Age and scientific performance. A large-scale study of Norwegian scientists

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Abstract

In this study we analyze the relation between age and scientific performance. The study is based on a large-scale cross-sectional analysis involving 11,500 Norwegian university researchers. In addition to analyzing whether there are significant age differences in the publication and citation rates at an overall national level, we investigate the issue according to variables such as the academic position, research disciplines and gender.

We find that there are large age differences in scientific productivity. The youngest and oldest researchers have the lowest annual production of publications. The productivity is increasing by age, reaching a peak late in the career, and declining thereafter. The study shows that persons above 60 are significantly less cited than their younger colleagues.

Introduction

To what extent does the age of scientists influence their scientific performance? This question has been a recurring issue in the bibliometric literature. One major topic has concerned the relationship between publication productivity and age. Although the results of previous studies have not always been entirely consistent, it seems to be quite firmly established that there is a curvilinear relationship between age and productivity. The average production of publication increases with age and reaches a peak at some point during the career and then declines (see e.g. (Kyvik, 1990; Cole, 1979; Barjak, 2006; Gonzalez-Brambila & Veloso, 2007). The pattern has been found across many fields and nations.

Another issue involves the relationship between age and the quality, significance and impact of the research. A traditional assumption has been that science is a “young man’s game” where the best work is done at a comparatively young age (Merton & Zuckerman, 1973, 503). Already in 1953 Lehman in a classical study found that the most important discoveries tended to be made by younger rather than older scientists (Lehman, 1953). Lehman concluded that the majority of scientists are most creative when they are in their late thirties or early forties. The study of Lehman has, however, been shown to be flawed methodologically (Cole, 1979). Nevertheless, some later studies have supported Lehman’s findings. Most of these studies have used various citation indicators as measures for scientific contribution. Other approaches such as analyses of the age of Nobel Prize winners (Stephan & Levin, 1993) have also been presented and supported the prevailing view on age differences in scientific achievements.

An examination of the literature on the relation between age and scientific performance does however reveal that the results are not consistent. While some studies have reported a negative association between age and citation rates, others have found different patterns. In a recent study of Spanish academics in three scientific areas it was found that citation rates declined steadily by age and that persons under 40 have the highest citation rates per publication (Costas, van Leeuwen & Bordons, 2010). Others studies have found the relationship to be curvilinear. For example, analyzing academics in various academic fields Stephen Cole (1979) reported that the overall citation rate was highest for persons between the ages of 40 and 44. Similarly, a study of Mexican scientists revealed a corresponding pattern, but with a delayed peak reached when the researchers were 56 years old (Gonzalez-Brambila & Veloso, 2007). A very different relationship was reported by Gingras et al. (2008) who in an analysis of Canadian researchers found a U-shape curve where that citation rates declined for persons between 28 to 50 and then increased until about 70. Other studies, however, have not found any evidence of age specificity in scientific impact. For example, Over (1988) reported that articles in Psychological Review published by older authors were overall cited as frequently as articles published by younger authors.

In order to provide further insights into these questions, we have carried out a large-scale cross-sectional analysis involving 11,500 Norwegian university researchers. The database applied has a complete coverage of the research output of the staff at the main Norwegian universities and includes all scientific and scholarly disciplines. It is therefore well suited for addressing these issues. In addition to analyzing whether there are significant age differences in the publication and citation rates at an overall national level, we investigate this issue according to variables such as the academic position, research disciplines and gender. Compared to many previous studies, typically involving a few hundred persons, the results of our macro-study have a high degree of reliability.

Data and methods

The study is based on databases which have been purchased from Thomson Reuters (formerly Institute for Scientific Information, ISI). One basic database is the *National Citation Report* (NCR) for Norway, containing bibliographic information for all Norwegian articles (articles with at least one Norwegian author address). The 2010 edition of NCR, with data covering the period 1981–2009 was used. Data for each paper include all author names, all addresses, article title, journal title, document type (article, review, editorial, etc.), field category, year by year and total citation counts and expected citation rates (based on the journal title, publication year and document type). In addition, the *National Science Indicators* (NSI) database containing aggregated bibliometric data at country and field/subfield levels was used. This database was applied for the purpose of creating reference standards for the calculation of field normalised citation indicators.

