How does prolific professors influence on the citation impact of their university departments?

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Abstract

Professors and associate professors ("professors") in full-time positions are key personnel in the scientific activity of university departments, both in conducting their own research and in their roles as project leaders and mentors to younger researchers. Typically, this group of personnel also contributes significantly to the publication output of the departments, although there are also major contributions by other staff (e.g. PhD-students, postdocs, guest researchers, students and retired personnel). The scientific productivity is however, very skewed at the level of individuals, also for professors, where a small fraction of the professors, typically account for a large share of the publications. In this study, we investigate how the productivity profile of a department (i.e. the level of symmetrical/asymmetrical productivity among professors) influences on the citation impact of their departments. The main focus is on contributions made by the most productive professors. The findings imply that the impact of the most productive professors differs by scientific field and the degree of productivity skewness of their departments. Nevertheless, the overall impact of the most productive professors on their departments' citation impact is modest.

Introduction

It is well known that there are large differences in publication productivity between researchers where a relatively small share of the individuals contribute to the majority of the publications. Such patterns have been found at various levels of the research system, such as institutions, departments and research groups. In Norway, several recent discipline evaluations commissioned by the Research Council of Norway have also put attention towards the large shares of unproductive researchers – and/or the conspicuous presence of a few highly productive and dominating individuals at the departmental level. The evaluations do not provide clear answers on whether such an asymmetrical productivity distribution is a strength or a weakness. Two different interpretations might be: 1) having a few highly productive researchers is stimulating the research performance (productivity/quality) of other staff members, 2) having a few highly productive researchers is a barrier for other researchers' performance, as resources, research focus and so on is concentrated on a few individuals. These prolific researchers are typically experienced seniors (professors), head of

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research groups, and often considered as the qualitatively best researchers at their departments. In this paper, we investigate what influence they have on their departments' citation impact. Since this group of researchers are often highly productive in their publication output, we may expect that their influence on their departments' citation indexes are strong, as the citation index usually increase with high publication output (e.g. Costas et al. 2009; Katz 1999).

The idea of productivity differences – where the publication output is highly dependent on a few individuals is not new. Already back in 1926, Lotka formulated his inverse square law of productivity, which states that the number of authors producing *n* papers is approximately $1/n^2$ of those producing one (Lotka 1926), implying that 60 per cent of all authors in a given field will have produced just one publication. Although most studies have shown that productivity differences are not as strong as predicted by Lotka, they do document the existence of such differences and that, generally, we may find them across both institutions and scientific fields (e.g. Abramo et al. 2012, 2013; Kyvik 1989, 1991; Larivière et al. 2010; Ruiz-Castillo & Costa 2014). In Ruiz-Castillo and Costas' (2104) study of 17.2 million authors in Web of Science (48.2 million publications), 5.9 per cent of the authors accounted for 35 per cent of all publications. The average percentage (of the scientific fields included) of authors with just one publication in 2003-2011 was 69 per cent.

Also identified a long time ago, is the extreme skewness of the citation distribution (e.g. Price 1965). For example, almost 50 per cent of some 50,000 Web of Science-indexed Norwegian articles from 1981-1996 had either never been cited or just cited once or twice five years after publication, while one per cent of the papers had been cited more than 50 times five years after publication (Aksnes 2005). In combining these two types of skewnesses, Abramo et al. (2012) found that 6.6 per cent of 39,000 Italian university researchers from the hard sciences did not have any publications in Web of Science over a five-year period, and that 7.8 per cent had not been cited. Such studies are applicable for the total population of researchers – there are fewer studies on productivity differences across e.g. university departments (for example Perianes-Rodriguez and Ruiz-Castillo (2014) who studied university economic departments where productivity distributions were very different across departments).

While productivity differences among *individuals* is a widely scrutinized research questions, less focus has been directed towards understanding under which circumstances productivity differences affect the citation impact at *group level*. Studies that investigate productivity and citation impact are typically aiming at analyzing the association between individuals' scientific production and their citation impact. For example, Abramo et al. (2014), identified a moderate correlation between being among the five per cent most productive researchers in Italian hard sciences, and the probability of having produced highly cited papers (i.e. the five per cent most cited publications in the same year and subject field). Lariviére et al. (2010) added a third dimension when analyzing the concentration of publications, citations and research funding among 13,000 Canadian university professors, concluding that the majority of all three dimensions were obtained by a small minority of professors. Another research tradition within productivity studies – with an extensive literature - is that of 'critical mass' research, considering the importance of the number of researchers on their groups' productivity (see von Tunzelmann et al. (2003) or University Alliance (2011) for overview articles). A more limited number of studies have analyzed how size may affect research quality at group level (e.g. Kenna & Berche 2011). Kyvik (1995) argued that one of the reasons why larger departments

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could promote scientific publications is that interactions are more likely in large than in small departments, leading Smeby & Try (2005) to claim that a 'cooperating climate' is a better predictor on such interactions than department size. In our study, we have used data at department levels from the four major research universities in Norway (Oslo, Bergen, Tromsø and the Norwegian University of Science and Technology (NTNU) in Trondheim), and focus analyses on professors and associate professors in full-time positions (*from now only referred to as "professors").* These staff members are the key personnel in the publication production at their departments, but also in the acquisition of new projects and funding, in leading research projects and in the mentoring of younger researchers. Hence, to the extent that the productivity and scientific quality can be nurtured, this group of senior staff represent the most influential group. We also believe this group represents the most likely driving force (or lack of thereof) for a 'cooperating climate', described above, rather than this being the result of postdocs, PhD-students, researchers, etc. who may only be present at their departments for a limited number of years.

Knowing that the productivity levels at Norwegian university departments are highly skewed (Piro et al. 2013), we want to study the influence of highly productive professors under different climates of departmental productivity. We measure productivity profiles of the university departments by a *skewness indicator*, indicating how asymmetrical the scientific production is. At some departments, a small fraction of these researchers produces a high share of the publications. At other departments, the production is distributed more evenly across staff members. In both cases, the average productivity may be the same – but under very different conditions. We may hypothesize that at departments where the majority of the publication output is produced by a larger group of staff members – compared to a very few – it is more likely that the departments' citation indexes will be less dependent upon the contributions from a few researchers, i.e. in so far that the latter group is in fact highly cited. In departments with less skewed productivity profiles, the removal of the most productive researchers (again, in so far they are highly cited) will have a smaller effect upon citation indexes, as the concentration of publications and citations are more evenly distributed.

The first research question in our study is whether low, moderate or highly skewed publication distributions among professors are differently associated with the departments' citation indexes (and whether such associations are field-dependent). *The second research question* is whether being a highly productive professor has different impact on the departments' citation impact under different productivity profiles at department level. *The overall aim of this study* is to investigate whether an individual level predictor of citation impact (the productivity of professors) are dependent upon a group-level indicator (the composition of the productive professors) at the departments.

