Working Paper
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Dag W. Aksnes, Fredrik N. Piro & Kristoffer Rørstad

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Working paper	2018:14
Published by	Nordic Institute for Studies in Innovation, Research and Education
Addresse	P.O. Box 2815 Tøyen, N-0608 Oslo.
Visiting Address:	Økernveien 9, N-0653 Oslo.
Photomontage	NIFU
ISBN	978-82-327-0373-9
ISSN	1894-8200 (online)

www.nifu.no

Preface

This working paper presents the results of a study investigating whether there is a positive effect of size when it comes to the scientific performance of university departments measured in terms of publication productivity and citation impact. In other words, whether larger departments are better than small ones. The report is written as part of NIFU's strategic institute project concerning the relation between input and output measures.

Oslo, 17.12.18

Susanne L. Sundnes
Head of Research

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Summary

In this study, we investigate whether university department size is important in determining publication productivity and citation impact. Drawing on a unique dataset containing a variety of different variables at department levels, we are able to provide a richer picture of the research performance than what typically has been the case in many previous studies. In addition to analyzing the basic question of how size relates to scientific performance, we address whether the funding profile of the departments plays a role, whether the scientific performance is influenced by the composition of the academic personnel (in terms of gender, academic positions, recruiting personnel and the share of doctoral degree holders). The study shows that virtually no size effect can be identified and highly productive and highly cited units are found among both small, medium and large departments. For none of the organizational variables we are able to identify statistically significant relationships in respect to research performance at an overall level. We conclude that the productivity and citation differences at the level of departments cannot generally be explained by the selected variables for department size, funding structure and the composition of scientific personnel.

1 Introduction

In recent years, many countries have seen a strong emphasis and encouragement towards merger of research units – both within and across institutions (European Commission, 2009). Underlying this development are beliefs that larger departments are more cost-effective, reduces the administrative costs, and have advantages for both the study programs and research activities carried out. In addition to increased economies of scale and scope, rationales such as creating institutions that more effectively are capable of dealing with particular challenges typically are put forward as justifications for mergers in higher education (Goedegebuure, 2012).

There is also a widespread belief that the quality of research suffers when the units are too small and that the number of researchers should be above a certain threshold (see e.g. Vehlo, 2006). The concept of "critical mass" is often used in this context. When applied in research policy, the expression alludes to an acceleration of the productivity or quality of a research unit above a certain size threshold.

The empirical justification for the size policy, however, does not seem to be particularly strong. A review of mergers in higher education in the early 1990s concluded that their rationale often is based on questionable assumptions as to the expected outcomes in terms of increased economies of scale and scope (Goedegebuure, 1992). Similarly, a study performed by SPRU concluded that "there seems to be little if any convincing evidence to justify a government policy explicitly aimed at a further concentration of research resources on large departments or large universities in the UK on the grounds of superior economic efficiency" (von Tunzelmann, Ranga, Martin, & Guena, 2003).

Also when analyzing publication productivity specifically, there is little empirical evidence for the benefit of size. In a review of the literature more than twenty years ago, Johnston (1994) concluded that "research output is linearly related to size with no significant economies of scale apparent". Later on, von Tunzelmann et al. (2003) concluded along the same lines. More recently, Evidence, in a commissioned report for the University Alliance (2011), found no evidence of critical mass in an analysis of the relationship between department size and various publication measures; both small and medium-sized research units tended to be at least as productive as large units. These results do not support the common assumption that department size in itself is beneficial for research productivity. Bonaccorsi & Daraio (2005) found even support for an opposite pattern where the most productive institutes in almost all areas were the small ones.

In this study of the Norwegian research system, we attempt to obtain further insights into the relationship between department size and scientific performance. Drawing on a unique dataset containing a variety of different variables at department levels, we are able to provide a richer picture of the research performance than what typically has been the case in many previous studies. In addition to analyzing the basic question of how size relates to scientific performance, we will address whether the funding profile of the departments plays a role, whether the scientific performance is influenced by the composition of the academic personnel (in terms of gender, academic positions, recruiting personnel and the share of doctoral degree holders). The relative importance of the different variables is investigated using multiple regression analysis. Most previous studies have analyzed the question focusing on publication productivity, while there are fewer studies that have investigated research quality and size. Using data on the citation rate of the publications, we are able to assess both the publication productivity and scientific impact of the units. Finally, due to Norway's good national research documentation system, all fields of learning may be included in our analyses, which is unusual in productivity studies.

More specifically the following supplementary research questions and hypotheses are addressed:

The role of external funding

The institutions receive the majority of their funding through general government grants (i.e. internal funding). However, the relative importance of this funding source has been decreasing in recent decades, and the academic staff has to acquire a greater proportion of funding from external sources to undertake research. Additional external funding might contribute to improved research conditions, although a competitive funding system also has certain costs, in particular that more time has to be spent on writing research applications. In the study, we will investigate whether the units receiving high proportions of external funding are more productive and have higher citation impact than the other units. The argument in favour of the hypothesis would be that those members of academic staff who apply for external funding have to document their past ability to publish their research. In the competition for research funding, the number of publications by applicants has become an important criterion for being worthy of future funding.

The qualifications of the academic staff

Since 1995, a doctoral degree has been a requirement for obtaining a permanent position in the research universities in Norway. However, there are still personnel in academic positions lacking doctoral qualifications, particularly at the university colleges. Generally, personnel holding doctoral degrees would be expected to be better qualified and prepared for an academic career than people lacking such qualifications. A previous study based on Norwegian data also showed that academic staff holding a doctorate are more productive in terms of scientific and scholarly publishing than other staff (Kyvik & Aksnes, 2015). In the study, we will therefore assess whether there is a positive relationship between the proportion of the staff holding doctoral degrees and the units' academic performance in terms of productivity and citation impact.

The composition of the scientific staff

Several previous studies have shown that the average productivity of publications varies significantly across academic positions, where full professors are the most prolific group of personnel. For example, Rørstad and Aksnes (2015) showed that the publication rate of associate professors is generally 20-30 per cent below the one of the full professors, while the publication rate is lowest for PhD students. Based on such previous findings, one might assume that units with high proportions of full professors will have higher publication rates than the other units, while high proportions of PhD students will be negatively associated with productivity. The extent to which this actually is the case will be investigated trough the present study.

The gender composition

There is strong evidence that female researchers tend to publish fewer publications than their male colleagues. This pattern has been found across many fields and nations (see e.g. van Arensbergen, van der Weijden & van den Besselaar, 2012, Long, 1992; Xie & Shauman, 1998). Less is known about whether similar gender differences can also be found in terms of citations. The few studies that actually have investigated this issue have not provided consistent results (Gonzalez-Brambila & Veloso, 2007; Long, 1992; Bordons et al. 2003) although a study of Norwegian researchers showed that females on average were cited slightly less than men (Aksnes, Rorstad, Piro & Sivertsen, 2011). Based on such previous findings one might expect that departments with high rate of females fare less well when it comes to productivity and possibly citation impact.

