micro decisions taken in relative isolation by many different actors. This type of unintended concentration of funding will in particular occur when different funding agencies operate with relatively uniform excellence criteria and when they lack oversight over allocation decisions made elsewhere in the system. Both conditions appear to be widespread in most funding systems.

Aggregated allocation patterns are in other words most often shaped by a number of interconnected, science-internal and science-external factors that produce intended as well as unintended effects. This interplay needs to be taken into consideration when suggestions of 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 however indications that most countries and most fields are in need of initiatives leading to less concentration rather than more. While policy makers obviously worry about spreading out the available funding too thinly, and while 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 towards concentration - and that this may harm the progress of science. As highlighted by both the History and the Philosophy of Science scientific advancement is best promoted by ensuring competition between ideas, theories, paradigms, 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.

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