We believe this is an important research question, as it may enrich our understanding of what influence the most prolific researchers have on their departments. With the seemingly increasing focus on scientific excellence in science policy, attracting productive researchers would appear an appropriate strategy for any research institution.

Data and methods

In this study, we use publication data from Web of Science (WoS) and the national Norwegian publication database, CRIStin (Current Research Information System in Norway). In 2004, Norway implemented a bibliometric model for performance-based funding of research institutions. These

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institutions' budget allocation is now partially based on their scientific and scholarly publishing, as documented in CRIStin. The database includes all types of scientific publications, in all fields of research in the higher education sector. Two criteria determine whether publication channels can be accepted for the model: (1) they must use external peer review, and (2) no more than two thirds of the authors that publish through a channel can be from the same institution (Schneider 2009). Only publications classified as original articles or overview articles are rewarded in the funding system. Bibliographic data are collected through a common documentation system used by all institutions, resulting in a complete, verifiable, and structured data for use in bibliometric analysis.

In the CRIStin database, publication activity is reported by the institutions as standard bibliographic references, which are analyzable by publication channel and type of publication. A dynamic authority record, covering 19,000 controlled scientific and scholarly publication channels ensures that references from non-scientific publications are not entered into the system. Publication data from professional bibliographic data sources (e.g. the Web of Science) is imported to the CRIStin system, to facilitate the registration of publications by the employees. The database is therefore well suited to productivity analyses across subject fields, as a large-scale database, with complete data covering not only journals, but also monographs and book chapters. The researchers have unique IDs in the CRIStin system. This provides us with information about each researchers' affiliation and position. However, a researcher is included in the database only as far as he or she has registered a publication, i.e. researchers that have not yet published are not part of the database.

This study is limited to the four major research universities in Norway who account for 72 per cent of national research output in the higher education sector. From the period 2009-2010, we have identified all full-time professors at these universities, and their scientific publications in 2010-2012. For the citation analyses where department citation index is the key variable, we have identified all publications from the university departments in order to create the citation indexes.

A total of 2,778 full-time professors at 108 university departments were included in the calculations of productivity differences at department level: 40 departments within medicine and health sciences (including psychology), 24 departments within the social sciences, 24 departments within the natural sciences and 20 departments within engineering. Departments within humanities were excluded as the number of publications that are indexed in Web of Science in this field, thereby also the citation numbers, is too small for calculating reliable citation indicators. The study was further limited to departments with at least five full time staff members (professors) who had published during the period (at such small units, the publication and citation numbers are volatile, potentially caused by random fluctuations). Further, a threshold of 20 fractionalized publications in Web of Science at department level was used in the calculation of field normalized citation indicators, where the field normalization is done at item level – the citation for each paper is divided by the average citations for the field of that paper (cf. Lundberg 2007). In the citation analysis (of Web of Science publications), we included the 1,084 (out of 2,778) professors who had published one or more articles in journals indexed in Web of Science during the period where the author address matched their full-time professor affiliation.

Productivity data is based on publication points, i.e. fractionalized publications (2010-2012) in the Norwegian funding system for higher education institutions. In this system, scientific articles and

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book chapters (anthologies) are given one point, and monographs five points. However, we also analyse the publication productivity based on the number of Web of Science publications (using whole-counts). Baccini et al. (2014) advocate the use of both databases such as Web of Science/Scopus and national databases so that research activities from the social sciences and humanities are not systematically undervalued, but we also believe these two ways of measuring research production (fractionalized publication points versus number of unfractionalized publications in WoS) measure two very different things. Many researchers who have contributed to a very large number of publications may end up with a relative small number of publication points after fractionalization (and opposite: a researcher with just one publication may end up with many points if he or she is the only author of a monograph). We believe that it is important to apply this complementary measurement principle, as the size based on whole-counts indicates how active the researchers are in different networks, their supervision role, etc., which may also be seen as a type of productivity although it generates a lower number of (fractionalized) publication points.

For each department we have calculated a *skewness indicator* (Doane & Seward 2011), representing how (a)symmetrical the distribution of both fractionalized publication points and number of WoS publications (whole counts) are among full-time professors, i.e. how much it differs from the normal distribution. The rule of thumb is that a skewness greater than 1.0 (or less than -1.0) is substantial and that the distribution is far from symmetrical (GraphPad Software 2015). In order to prove normal univariate distribution, values between -2 and +2 are considered acceptable (George & Mallery, 2010). Hence, the skewness indicator has been categorised as low (less than ±1.0), medium (±1.0 – ±2.0) or high (more than ±2.0). We chose three categories, as a dichotomous categorization of the departments would not take into account what we believe is an *a priori* logical way to expect a distribution of productivity differences: university departments are not either skewed or not skewed. Rather, it is more likely that all departments are skewed; with some being either highly or only moderately, skewed. Admittedly, this choice will be decisive to our results, but so would any other categorization of skewness be, and in using a threefold categorization we have managed both to create a discriminating skewness indicator, without losing to many degrees of freedom (as a more comprehensive skewness scaling would have caused). However, in the analysis of WoS publications only, we labelled the departments more pragmatically as almost all departments were highly skewed (cf. Table 1). At some departments, the number of WoS publications among professors varies from zero to several hundreds, leading to highly uneven individual publication numbers. We allowed the skewness labelling of WoS publications to follow the same distribution as the skewness distribution based on publication points, which roughly showed a 25-50-25 distribution (25 per cent of the departments being lowly skewed, 50 per cent being moderately skewed and 25 departments being highly skewed).

In addition to this, we calculated the percentage of professors at each department contributing to 25 and 50 per cent[1], respectively, of the publication output among the professors at the departments (both in terms of publication points and number of WoS publications). The rationale for doing this was to identify the most productive permanent staff members, whose contribution to their departments' citation impact is the focal point of this study. Again, the decision to define a highly

[1] We also calculated numbers for professors contributing to 75 per cent, but this was largely identical to the numbers for 50 per cent, and the results are not presented here.

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productive professor as one that contributes to 25 or 50 per cent of the scientific production will be decisive to our results. Our choice was not derived from results in – or lessons from - other studies (simply because we have not found any studies that define how high productivity a researchers must have to be labelled 'highly productive'). Nevertheless, initial results showed (see next section) that the measures identified 10 and 24 per cent, respectively, of the professors contributing to 25 and 50 per cent of the publication output, which to us appeared to be probable percentages of highly productive professors at the departments.

Results

Table 1 provides descriptive statistics from the Norwegian university department. The average number of publication points is on average higher in the social sciences than in natural sciences and medicine (see also Piro et al. 2013).