The supplementary research issues described above are analysed at the level of departments. Many of the studies referred to have on the other hand been carried out at the level of individuals. It remains to be seen whether the patterns identified at an individual level are also evident at the aggregated department level. Possibly, there might be processes at departmental levels or aggregation effects which mean that different patterns are observed.

As is evident from the discussion above, the different research questions have previously been investigated to a varying degree. There are numerous studies on the relationship between department size and publication productivity. On this issue, the present study may be considered to be a replication. However, as the topic concerning department size and mergers still appears important within research policy contexts, we think an additional study based on recent data is of interest. The question of how department size relates to impact measured through citations has, as far as we know, received scant attention. On the other hand, there are a few examples of using the outcome of peer evaluations for addressing the question of size and quality, see e.g. Toivanen & Waterson (2013). Here, the study provides new findings and additions to existing knowledge. This also holds for the supplementary research questions concerning the role of external funding, the composition of the academic staff etc. It should be emphasised once more that the object of the study is *the department*. In the literature, the issue concerning productivity has also been analysed in respect to *research groups* (see e.g. Cook et al., 2015; Rey-Rocha et al. 2002) or to various segments of personnel at a research unit, e.g. researchers in different productivity groups (Piro, Rorstad, & Aksnes, 2016). This is a related but separate research field, with deviating findings on the importance of size. We will return to the issue briefly in the discussion part of the paper.

2 Data sources and methodology

The present study includes 210 units within the higher education sector in Norway. The units represent departments at universities and specialized university institutions. The included units, account for approximately 80 per cent of the national research output in the higher education sector in Norway. The performance of the departments is analysed over a three-year period. On the input side, the study is, in total, based on 17,117 work years R&D (full time equivalents, FTEs).

Data on the research input are obtained using national R&D statistics. In Norway, the Nordic Institute for Studies in Innovation, Research and Education (NIFU) is responsible for collecting the statistics for the higher education sector and the institute sector. The statistics are prepared according to the OECD guidelines, as published in the Frascati manual (OECD, 2002). A variety of different variables at department and institute levels are available through this statistics. In this study, the size of the departments and institutes is measured as number of work-years R&D. The latter numbers include time devoted to R&D, only. Thus, teaching and other activities are excluded. In Norway, the calculation of number of R&D work years is partly based on time-use surveys to the academic staff. Based on this, for each field, type of positions (professor, PhD-students etc.) and institutions, average time devoted to R&D is calculated. Hence, by using R&D work years as an indicator in this study, the actual time spent on R&D is taken into account. Average time spent on R&D is around 40 to 45 per cent for the tenured staff. The figures are therefore suitable as a measure of the research efforts carried out and allow comparisons of units with different distributions of research and education. This would not have been the case if using number of people ("head counts") as basis for the analysis. Therefore, the latter measure has not been applied in the study.

We have used data from 2009, 2010 and 2011. For the majority of the 210 units analysed, we have three observations and the total number of observations underlying the analysis is 565. Units with less than three work years R&D (full-time equivalents (FTEs)) were excluded from the analysis. During the period, there have been several mergers and organizational changes in the research sector in Norway. Such changes may cause incomparability of the input and output statistics. Thus, units affected by these changes have been excluded.

Data on publication output is based on a bibliographic database called CRIStin (Current Research Information System in Norway), which is a common documentation system for all institutions in the higher education and institute sector in Norway. CRIStin has a complete coverage of the scientific and scholarly publication output of the institutions. A dynamic authority record of so far 25,000 controlled scientific and scholarly publication channels in the database ensures that references to non-scientific publications are not entered into the system.

In order to obtain an indicator that adjusts for different publication practices, we have calculated publication output as article equivalents. First, co-authored publications are fractionalised according to the number of authors (if an article has five authors, each author is credited with 1/5 (i.e. 20 per cent) of the article). Based on this principle each department's share of a publication is calculated. Second, monographs are weighted as equal to five articles (in journals or books) in order to make the research efforts behind different types of publications comparable. The weighting of monographs corresponds to the principle applied in the Norwegian and Danish performance based funding model (Sivertsen, 2010). In the Flemish performance-based funding system for university research, books are assigned a weight factor of 4 articles (Engels, Ossenblok, & Spruyt, 2012). The weighting principle is admittedly somewhat random as no empirical investigation has been carried out of the time and efforts needed for different types of publications. It should be noted that monographs account for a very small proportion of the publications, and only in the humanities and the social sciences does this publication type have a substantial volume.

It should be noted that there is a time lag from the research is carried out until the research appear as published articles (usually one to two years or longer). This fact needs to be taken into account when calculating research productivity indicators. We do not know any study that have investigated this issue empirically, and here we have applied a two-year time lag as a proxy. This means that the 2012 publication data, for example, are compared with the R&D input data from 2010. For most of the units, we have annual publication counts covering the period 2011-2013, while input data are from 2009-2011.

In addition to productivity measures, citation indicators have been calculated using data from Thomson Reuters' Web of Science (WoS) database. Many publications in CRIStin are not indexed in WoS. Therefore, this analysis is based on a more limited dataset. WoS basically covers publications in international journals. The coverage of the publication output in the humanities and social sciences is generally modest to poor due to a different publication pattern with monographs, book chapters and non-indexed national journals. Therefore, many of the departments in these fields are not included in the citation analysis. A threshold value of minimum 10 WoS articles annually was adopted in order to obtain reliable citation figures. Moreover, departments within the humanities are excluded, due to the publication and citation pattern of the field. The analysis is based on the articles published in the period 2011-2013 and citations obtained throughout 2014. This is a sufficiently long observation period for measuring scientific impact reliably, considering that our study is a macro analysis.

The average citation rate varies considerably between the different scientific disciplines. In our study, we have normalised the citation counts using the average citation rates of field and year in which the particular papers have been published (using Thomson Reuters' journal-based field delineations). A citation indicator is subsequently calculated as the ratio of the citation rate of the articles to the average subfield citation rates. For example, an index value of 1.50 would mean that the articles are cited 50 per cent more frequently than the world average.

To determine the role of the funding profile, the share of different funding sources was calculated for each department. The average proportions for the universities and specialized university institutions by domain are shown in Table 1. The core funding, general university funds, accounts for the majority (50-75 per cent) of the funding in all domains. The second most important source of funds is the Research Council of Norway, which on average contributes to 19 per cent of the total funding, but with large variations across domains.

Table 1. Relative distribution of funding by source and domain, proportions (N=565).

Domain	No. of departments	General university funds	Research Council of Norway	Industry	Ministries	Other national funds	Abroad	Total
Humanities	91	0.73	0.13	0.03	0.07	0.02	0.02	1.00
Social sciences	218	0.74	0.13	0.02	0.09	0.01	0.02	1.00
Natural sciences	98	0.50	0.35	0.04	0.05	0.02	0.04	1.00
Technology	87	0.50	0.29	0.13	0.03	0.02	0.03	1.00
Medical and health sciences	71	0.59	0.14	0.03	0.15	0.06	0.02	1.00
Total	565	0.64	0.19	0.04	0.08	0.02	0.03	1.00

As described above, previous studies carried out at the individual level, have shown that experienced researchers such as professors tend to publish more than their less experienced colleagues do. Moreover, on average, male researchers have higher productivity than female researchers. We have therefore analyzed the composition of the research personnel at the units included. The results by domains are shown in Table 2. At this aggregated level, the shares of professors only show small variations across domains, while there are larger differences for some of the other variables such as associate professors, other tenured staff and male researchers.

Table 2. Relative distribution of the scientific personnel by position, gender (men) and doctoral degree holders (N=565).

Domain	No. of departments	Professors	Ass. Professors	Other tenured	Post. Docs	PhD stud.	Men	Doctoral degree holders
Humanities	91	0.22	0.26	0.17	0.11	0.24	0.57	0.42
Social sciences	218	0.22	0.24	0.14	0.10	0.30	0.54	0.49
Natural sciences	98	0.22	0.16	0.04	0.19	0.39	0.70	0.54
Technology	87	0.20	0.15	0.07	0.13	0.45	0.77	0.44
Medical and health sciences	71	0.23	0.14	0.12	0.14	0.36	0.46	0.51
Total	565	0.22	0.20	0.12	0.13	0.34	0.60	0.48

In order to analyze whether these variables are associated with the publication output (article equivalents per R&D work year (FTE)) and citation indexes, they are included in a linear regression (OLS) analysis. We have restricted these analyses to the variables that show the largest variations across the units and which are expected to make a significant contribution to the regression models. The outspread of the individual variables is illustrated as boxplots in Figures 1 and 2. The boxplots are showing the distribution of each variable, the median values, upper and lower quartile, start and endpoint and outliers. All values are in the range from 0 to 1. The following variables (measured as department proportions) were included: Core funding (GUF), Research Council of Norway funding (RCN), Professors, PhD students, Men and Doctoral degree holders. The selected variables were analyzed for potential cases of multicollinearity. As the output variables are not normally distributed, they were log-transformed as a pre-treatment before linear regressions were conducted. Histogram plots of the output variable (article equivalents per R&D work year (FTE)) are shown with and without log-transformation pre-treatment in Figure 3. This figure shows that using log-transformation, the output variable is approaching a normal distribution. This also holds at the level of domains and for the citation indicators. In other words, assumptions made for linear regression analysis are justified.

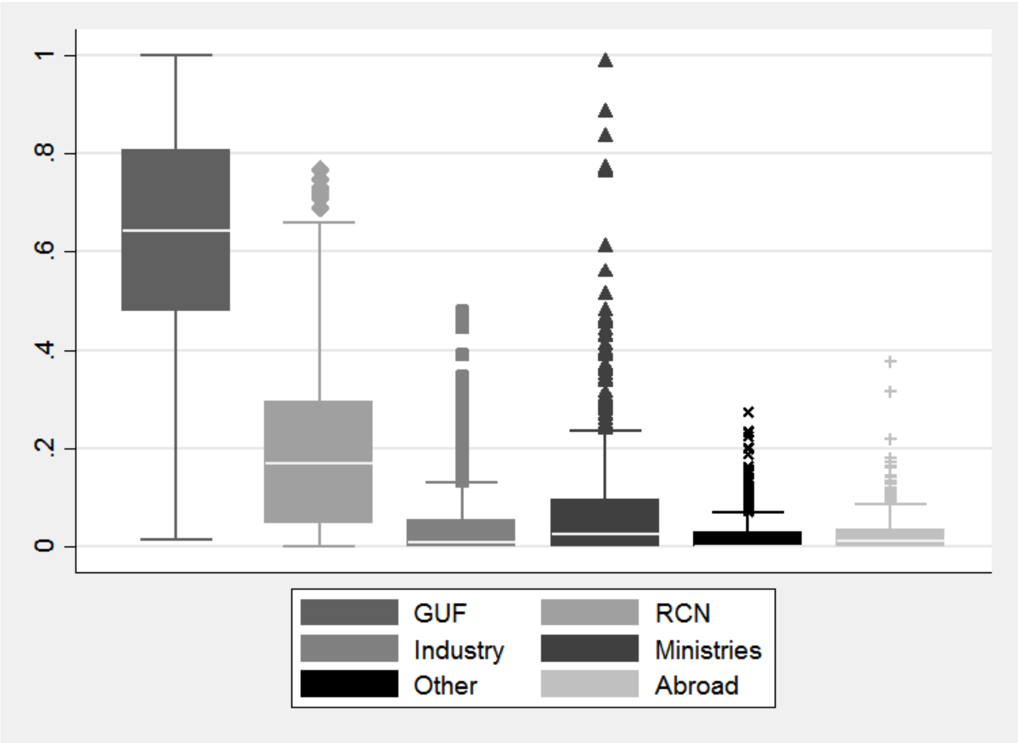

Figure 1. Boxplot of the proportions of funding sources (N=565).

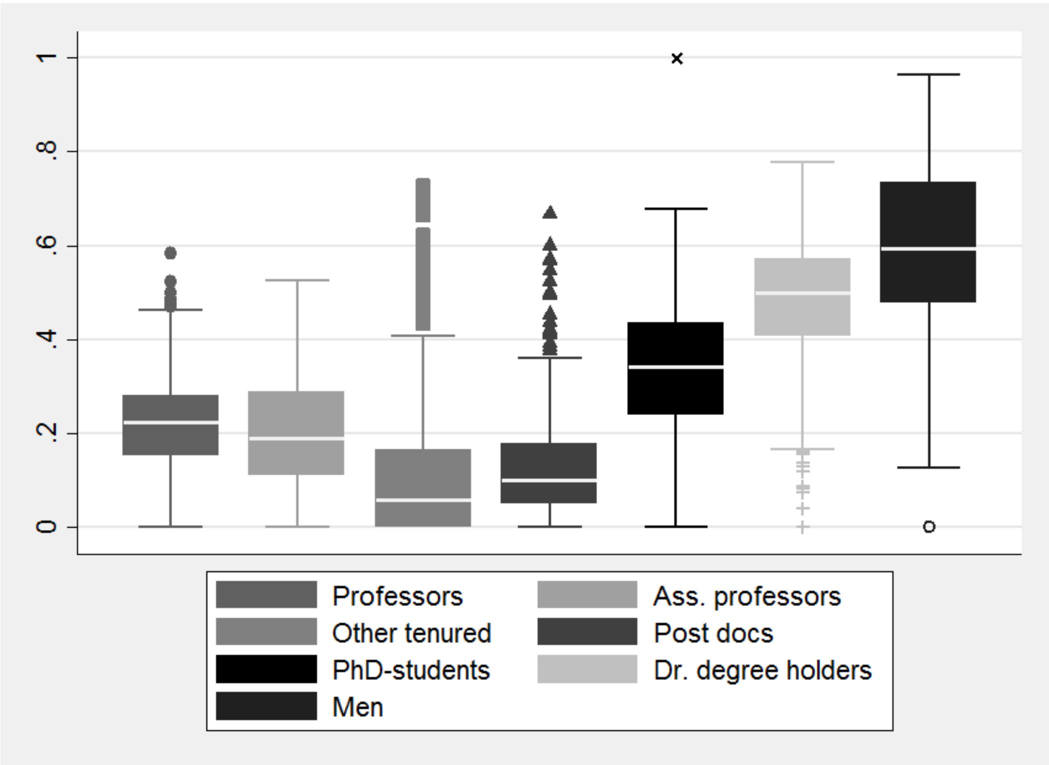

Figure 2. Boxplot of the proportion of scientific personnel by position, gender (men) and doctoral degree holders (N=565).