Table 1 Descriptive staff, productivity and skewness data (by field and in total)

	Eng.	Nat.	Med.	Soc.	Total
Number of departments	20	24	40	24	108
Man-years statistics					
Mean number of staff man-years (scientific and non-scientific)	89.9	93.6	92.5	41.7	81.2
- Minimum	35.6	25.7	13.8	10.8	10.8
- Maximum	188.0	198.8	283.2	85.9	283.2
Mean number of full-time professors	22.7	28.4	30.7	17.6	25.8
Mean Percentage professors of total man-years	26.4	31.1	26.9	42.9	31.3
- Minimum	13.4	17.1	10.1	19.0	10.1
- Maximum	49.9	54.5	55.1	61.3	61.3
Publication statistics					
Mean number of publication points	125.1	99.7	81.1	71.5	91.2
- Minimum	44.7	21.2	8.7	18.7	8.7
- Maximum	332.3	203.1	229.8	157.3	332.3
Mean number of WoS publications	128	289	288	36	203
- Minimum	12	22	23	13	12
- Maximum	322	749	1063	87	1063
Mean number of publishing persons at the departments	113	130	148	39	113
Mean number of publication points from professors	64.0	49.6	37.9	44.1	46.7
Mean publication points per professor	3.02	1.79	2.05	2.56	2.29
Mean number of WoS publishing professors at the departments	8	12	12	6	10
Mean number of WoS publications per professor	8.8	14.1	11.9	2.8	10.8
Skewness statistics					
Average skewness value (publication points)	1.59	1.54	1.60	1.41	1.53
- Minimum	0.31	0.51	0.11	0.45	0.51
- Maximum	3.42	3.04	3.47	3.56	3.56
Average skewness value (WoS publications)	1.79	1.96	1.77	1.87	1.84
- Minimum	0.23	0.28	0.47	0.40	0.23
Maximum	4.48	3.30	3.19	3.37	4.48
Mean share of professors contributing to 25% of publication points among professors	0.11	0.11	0.09	0.11	0.10
- Minimum	0.05	0.07	0.04	0.07	0.04
- Maximum	0.17	0.22	0.18	0.20	0.22
Mean share of professors contributing to 25% of WoS publications among professors	0.07	0.07	0.07	0.11	0.08
- Minimum	0.03	0.03	0.03	0.03	0.03
- Maximum	0.17	0.22	0.42	0.63	0.63

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Mean share of professors contributing to 50% of publication points among professors	0.22	0.25	0.22	0.28	0.24
- Minimum	0.14	0.08	0.14	0.07	0.07
- Maximum	0.33	0.45	0.33	0.40	0.45
Mean share of professors contributing to 50% of WoS publications among professors	0.14	0.14	0.14	0.16	0.14
- Minimum	0.07	0.06	0.06	0.05	0.05
- Maximum	0.33	0.27	0.42	0.63	0.63

The 2,778 full time staff members contributed with a total of 51.2 per cent of the publication points produced, i.e. almost half of the publication output was produced by doctoral students, post docs., guest researchers, technical staff, students, etc. The highest shares of output from permanent professors was found in the social sciences (61 per cent), whereas the shares differed little in engineering (51 per cent), natural sciences (50 per cent) and medicine (47 per cent). This may reflect differences in the staff composition at field levels, for example in terms of technical staff, non-tenured and recruiting personnel.

The lowest skewness values based on fractionalized publication points are on average found in the social sciences, but when measured by number of WoS publications, the skewness is almost as high as that in the natural sciences – an expected consequence as publishing in WoS journals is more seldom in the social sciences (cf. Baccini et al. (2014) who identified an extreme skewness in Scopus publication data among Italian researchers, but a more linear publication distribution when a national database for publishing was used). For all fields, the skewness value increases when it is based on WoS publications rather than publication points.

On average, the shares of full-time professors contributing to 25 per cent of the total publication points among professors differ little by scientific field. The share is 9 per cent in medicine and 11 per cent in all other fields. Within each field, the differences between the departments vary from four to more than twenty per cent. In the professors' contributions to WoS publications, the shares differ much more by field (it is especially high in the social sciences, where there is often only a handful of staff members that publish at all in journals indexed in WoS).

Fig. 1 Mean proportion of professors contributing to 25 and 50 per cent of publication points and Web of Science publications

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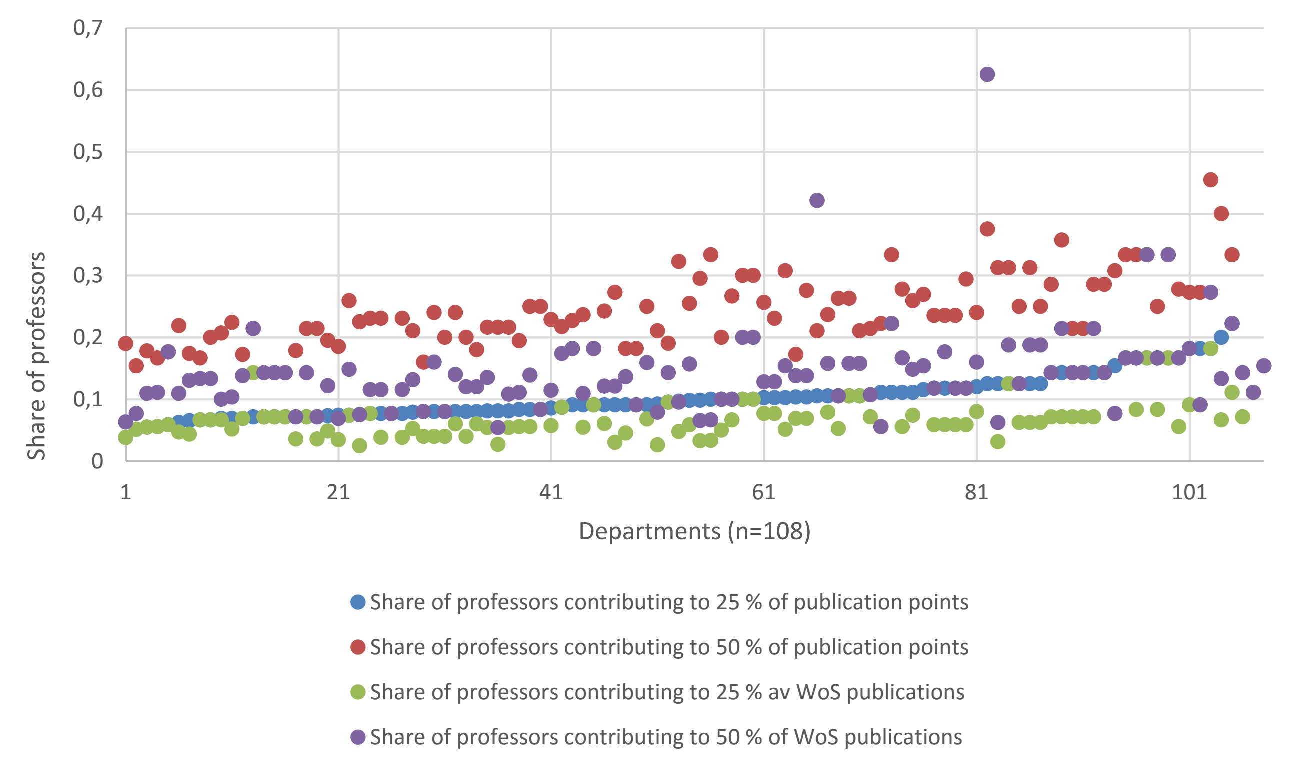

A stable pattern is observed when we look at the percentage of professors making up 50 per cent or more of the publication points. The shares only vary on average from 22 to 28 per cent across fields, but within each field there are strong differences between departments. The most differentiated picture is observed for the social sciences where the shares vary from seven to 40 per cent. In WoS publications, medicine stands out in addition to social sciences as a field with strong differences in professors' shares of the output. Overall, there are no major trend differences between the shares of professors contributing to 25 and 50 per cent of the publication output (Figure 1).

Field normalized citation indexes by individual level productivity

There was no significant correlation between these professors' publication points and their field normalized citation indexes (also not when studying correlations by field). The publication output, however, is significantly correlated with the field normalized citation index when we use number of Web of Science publications (r=.231, sig:.000). The correlation is not significant for researchers in engineering and social sciences, but is so in the natural sciences (r=.303, sig:.000) and in medicine (r=.317, sig:.000).

In Table 2, we compare the field normalized citation indexes across fields, based on a categorization of the professors from being among the 20 per cent most productive professors to being among the 20 per cent least productive professors. The professors are classified both according to their productivity levels within their scientific fields, and in total (i.e. their institutional affiliation is not considered in the latter, only the field they belong to). In engineering it is the group of the least productive researchers that have the highest citation index (Table 2).

Table 2 Mean field normalized citation indexes by levels of productivity among professors

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Productivity based on publication points	Eng.	Nat.	Med.	Soc.	Total field	Total overall
1 (the 20% least productive professors)	139.6	102.9	122.1	119.5	119.4	117.6
2	85.1	144.9	132.1	111.0	125.5	134.4
3	98.6	152.8	126.5	134.9	130.3	127.0
4	83.3	125.7	117.0	91.2	110.8	119.8
5 (the 20% most productive professors)	109.6	127.4	122.2	129.3	122.5	109.3
Productivity based on number of WoS publications						
1 (the 20% least productive professors)	148.7	81.8	87.6	104.1	96.4	105.0
2	75.7	108.6	100.3	132.3	102.9	90.1
3	97.5	126.3	122.6	87.1	116.9	109.6
4	96.6	154.1	134.1	136.4	133.3	129.1
5 (the 20% most productive professors)	114.4	188.8	180.0	141.2	167.9	168.5
N	169	290	483	142	1084	1084
Total average field normalized citation index	103.1	130.8	123.9	117.1		121.6

There is not much evidence in Table 2 to support the hypothesis that the most productive professors are also the most cited professors when we look at their production of publication points, but this is completely different when we use (whole counts of) number of WoS publications. In medicine and natural sciences in particular, we find a strong linear relationship with the citation index increasing strongly as the productivity levels increase.

Field normalized citation indexes by department level productivity

In Table 3, we present field normalized citation indexes by field. First, in total for the departments, and then after the contribution of the professors contributing to 25 and 50 per cent of the professors' total output are removed from the analysis. We present the results both in crude numbers and then standardized by the initial index (i.e. the citation index for the field is set as 1.0). In removing the professors contributing to 25 and 50 per cent of the output, we do not only remove each author's contribution, but we remove the publication itself. By doing so, we make sure that any traces of the most productive professors are not present in the publications that the new citation indexes are derived from.

Table 3 Mean department field normalized citation indexes across fields and productivity levels

Analysis based on: Publication points	Eng.	Nat.	Med.	Soc.	Total
Mean citation index	105.2	139.1	124.2	114.5	121.8
Mean citation index excl. 25 % most productive professors	106.4	138.3	121.4	115.0	121.0
Mean citation index excl. 50 % most productive professors	104.6	140.6	120.5	114.5	120.6
Standardized[1] mean citation index excl. 25 % most productive professors	1.01	0.99	0.98	1.00	0.99
Standardized[1] mean citation index excl. 50 % most productive professors	0.99	1.01	0.97	1.00	0.99
Analysis based on: WoS publications	**Eng.**	**Nat.**	**Med.**	**Soc.**	**Total**
Mean citation index	105.2	139.1	124.2	114.5	121.8

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Mean citation index excl. 25 % most productive professors	106.5	138.2	120.5	114.6	120.5
Mean citation index excl. 50 % most productive professors	104.3	140.8	119.7	113.9	120.2
Standardized[1] mean citation index excl. 25 % most productive professors	1.01	0.99	0.97	1.00	0.99
Standardized[1] mean citation index excl. 50 % most productive professors	0.99	1.01	0.96	0.99	0.99

[1]Citation index including the most productive professors is set at 1.00.

Removing the most productive professors' contributions has practically no effect; neither in total nor in any fields. In total, there is a drop in the field normalized citation index, but the reduction is very small and in addition, it is not present in all fields. Medicine makes an exception, in that the removal of both the most productive publication points- and WoS-producing professors leads to decreasing citation indexes. How can we explain that removing the most productive professors in natural sciences does not lead to decreased citation indexes, when we in Table 2 observed a significant correlation between number of publications and citation index in this field? The explanation is methodological. The positive correlation that we identified was at the individual level, whereas the numbers in Table 3 are calculated as averages of the departments' indexes. This correlation may differ between departments, thus levelling out the effect when analyzing average effects at the field levels.

The departments also vary by their degrees of skewness, i.e. how asymmetrical the data is distributed. Based on the unevenness of the publication output distribution among full-time professors, all departments have been assigned skewness values (low, medium or high levels) (Table 4) used in further analyses.

Table 4 Skewness distribution (number of departments) by field levels

Field	Skewness measured by	Low skewness	Medium skewness	High skewness	Total
Medicine and health sciences	Publication points	9	16	15	40
	WoS articles	9	22	9	40
Social sciences	Publication points	7	13	4	24
	WoS articles	8	8	8	24
Natural sciences	Publication points	4	14	6	24
	WoS articles	3	13	8	24
Engineering	Publication points	4	12	4	20
	WoS articles	4	12	4	20
Total	24	24	55	29	108

The highest share of highly skewed departments is observed in medicine and health sciences, while social sciences has the lowest share. In the latter field, the skewness increases when we go from studying publication points to WoS publications only, which is not surprising as this publication form is not as codified in social sciences as in the remaining three fields studied here. When the skewness is based on WoS publications only, the publication output of the departments in the natural sciences shows the most skewed pattern. Here, both the skewness of departments within medicine and