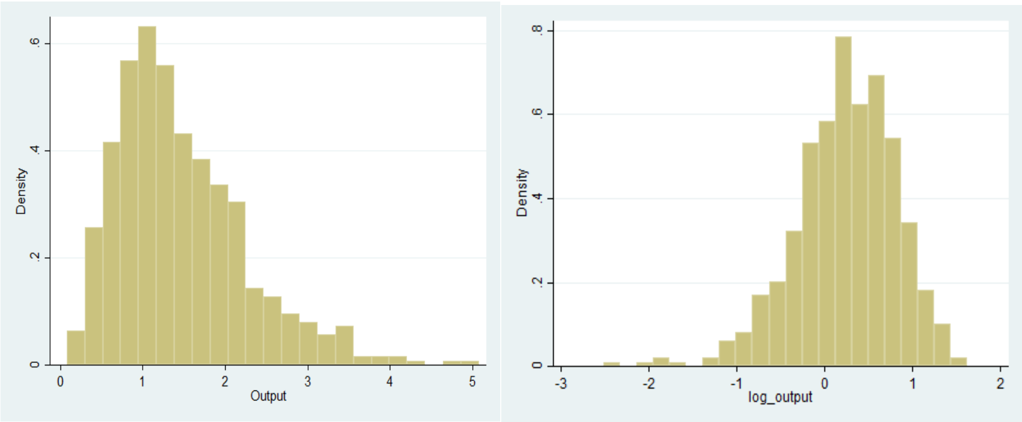

Figure 3. Histograms showing the output variable without any pre-treatment and after log transformation

3 Results

As a first step, we carried out an overall analysis of how the size of the departments relates to their publication volume. Here we would expect to find a strong correlation: the larger the departments, the larger the publication volume. Figure 4 shows a scatterplot with the results for the university departments and specialized university institution departments using number of R&D work years (FTEs) as input variable. Applying a simple linear regression model, we find an R^2 value of 0.51. Thus, department size explains half of the variance in publication output, which is perhaps somewhat lower than one might have expected.

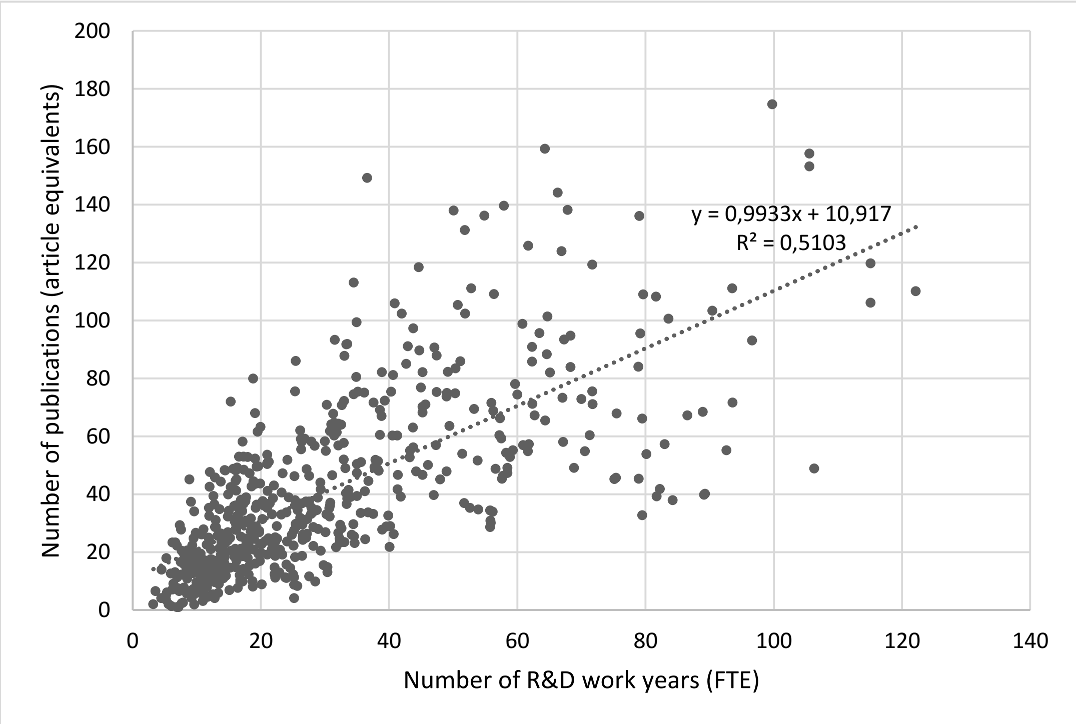

Figure 4. The relationship between department size (number of work years R&D (FTEs)) and publication output (number of article equivalents) (N=565).

In order to analyze whether larger departments have a higher relative productivity than smaller departments, we calculated the number of article equivalents per number of work years R&D (FTEs). The results are shown as a scatterplot (Figure

5) where the number of R&D work years (FTEs) is used as input variable. There are very large variations in the average productivity at department levels, particularly for the small departments. However, virtually no size effect can be identified and highly productive units are found among both small and medium sized departments. The linear regression line has a slightly negative slope with an R^2 value of only 0.05. There is no indication that a critical mass or a threshold value is present. Among the units with highest productivity, we find several small departments. This is probably due to the presence of one or a few highly prolific researchers, who influence significantly the average of their small departments.