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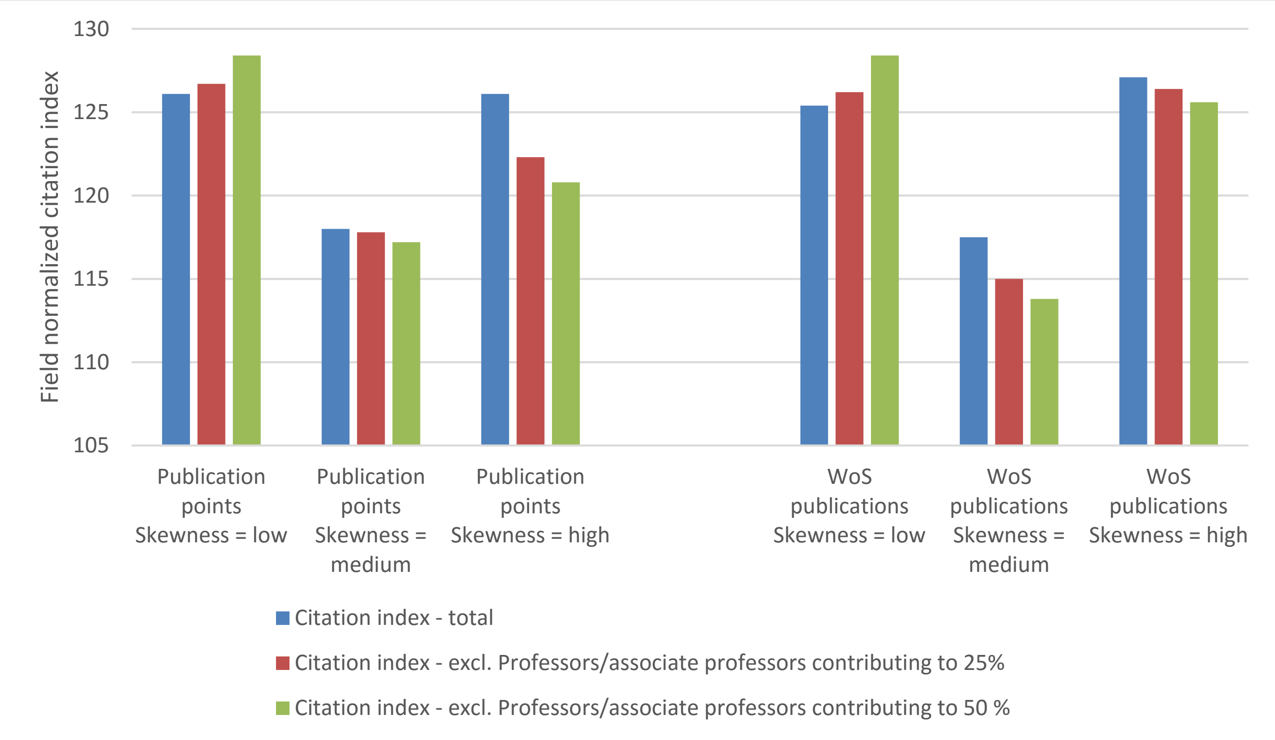
engineering follow a normal distribution, whereas the social sciences departments are divided in three equally large groups (Table 4).

Fig. 2 University departments' field normalized citation indexes across different types of department skewnesses, before and after exclusion of most productive researchers



Although the differences in skewness is not that large at field level, more than half of the departments have different skewness levels when we base the calculations on WoS publications instead of publication points. 61 departments change their skewness type when we use WoS publications instead of publication points (change from low to high skewness or vice versa). Field normalized citation indexes are generally higher in highly skewed departments compared to medium and lowly skewed departments (Figure 2).

Excluding the most productive professors (i.e. those accounting for 25 per cent of the publication output), leads to *higher* field normalized citation indexes in the least skewed departments, independent on whether productivity is measured in terms of publication points or in terms of WoS publications (Table 5).

Table 5 Field normalized citation indexes at department level across skewness types (standardized values in parenthesis)

Skewness in publication points	Total	Excl. 25%[1]	Excl. 50%[2]	Std. Excl. 25%[3]	Std. Excl. 50%[3]
Skewness = low	126.1	126.7	128.4	(1.005)	(1.018)
Skewness = medium	118.0	117.8	117.2	(0.998)	(0.993)
Skewness = high	126.1	122.3	120.8	(0.970)	(0.958)
Total	122.0	121.0	120.6	(0.992)	(0.989)
Skewness in WoS publications					
Skewness = low	125.4	126.2	128.4	(1.006)	(1.024)

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Skewness = medium	117.5	115.0	113.8	(0.979)	(0.969)
Skewness = high	127.1	126.4	125.6	(0.994)	(0.988)
Total	121.8	120.6	120.2	(0.990)	(0.987)

[1] Citation index after excluding publications from the 25% most productive professors. [2] Citation index after excluding publications from the 50% most productive professors. [3]Citation index including the most productive professors set at 1.00.

In the medium skewed departments, field normalized citation indexes decrease both when removing the 25 per cent most productive professors, and further when those contributing to 50 per cent are removed. This is so both when measuring productivity in terms of publication points and in terms of WoS publications. The same patterns are observed in the highly skewed departments. Some differences should be noted: first, in the medium skewed departments the reduction in citation indexes based on productivity by publication points is very small, whereas the reduction when based on WoS publications is far more substantial. In the highly skewed departments, the reduction in citation index observed in the analysis based on WoS publications (from 127.1 to 125.6) is much smaller than what we see when analyzing productivity based on publication points (from 126.1 to 120.6). This is the single most important reduction in citation index after removing the most productive professors.

We then investigate whether these findings also are present at field level, or whether grouping the departments by field would level out the variations. Reproducing the numbers in Table 5 at field level shows that it is in the highly skewed departments where the field normalized citation index declines the most after removing the most productive professors (Table 6).

Table 6 Mean field normalized citation indexes at department level and standardized citation indexes across skewness types and scientific fields

Skewness in publication points	Field	Citation index	Cit. index excl. 25%[1]	Cit. index excl. 50%[2]	Stand. 25%[3]	Stand. 50%[3]
Skewness = low	Engineering	101.1	101.3	100.0	1.00	0.99
	Natural sciences	162.7	161.7	167.9	0.99	1.03
	Medicine and health	119.4	118.7	117.1	0.99	0.98
	Social sciences	128.1	131.4	136.4	1.03	1.06
	Total	126.1	126.7	128.4	1.00	1.02
Skewness = medium	Engineering	101.7	105.3	105.8	1.04	1.04
	Natural sciences	135.1	134.7	138.6	1.00	1.03
	Medicine and health	119.7	115.6	113.2	0.97	0.95
	Social sciences	112.7	113.7	109.6	1.01	0.97
	Total	118.0	117.8	117.2	1.00	0.99
Skewness = high	Engineering	120.1	114.8	105.5	0.96	0.88
	Natural sciences	132.6	131.0	126.9	0.99	0.96
	Medicine and health	133.0	129.2	130.3	0.97	0.98
	Social sciences	96.3	90.7	91.1	0.94	0.95
	Total	126.1	122.3	120.8	0.97	0.96