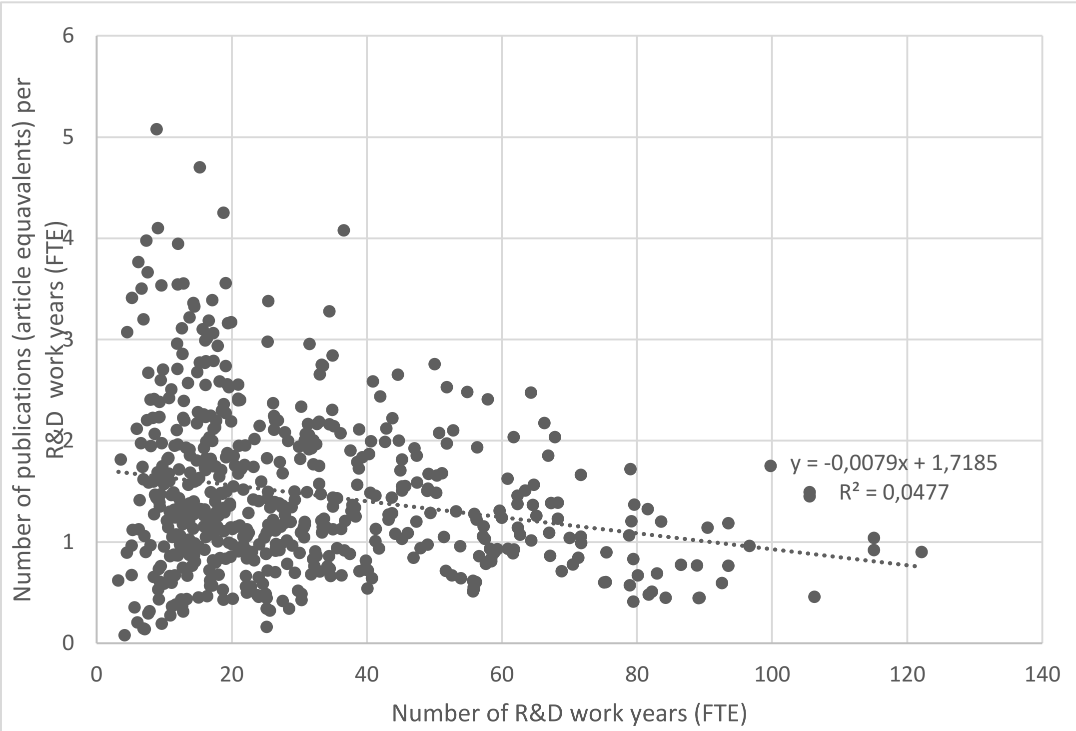

Figure 5. The relationship between department size (number of work years R&D (FTEs)) and productivity (number of article equivalents per work year R&D (FTEs)). (N=565).

In our study, we have used article equivalents to adjust for different publication practices. However, a previous study, partly based on an identical data material, has shown that the indicator is not neutral across disciplines/domains (Piro, Aksnes, & Rorstad, 2013). On average, a researcher in the social sciences and humanities obtains significantly higher productivity rates than researchers in other fields, using this formula. We have therefore performed an analysis taking into account the domain of the departments.

When plotting the size of the departments against the productivity level (cf. Figure 5), we get a negative slope for four out of five domains and only for the humanities does the productivity increase with department size. However, the correlation is very weak with R^2 values in the range of 0.00-0.14. Thus, the conclusions above remain also when adding this variable to the analysis. Overall, the productivity is higher in the social sciences, humanities and technology than in the natural sciences and medicine.

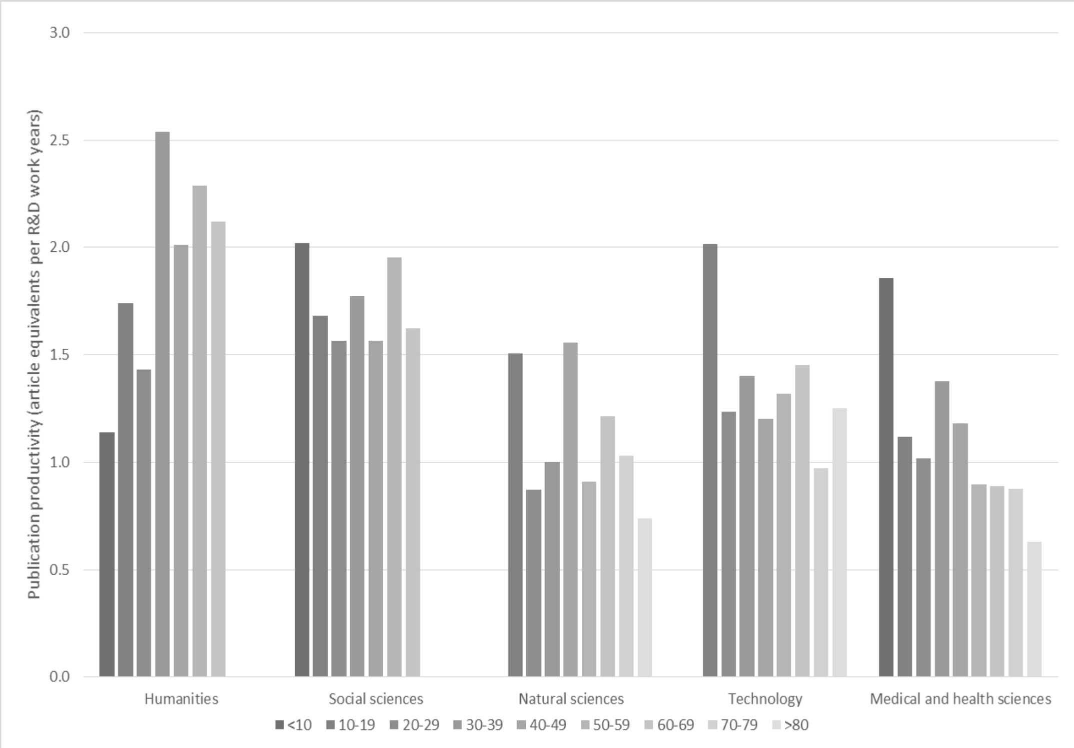

Figure 6. Average productivity (number of article equivalents per work year R&D (FTEs)) by department size intervals and domains (N=565).*

**) Figures are shown for categories with more than five units, only.*

However, it is difficult to identify any distinct pattern of increasing or decreasing productivity rate. In the humanities, the larger departments have a higher productivity than the smaller ones, while the opposite is true for medical and health sciences. For the other domains, there is no clear pattern and the productivity rates do not systematically vary by size (Figure 6).

As a next step, we investigated how the composition of research personnel and the funding sources were related to the publication output and department size. In order to reveal any association between these variables, linear regressions were conducted. The results are summarized in Table 3. All the independent variables are in the range zero to one, except the department size intervals (1-11).

Table 3. Regression summary* for publications productivity (log of article equivalents per FTEs) and selected variables by domains (N=565).

	Humanities	Social sciences	Natural sciences	Technology	Medical and health sciences
Number of observations	91	218	98	87	71
R^2	*0.50*	*0.06*	*0.42*	*0.49*	*0.25*
General university funds	**2.08** (0.000)	0.03 (0.838)	0.10 (0.426)	**1.09** (0.003)	**-0.79** (0.016)
Research Council of Norway funding	0.85 (0.183)	-0.14 (0.678)	**-0.75** (0.045)	-0.34 (0.323)	-0.63 (0.411)
Professors	**-1.73** (0.047)	**0.95** (0.022)	1.17 (0.089)	0.72 (0.543)	-0.08 (0.929)
PhD-students	1.54 (0.058)	-0.32 (0.308)	-0.03 (0.764)	**1.67** (0.00)	-0.31 (0.519)
Men	-0.05 (0.978)	**-0.75** (0.001)	**1.48** (0.000)	**0.99** (0.002)	-0.40 (0.380)
Doctoral degree holders	**3.15** (0.000)	-0.12 (0.741)	**-1.81** (0.007)	0.77 (0.688)	0.78 (0.269)
Department size (interval)	-0.14 (0.209)	-0.06 (0.812)	-0.10 (0.881)	-0.24 (0.153)	**-0.04** (0.021)

**) Unstandardized regression coefficients, P-values in brackets. Statistically significant relationships are shown in bold (95% confidence interval).*

The regression results (Table 3) show that the publication productivity can only partly be explained by our selected variables for department size, funding structure and the composition of scientific personnel. For the humanities, the natural sciences and technology, we obtain a fairly good correlation between publication productivity and the independent variables, with R^2 values in the range of 0.42 to 0.50. Thus, these variables explain about half of the variance in publication productivity. For medical and health sciences, the variables explain about one fourth (R^2 = 0.25), while for the social sciences the R^2 value is 0.06, only.