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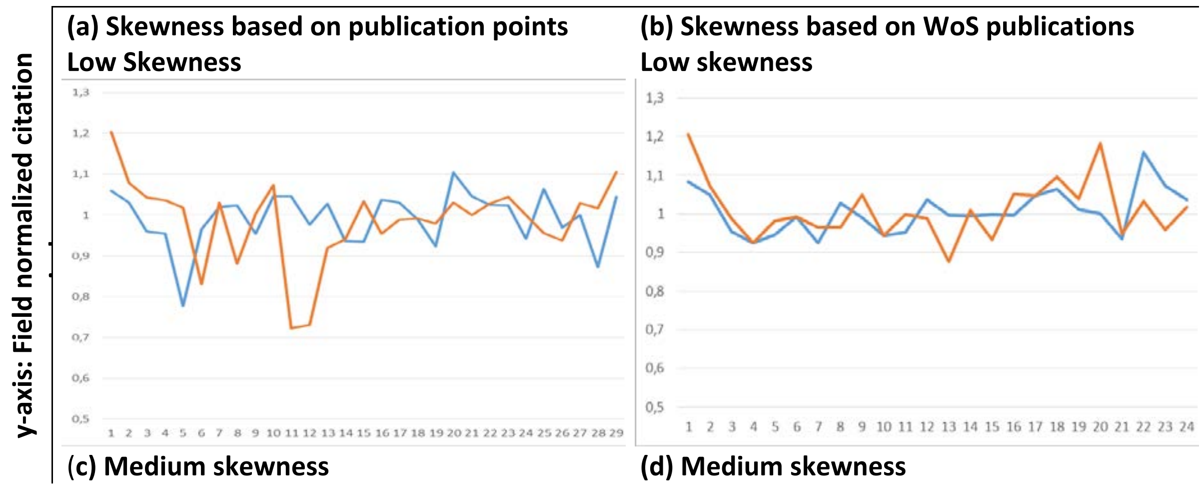
Skewness in WoS publications	Field	Citation index	Cit. index excl. 25%[1]	Cit. index excl. 50%[2]	Stand. 25%[3]	Stand. 50%[3]
Skewness = low	Engineering	106.2	112.3	115.3	1.06	1.09
	Natural sciences	165.5	171.2	173.9	1.03	1.05
	Medicine and health	119.3	114.4	115.1	0.96	0.96
	Social sciences	126.7	129.5	133.0	1.02	1.05
	Total	125.4	126.2	128.4	1.01	1.02
Skewness = medium	Engineering	101.1	101.9	98.1	1.01	0.97
	Natural sciences	128.3	127.1	127.1	0.99	0.99
	Medicine and health	122.6	117.8	117.6	0.96	0.96
	Social sciences	110.1	107.3	105.1	0.97	0.95
	Total	117.5	115.0	113.8	0.98	0.97
Skewness = high	Engineering	116.7	114.6	111.8	0.98	0.96
	Natural sciences	146.6	143.8	150.6	0.98	1.03
	Medicine and health	132.7	133.3	129.2	1.00	0.97
	Social sciences	106.5	107.2	103.6	1.01	0.97
	Total	127.1	126.4	125.6	0.99	0.99

[1] Citation index after excluding publications from the 25% most productive professors. [2] Citation index after excluding publications from the 50% most productive professors. [3]Citation index including the most productive professors set at 1.00.

This is particularly so in engineering, where the citation index drops 12 per cent in an analysis based on publication points, and four per cent in an analysis based on WoS publications. In medicine, the citation indexes always decline from baseline when the professors contributing to 50 per cent of their groups' output are removed, while there is an exception to this for those making up 25 per cent. In low and medium skewed departments, the results are rather mixed when the most productive professors are excluded, whereas in highly skewed departments, the results are more unambiguous (Table 6).

The results so far have been based on departments grouped either by field or by levels of skewness. We now illustrate the impact at single departments when we remove the most productive professors, so that individual differences between the departments become more clear (Figure 3).

Fig. 3 Standardized field normalized citation index for each department after removing the professors contributing to 25 (blue line) and 50 per cent (red line) of the publication output



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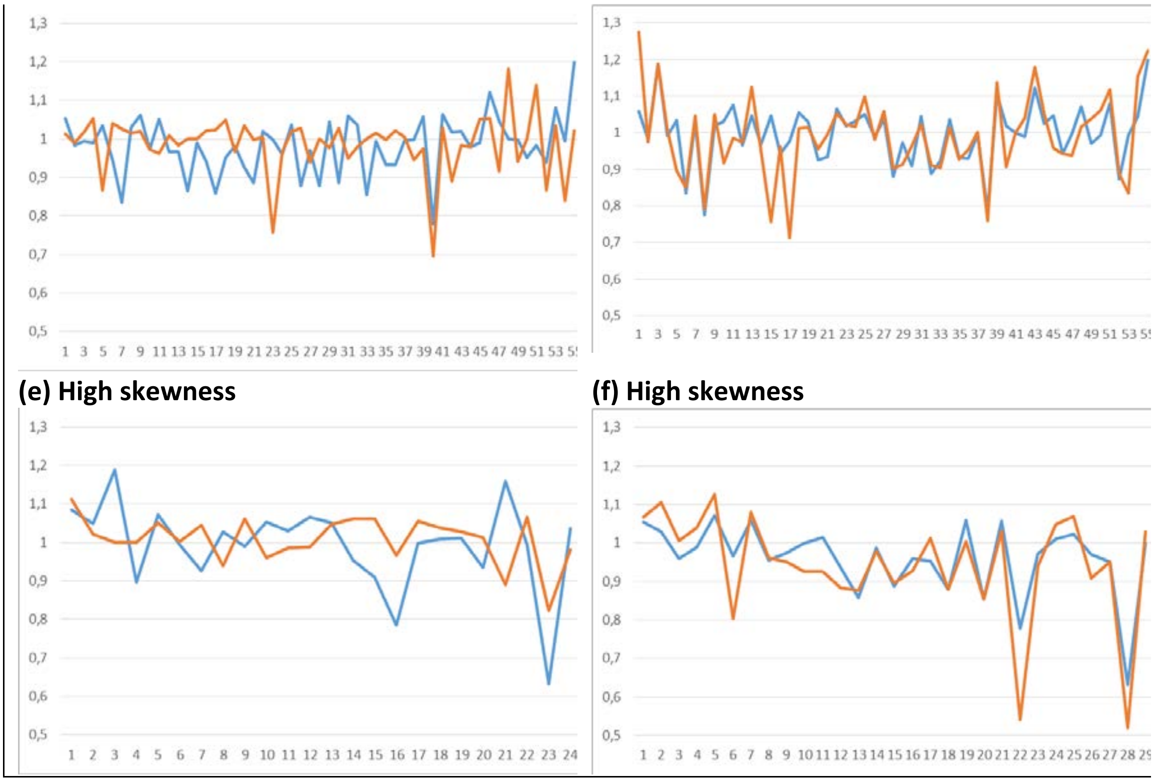

x-axis: University departments with highest citation index to the left, lowest to the right