At the level of domains, a few statistically significant relationships are identified. The proportion of general university funds is significant and positively correlated with the publication productivity in the humanities and technology, and negatively correlated in the medical and health sciences. On the other hand, the proportion of external funding from the Research Council of Norway, is significant and negatively correlated with the publication productivity in the natural science. When it comes to the composition of the scientific personnel, we find that the proportion of men is significantly positively correlated with the productivity for both the natural sciences and technology, while it is negatively correlated for the social sciences. The proportion of PhD-students is statistically significant for technology only, as is the proportion of doctoral degree holders for humanities and the natural sciences, with positive and negative relationships, respectively. Department size interval is negatively associated with publication productivity in all domains, but with low regression coefficient values and only for medical and health sciences is the relationship statistically significant.

As is evident, the results are confusing and difficult to interpret. Some variables show both a positive and negative association with the publication productivity across domains. There are also counter-intuitive findings, for example that the proportion of professors is negatively associated with the publication productivity in humanities. As the statistically significant relationships are limited to a few domains and variables only, we are not able to prove a general validity. Therefore, we cannot draw final conclusion on the importance of the variables on publication productivity at department level.

The boxplot in Figure 7 shows how the publication productivity is distributed by size-intervals. The publication productivity has the largest spread for the smaller departments. This is not surprising, as the presence or absence of prolific personnel will influence significantly on the average value of the smaller units.

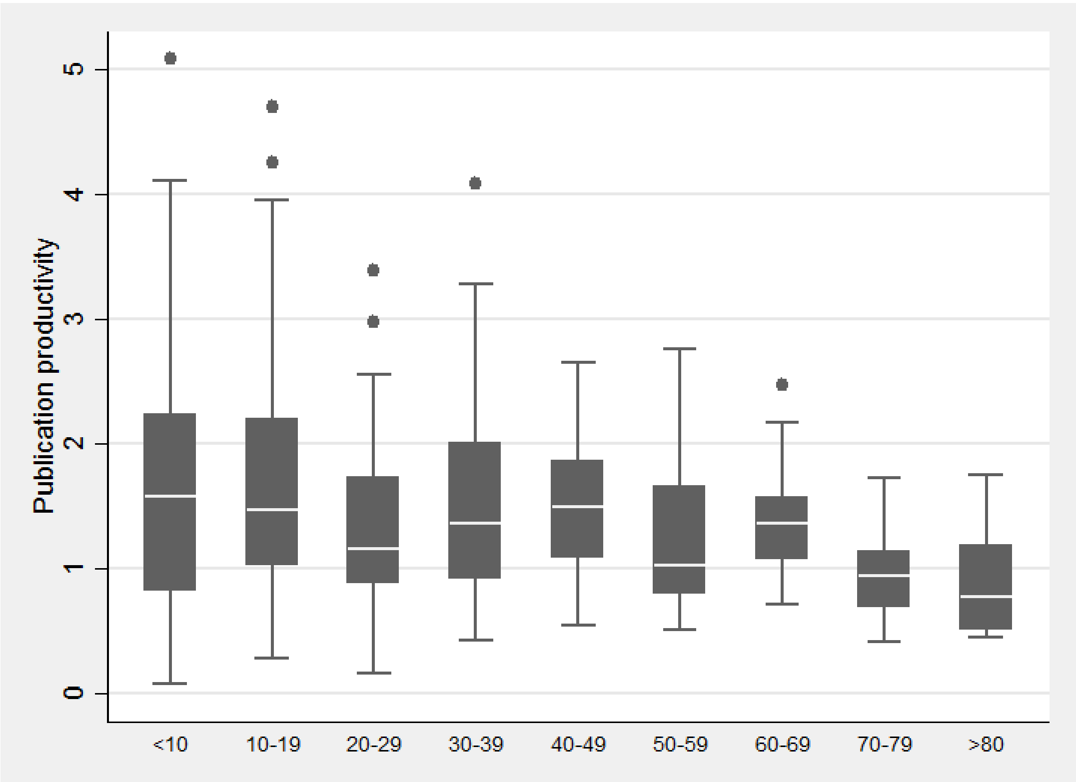

Figure 7. Boxplot of the publications productivity (article equivalent per FTEs) by department size interval (number of work years R&D (FTEs)) (N=565).

Citation impact indicators

As a next step, we analysed how the performance of the departments in terms of citation rates relates to their size. The relative citations index versus departments size (number of R&D work years (FTE)) is shown in Figure 8. The majority of the units are cited above the world average (1.00). However, there is no systematic pattern for this indicator either. The trend line shows a slight increase in citation rate by size, but the correlation coefficient is very low with an R^2 value of just 0.02. Moreover, there are clearly no signs of any breakpoints where larger departments are more cited. Also when analysing the relationship at the level of domains, there is no distinct pattern and the citation indexes do not systematically vary by size.

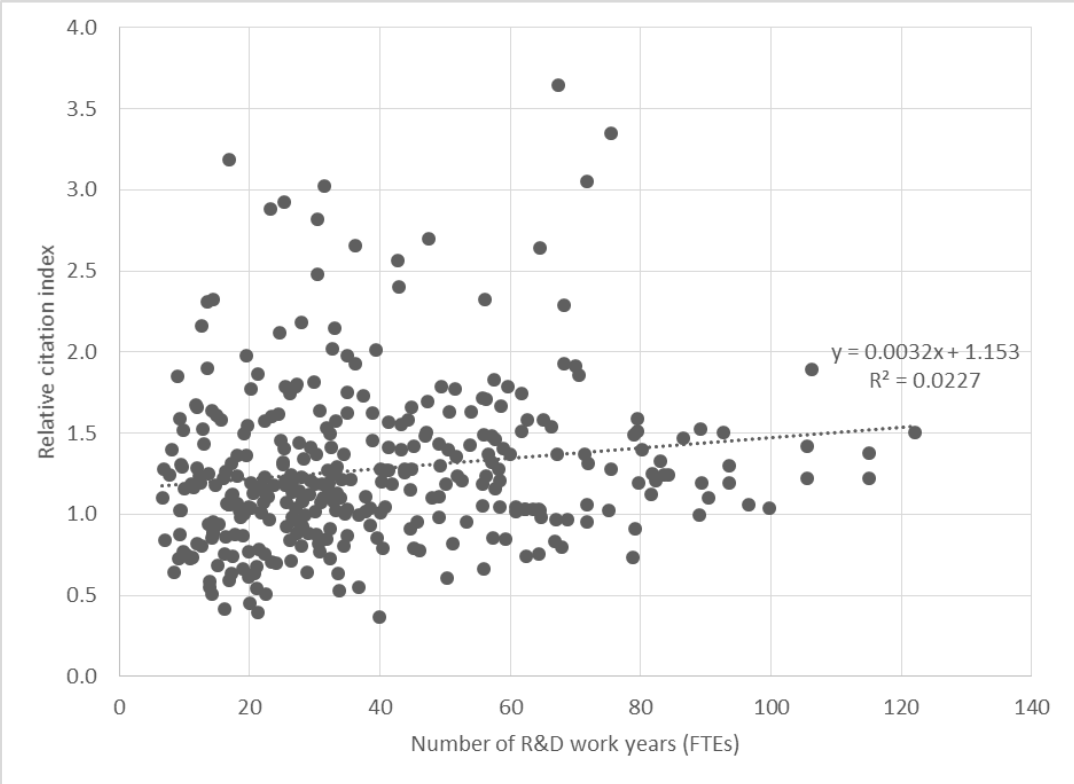

Figure 8. The relationship between department size (number of work years R&D (FTEs)) and relative citation index (N=338).

The boxplot in Figure 9 shows the variation in the relative citation index by department size intervals. There are some variations in the spread across size-groups, but overall results indicate that department size is not strongly associated with citation indexes.

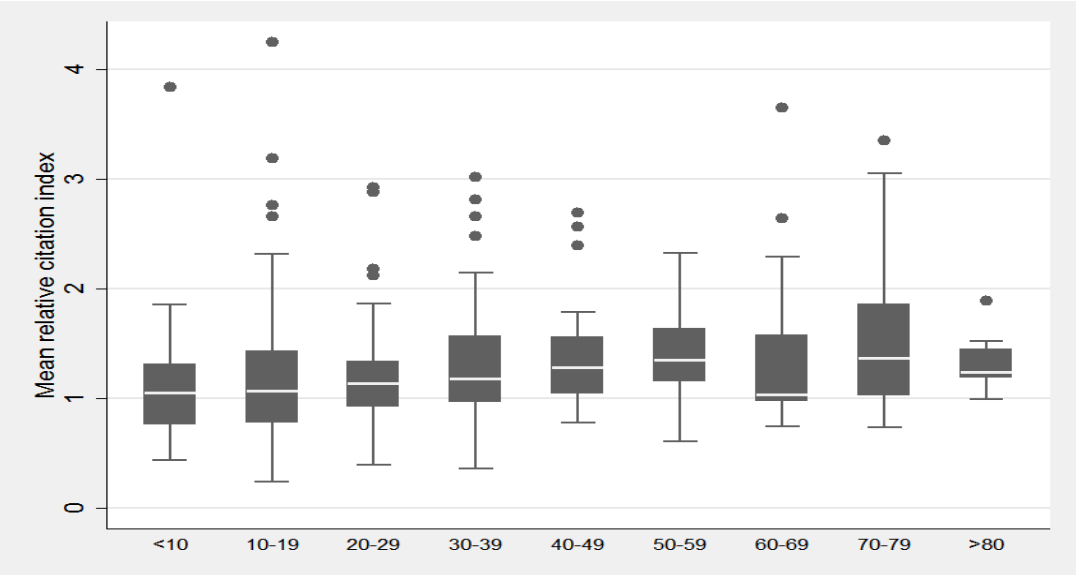

Figure 9. Boxplot of relative citation index by department size-intervals (number of work years R&D (FTEs)) (N=338).

In Figure 10, the relative citation index is shown by domain and department size intervals (number of work years R&D (FTEs)). As can be seen, there is no distinct pattern at the level of domains either. However, for medical and health sciences, the citation index is increasing by size, and the smaller departments have a lower citation rate than the larger. To a certain extent, this also holds for the natural science departments. For the other domains, there is no clear pattern and the citation indexes do not systematically vary by size.

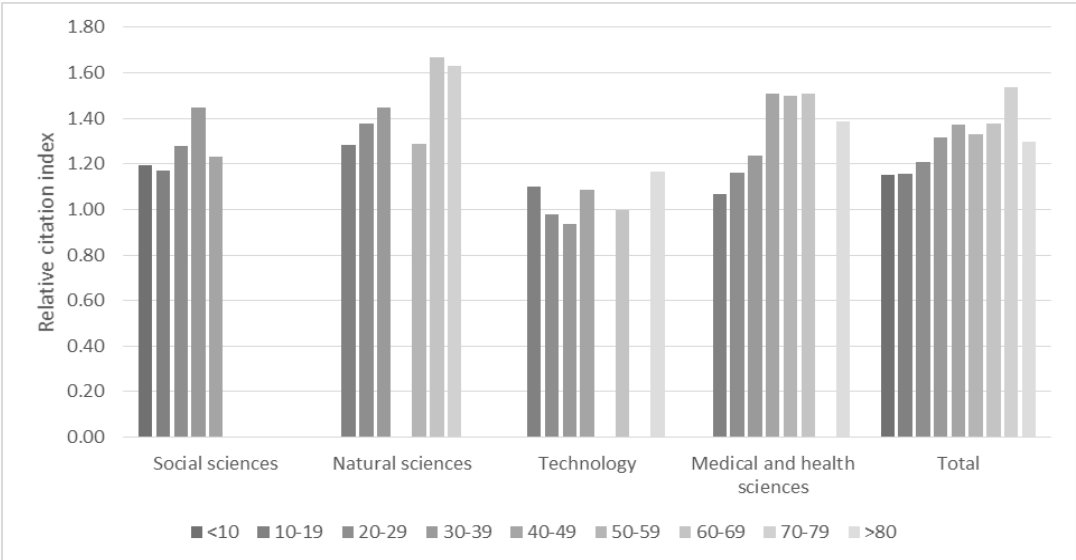

Figure 10. Relative citation index by department size (number of work years R&D (FTEs)) and domain (N=338).*

**) Figures are shown for categories with more than five units, only.*

Since the descriptive statistics show no evidence of any systematic association between department size and citation rates, we wanted to investigate the relationship further by adding other department variables and performing a regression analysis. The regression results are summarized in Table 4.

Table 4. Regression summary for the relative citation index and selected variables by domain (N=338).