The departments are ranked in Figure 3 by their initial citation indexes, i.e. the departments to the left had the highest citation indexes. The results may be interpreted in several ways, but we believe three main patterns are visible. *First*, there are many observations where the (field normalized) standardized citation indexes differ greatly from the line representing the removal of those researchers contributing to 25 per cent of the publication output, to the line indicating contributions to 50 per cent of the output. Furthermore, we observe many cases where this difference is the opposite of expected, i.e. that the citation index increases when we remove an extra group of researchers – that is, the professors that adds up between 25 and 50 per cent of the output. *Second,* the overall trend towards a decline in citation indexes is most prominent in the highly skewed departments, whereas the low and medium skewed departments seem more centered around the initial index (although with some extreme exceptions in both negative and positive direction). *Third,* while the overall change in citation indexes observed in this study, are small, it is quite clear from Figure 3 that in some departments the impact is massive when the contributions from the most productive professors are removed. In lowly skewed departments, the standardized citation index only goes below 0.9 on a few occasions (in the WoS analysis, this only happens once), while this is a general result for medium and highly skewed departments.

Correlation analysis at the individual level: how shares of highly productive researchers and productivity skewness are related to other staff members

So far we have studies the importance of highly productive professors and skewness of publication output at the level of *departments.* We now want to see how these two factors are associated with *individual publication productivity* and *citation impact* for all staff members at the departments, cf.

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the discussion of the professors as the creators of a productive climate and as mentors to younger researchers. From 108 departments, we include all postdocs (n=801), full-time researchers (n=823) and PhD-students (n=1,373) identified in the CRIStin database. Including the professors and associate professors, the new sample consist of 5,775 individuals. 41,7 per cent of these are from departments within medicine and health sciences, 28,8 percent from the natural sciences, 18,8 percent from engineering and 10,7 percent from the social sciences. In table 7, we show the statistically significant correlations between three measures of productivity skewness at department level and publication productivity/citation impact at the individual level. Numbers for the social sciences are not shown as no significant correlations were found.

For the whole sample there is a correlation between number of WoS publications and field normalized citation index of .300 (sig. 000), while there is less support for a correlation between number of publication points and the citation index (r=-0.77, sig.: .027). In general, the significant correlations are very modest. When breaking down these findings at either field level, or by academic position, the results get fragmented and difficult to interpret, but two major trend appears: 1) publication productivity is by large positively correlated with skewness in WoS publishing, and negatively correlated with skewness in publication points, 2) the field normalized citation index is only correlated with shares of highly productive professors, not with the skewness indicators.

Table 7 Correlations between department level skewness indicators and individual level productivity/citation indicators

Full sample	Percentage of highly productive professors	Skewness indicator (WoS publications)	Skewness indicator (CRIStin publications)	N
Number of WoS publications			.049 (.000)	5775
Number of CRIStin publication points	.062 (.000)	.082 (.000)	-.077 (.000)	5775
Field normalized citation index	.065 (.000)			3440
Number of WoS publications per researcher				
Medicine and health sciences (field)		.053 (.009)	.037 (.071)	2411
Natural sciences (field)	.055 (.025)	.058 (.019)	.075 (.002)	1666
Engineering (field)	.087 (.004)	-.153 (.000)	-.108 (.000)	1083
Professors (position)			.052 (.031)	1706
Associate professors (position)		-.065 (.032)		1072
Postdoctoral researchers (position)			.162 (.000)	801
Researchers (position)			.071 (.041)	823
PhD-students (position)	.110 (.000)	.065 (.016)		1373

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Number of CRIStin publication points per researcher				
Medicine and health sciences (field)	.119 (.000)	.131 (.000)	-.108 (.000)	2411
Natural sciences (field)				1666
Engineering (field)	-.107 (.000)			1083
Professors (position)		.078 (.001)	-.068 (.005)	1706
Associate professors (position)	.212 (.000)	.069 (.024)	-.186 (.000)	1072
Postdoctoral researchers (position)		.123 (.001)	-.095 (.007)	801
Researchers (position)	.137 (.000)		-.137 (.000)	823
PhD-students (position)		.151 (.000)		1373
Field normalized citation index per researcher				
Medicine and health sciences (field)				1524
Natural sciences (field)	.117 (.000)			1186
Engineering (field)				502
Professors (position)				851
Associate professors (position)		.177 (.008)		222
Postdoctoral researchers (position)	.100 (.008)			702
Researchers (position)	.100 (.006)			738
PhD-students (position)				917

Discussion

This study demonstrates two seemingly irreconcilable findings. First, that while the most productive professors are also the most cited professors, their impact on their departments' citation indexes is modest, i.e. removing the publications of the most productive people does in general only marginally reduce the citation indexes. Their impact, however, becomes more important when analyzing this issue by field and the productivity distribution of their departments. By large, high shares of productive professors and skewness in the productivity distribution among professors, are positively associated with other researchers' productivity and citation impact. This last finding is interesting, as it appears to contradict the first finding.

In the first finding, the crucial intermediate factor seems to be whether the most productive researchers are being so at a department that is highly skewed or not in terms of scientific productivity. In the most skewed departments, a small fraction of 9-11 per cent of the professors, may have a very large impact on their departments' citation impact, indicating that these researchers are involved in a large share of the most cited publications (and therefore are among the most cited researchers). In the lowly skewed departments, the removal of the most productive researchers does not have the same effect, arguably because the scientific production – and the citation impact – do not differ much between the professors. Such a productivity equality makes the departments less vulnerable to the absence of a few individuals. While the citation indexes in highly skewed departments initially is higher than in lowly skewed departments, the removal of a few top researchers would not affect the citation impact much in the one type, but it would do so in the other, and the citation indexes would converge (even tipping in favor of the lowly skewed departments). This might help explaining why the highly productive professors at the same time are

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a) not as important as expected to their department's citation index, and at the same time b) important to the productivity and citation impact of other staff members.

Most previous studies of researcher productivity have concluded that the skewness pattern of productivity and citation distributions has the implication that the average productivity and citation impact of individuals will be significantly influenced by a minority of prolific or highly cited researchers. Our present study does not contradict this, but it does question the importance of the most productive professors' contribution to the citation impact at department levels. The finding that the effect of removing the most productive researchers is not bigger is surprising. One would believe that these people are the cornerstones of any department, and that they pull the citation impact up. However, there are many factors that make such an assumption misleading.

First, while professors have the highest *productivity* (average number of publications per staff member at the universities) (Aksnes et al. 2011), their contribution to the total publication output of the departments is limited (varying from 47 to 61 per cent by field in this study), other staff groups play a significant role. A recent study of the University of Bergen even found that 19 per cent of the university's publication output was produced by retired personnel (Aksnes & Mikki, 2014). *Second,* former studies based on Norwegian data have shown that professors have somewhat lower citation indexes than other groups of personnel (postdocs, PhD students and other staff) (Aksnes et al. 2011). *Third,* full-time professors often play the roles as group leaders at their departments and therefore may have strong influence on the scientific performance of their staff members (i.e. their productivity and scientific impact). Thus, the citation indexes of the two groups may converge (Long and McGinnis 1981). Sinclair et al. (2014) suggested that the productivity of a doctoral candidate's supervisor will influence the productivity of the candidate, and some evidence suggest that the productivity pattern developed at this stage by the candidate will follow him or her later in the academic career.