	Social sciences	Natural sciences	Technology	Medical and health sciences
Number of observations	86	97	70	65
R^2	0.18	0.35	0.28	0.42
General university funds	0.02 (0.950)	**-1.97** (0.000)	0.74 (0.065)	**-0.63** (0.001)
Research council of Norway funding	0.50 (0.271)	**-1.24** (0.002)	**0.84** (0.035)	0.17 (0.686)
Professors	-0.68 (0.172)	-0.53 (0.383)	**-1.65** (0.039)	0.00 (0.997)
PhD-students	1.00 (0.085)	-0.25 (0.647)	-0.96 (0.165)	0.16 (0.580)
Men	0.19 (0.578)	-0.05 (0.879)	0.01 (0.976)	0.26 (0.334)
Doctoral degree holders	0.19 (0.698)	-0.72 (0.319)	-1.07 (0.240)	-0.32 (0.334)
Publication output (article equivalents)	**0.01** (0.005)	**0.01** (0.006)	0.00 (0.865)	0.00 (0.268)
Department size (interval)	-0.08 (0.110)	-0.04 (0.171)	0.00 (0.944)	-0.01 (0.665)

**) Unstandardized regression coefficients, P-values in brackets. Statistically significant relationships are shown in bold (95% confidence interval).*

The regression analysis shows that the variables are weakly to moderately associated with the relative citation index, as they account for 18-42 per cent of the variance at the level of domains. However, only in a few cases, the independent variables have a statistically significant association with the citation index, and the relationship between department size and the citation index is not significant within any domain.

Discussion

One may think of several reasons why larger departments have advantages to smaller ones when it comes to research performance. A previous study of Norwegian university departments found that the administrative load for tenured faculty tends to decrease with increasing department size, making more time available for research (Kyvik, 1995). Further, researchers at large departments may easier find colleagues with similar interests in larger departments, and these departments may be more likely to attract high quality researchers. Larger departments are also expected to be better at facilitating collaborative research groups, which may be important in regards to external funding, which is often being granted due to participation in international networks, and may lead to more international research collaboration, which positively affects the citation rates of the publications (Aksnes, Schneider, & Gunnarsson, 2012). One study also found that larger research units publish more in international than in national peer-reviewed journals, which suggest that research unit size positively affects international visibility (Horta & Lacy, 2011).

Nevertheless, we are not able to identify any benefits of larger departments when it comes to research performance measured through bibliometric indicators. To the contrary, the study shows that a) there are no systematic productivity or citation differences between small, medium and large departments, and, b) there is no evidence of a critical mass or a threshold level. As described in the introduction, similar findings have also been found in many previous studies. In particular, it should be noted that the question of department size and scientific performance was analyzed in a Norwegian context also 20 years ago (Kyvik, 1995). This study did not find any significant relationship between department size and productivity in scientific publishing. However, the study did not include analyses of scientific performance measured trough citations.

There may be several reasons for this apparent tension between the empirical results and the presumed benefits of larger departments. Prolific research groups may be found within both large and small departments. Possibly, the pros of having larger departments are only influential in some of the cases. In addition, both small and large departments may have their advantages and disadvantages. In fact, the study by Kyvik (1995) of Norwegian university departments found that it was faculty members in the smallest departments that were most content with the research environment. Although general contentment of employees may not be a determinant of scientific success, other contextual factors may, and these remain unaccounted for both in this and other studies.

In our study, we are focusing on the formal organizational level: the department. Larger departments, in particular, typically have sub-departments, which may operate quite independently of each other. When using the department as the only variable, internal differences in the organizational structure are concealed.

Moreover, it is the research groups that are the functional units of science. Previous studies indicate that the group is more important than the department in explaining research productivity (von Tunzelmann et al., 2003). In a study by Kenna & Berche (2011), focusing solely on the research group (both intra- and interdepartmental), clear evidence of critical mass was found. Their study analysed the relationship between the size of research groups in the UK (i.e. number of researchers) and the quality of the research (based on peer review assessments from UK's Research Assessment Exercise (RAE)). Von Tunzelmann et al.'s (2003, p. 8) review concluded that productivity typically increases with size among small groups, but there is an inverse relationship for large groups, with an optimal size of around five to nine people being observed in many sciences (not so in social sciences, arts and humanities). They argue: "productive departments seem to be composed of a series of teams, each around the optimal size of eight or nine people on average. Hence, to the extent there is an optimal size for the department, this may merely reflect the number of teams making up the department."

Hence, the lack of size dependency in our study does not necessarily mean that the concept of critical mass should be rejected. Rather it adds support to previous findings that critical mass does not operate at the formal level of a department. Instead, the concept may be relevant at the research groups being formed by people who work closely together, sharing academic interests, etc. Moreover, our study is only valid in reference to research, and we have not addressed other aspects such as administrative cost-effectiveness, teaching and other tasks of a university department.

In our study, we have also included other departmental variables in the analyses. At the level of domains, the included variables explain from 6 to 50 per cent of the variance in publication productivity. However, almost all the included variables have both a positive and a negative association with the publication productivity across domains. This also holds for the citation indicator. The included variables explain 20-40 per cent of the variance in citation index at the level of domains.

Nevertheless, only in a few cases are we able to identify statistically significant relationships. For example, for publication productivity this applies to the proportion of men in the natural sciences and technology, the proportion of PhD-students in technology, doctoral degree holders in humanities, and the proportion of general university funds in the humanities and technology. The lack of statistical significance in other cases does not necessarily mean that there is no effect. Considering that the sample size is not very large, this is important to emphasize, and the lack of statistical significance could also be a consequence of model misspecification, measurement error, etc. On the other hand, as statistically significant relationships are limited to a few domains and variables only and the regressions coefficients often show both positive and negative values, there are god reasons for concluding that the productivity and citation differences at the level of departments cannot generally be explained by the selected variables for department size, funding structure and the composition of scientific personnel.

Therefore, the hypotheses stated in the introduction cannot be sustained by the empirical findings of the study. This is surprising as several of the variables have been shown to be influential at the level of individuals: for example, that men on average have higher publication productivity than women, while professors have higher productivity than other categories of scientific personnel (cf. the introduction of this report).

Accordingly, when analyzing the underlying data used in this study we find that women on average have published about 32 per cent fewer publications (article equivalents) per person than their male colleagues. There are probably several factors explaining why this gender difference is not reflected in our aggregated department figures. One is that the gender variable used is the proportion of men (or women) of the academic personnel which is a rather different measure than average gender productivity. Scientific productivity is very skewed. Typically, a small minority of the staff at a department have contributed to a majority of the publication output, while a majority of the staff have none or very few publications. The presence or absence of particularly prolific researchers is highly influential in determining the average publication output of a department (Piro et al., 2016), and apparently more important than the gender composition of the academic personnel.

We may conclude that patterns present at the level of individuals are concealed when aggregated department units are analyzed. This is an important finding, which is also related to the fact that scientific performance is influenced by several different variables. At the level of departments, other factors than those investigated here are more important for explaining the variance in publication productivity and citation rates. Thus, one has to look at other aspects of the organizational structure in order to explain these differences.

Knowledge concerning factors influencing on the scientific performance of scientists and research organizations is important in research policy and management. Based on such knowledge one may be able to create better research conditions and design effective organizations to increase productivity and fostering high quality research. Our study, does not give support to the widespread policy assumption that small departments in this respect are unfavorable compared to larger departments. Although there may be arguments in favour of larger departments along other dimensions, the lack of empirical support when it comes to research performance is an important finding to bring forward in discussions about the organization of the higher education systems.

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