These factors may also be relevant in explaining the patterns observed in our study. At the same time, there are other influential variables. For example, average scientific productivity and citation impact show large variations across age, gender, academic position and field at the universities that we have studied (see e.g. Aksnes and Rørstad 2015; Aksnes et al. 2011). We have not analyzed individual characteristics of the professors. Studies from e.g. Norway (Aksnes et al. 2011) and Canada (Gingras et al. 2008) highlight the importance of for example age. From the Norwegian study is was shown that among university researchers the citation index peaked at age 40-49 for male researchers and 30-39 for female researchers – then declining in both groups. In the Canadian study, the researchers were at their most productive at the age of (+/-) 50 years, but their citation impact was at the same time at its lowest. Still, the average number of papers in highly cited journals and highly cited papers kept rising continuously until retirement. It is thus difficult to address methodologically whether there is a causal relationship between organizational context and productivity – and impact. Are the departments differently compiled in terms of the professors' age, gender and so on? Or may it be that the best departments or groups generally encourage and stimulate the productivity of newcomers, often through collaboration with a successful mentor? In an Italian study of academic staff within the hard sciences, it was found that the concentration of top researchers (i.e. individuals being among the 20 per cent most productive researchers) was negatively correlated with that of unproductive researchers (Abramo et al. 2013). These results may be interpreted in two very

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different ways: top researchers are attracted towards institutions that are highly productive, or alternatively: in institutions where top researchers are present, they exercise a kind of formal or informal leadership that has a positive influence on other staff members' productivity. However, it may be that targeting the most productive professors is not the best way to identify the 'productivity climate' at a university department. There are other persons or groups of personnel that may be the true carriers of a productive climate – not being picked up in our analysis. If all staff categories had been included in the denominator, the results would most likely have become different, as some of the most productive staff members at the universities are not professors.

A more fine-tuned analysis where individual characteristics of the most productive professors were taken into account could possibly have identified more substantial explanations of why these professors have a high degree of influence on the citation index in some departments, but not in other (even sometimes a negative impact) as we have shown here. We have kept our analysis as straightforward as possible as the number of skewness and productivity measures has been quite extensive in this study. We acknowledge that by removing all publications of the highly productive professors from the analyses, we have not taken into account field differences in co-authorship practices. In some fields, where many co-authors per paper is common, the exclusion of highly productive professors may have a larger effect than in those fields where most papers are authored by one or two scholars. Another issue, which remains unaccounted for, is that being a highly productive researcher (according to our definition), may mean a very different thing from one department (or scientific field) to another. At some departments, the professors that make up 25 (or 50) per cent of the publication output may not have a much higher publication output than the other professors, whereas at other departments the most productive professors may have an extraordinary high publication output. Alternatively, some professors have a moderate publication output compared to professors at other departments, but are still regarded as highly productive, because their department colleagues have in general a low publication output.

At a department where the citation impact of removing all publications from the most productive professors are not changed at all, we may claim that the professors – even when being highly cited- are not necessarily much more cited than their colleagues despite their high productivity. Ruiz-Castillo and Costas (2014) found that the association between publication productivity and citation impact among 17.2 million authors (2003-2011) were "essentially uncorrelated", accordingly revealing "that the most prolific authors need not necessarily be those with the highest impact" (p.926). However, their sample was very different from ours, since we have only included a selected group of professors, all being employed at university departments in the same period. Nevertheless, in larger sample of departments than ours (n=108), the results could have been presented with more certainty as it would have allowed further stratification of results based on whether the most productive professors at a department are in fact highly productive professors when being compared to professors at other departments too.

Given that our study encompasses 2,778 professors, it was surprising that as many as 1,084 (61 per cent) of them had not published in Web of Science in the subsequent three years after the employment period that was used. This is a very high share of researchers without publications in WoS, cf. Abramo et al. (2012), where 6.6 per cent of researchers from hard sciences at Italian universities did not have any WoS publications. Some of the absence of WoS publications can be

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explained by field characteristics (less common in social sciences) and some by the very fact that sometimes researchers do not get their papers published in WoS during a certain time period. But the most important explanation to the unproductiveness is that we only included publications where there was a match between the author address in the publication and the department where the researcher had a full-time professor position. We have noticed that many professors have listed their second affiliation (research centre, university hospital, etc.) in their WoS-publications, or had their current department address, but were registered in our database with another academic category (postdoc etc.).

The importance of contextualizing results

It is commonly believed that good scientific environments stimulate productivity and several studies have shown that productivity of scientists is influenced by the environment. Organizational context can influence on whether a research group will flourish or not. Bland et al. (2005) discuss how the characteristics and combinations (and interaction) of individual, institutional and leadership factors explain research productivity, concluding that it is the dynamic interplay of individual and institutional characteristics, supplemented with effective leadership, that determines the productivity of individuals and departments. Baccini et al. (2014) concluded that researcher's productivity at an Italian university appeared to be stimulated by a high number of administrative and technical staff members, whereas results regarding the composition of senior and junior researchers at the departments was less clear. While this is helpful in explaining *productivity* it does not provide any links to the productive researchers' citation impact.

A basic finding with respect to citations is that there seems to be a power law relationship between the number of publications and number of citations. For example, van Raan (2008) studied the relationship at the research-group level and found that the lower performing research groups in particular had a size-dependent cumulative advantage for receiving citations (measured in terms of number of publications). Similar conclusions have been drawn for countries, research fields, and institutes as well as for individuals (Costas et al. 2009; Katz 1999). Yet, there are studies that somewhat contradict these findings. Larivière at al. (2010) demonstrated (although with strong field differences) that while high productivity is concentrated in a limited sample of all professors, the share of the professors being both highly productive (among the ten per cent most productive) and highly cited (among the ten per cent most cited) is extremely small.

Much in line with Katz's (2000) emphasis on size as a mediating factor, we have tested "skewness" as a mediating factor that high productivity may operate through with different effects depending on the levels of skewness. Our study has demonstrated that the impact of highly productive professors differ by the skewness levels of their respective departments, both in total and by scientific field, and that the skewness of the professors' productivity may influence other staff members' productivity and citation impact. We believe that in order to understand what nurtures quality in research groups or at the level of departments/institutions, more studies that analyze potential mediating factors ought to be carried out. Following Katz's (2000) argumentation, we argue that studies that solely analyzes the relationship between single factors and citation impact may either over- or underestimate the relationship, as the linearity/non-linearity of these factors may depend on contextual factors.

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