As a secondary data source we applied a bibliographic database developed as a common documentation system for all institutions in the Higher Education Sector in Norway. The database has a complete coverage of the scientific and scholarly publication output of the institutions. The publication data are partly imported to the documentation system from professional bibliographic data sources (e.g. *ISI Web of Science*, Thomson Reuters) in order to facilitate the registration of publications by the employees. As basis for this study we selected publication data from the four major Norwegian universities (University of Oslo, University of Bergen, The Norwegian University of Science and Technology in Trondheim, and the University of Tromsø) for the four year period 2005–2008.

Finally, in order to provide information on individual characteristics of the persons (age (in 2007), recent work affiliations and position), the data in the bibliographic database was coupled with another database, the *Norwegian Research Personnel Register*. The latter database contains individual data for all researchers in the Higher Education Sector and Institute Sector in Norway.

The publication analysis is based on 11,519 persons who had at least one publication indexed in the Norwegian bibliographic database during the period 2005-2008 and who we were able to identify in the *Research Personnel Register*. In total these persons had contributed to 59,868 publications, constituting 33,902 unique publications (many publications are authored by more than one person included in the study). Only scientific/scholarly books, and regular articles and review articles in scientific/scholarly books and journals are included.

As a subset of all publications we identified the articles indexed in *ISI Web of Science* (WoS, covering the *Science Citation Index Expanded, Social Science Citation Index, Arts and Humanities Citation Index*). As citation counts only are available for the ISI-indexed publications, we have restricted the citation-study to these publications. In total, 8,456 persons had published at least one ISI-indexed article during the period, comprising the personnel who have been included in the citation analysis. In other words, we find a significant number of persons without such publications. The large majority of these are researchers within the social sciences and the humanities where the ISI coverage of the research literature is poor. The citation study is based on 37,698 articles constituting 17,239 unique articles. The distribution of persons by age groups in the two set of analyses is given in Table 1.

Table 1. Number of persons included in the publication and citation analyses, by age group.

Age group	*Number of persons – publication analysis*	*Number of persons – citation analysis*	*Age group*	*Number of persons – publication analysis*	*Number of persons – citation analysis*
< 25	44	24	50-54	1,129	834
25-29	1,063	750	55-59	960	677
30-34	2,279	1,760	60-64	884	595
35-39	1,814	1,381	65-69	530	360
40-44	1,325	965	70-	293	201
45-49	1,198	909	Total	11,519	8,456

The publications were assigned to four broad fields (natural sciences (including mathematics), engineering, medicine/health sciences, social sciences and humanities) and to disciplines. The basis for this classification is data on the educational background of each person in the Research Personnel Register. Due to missing educational data for some of the persons, we have in these cases based the classification on the research areas of the institutes the persons were affiliated with.

Three publication indicators were calculated:

- Average number of publications (whole counts) per person.
- Average number of fractionalised publications per person (each publication is divided by its number of authors).
- Average number of article equivalents per person (fractionalised publication counts combined with a weighting of monographs as equal to 5 articles (in journals or books) (in order to make the research efforts behind different publication types comparable).

The individual articles and their citation counts represent the basis for the citation indicators. In the citation indicators, we used accumulated citation counts and calculated an overall (total) indicator for the whole period. This means that for the articles published in 2005, citations are counted over a 5-year period while for the articles published in 2006, citations are counted over a 4-year period (or more precisely a 3–4 year period: the year of publication, 2007, 2008 and 2009). The period for which citations are taken into account accordingly varies from 2 to 5 years depending on publication year. This is a sufficiently long observation period for measuring scientific impact reliably, considering that our study is a macro analysis (based on more than 37.000 publications and 300.000 citations received by these publications). The only exception would probably be the humanities, where the number of citations per paper is very low and citations accumulate slowly. However, as the field only accounts for 3% of the persons included, we do not consider it as a significant limitation of our study.

The average citation rate varies a lot between the different scientific disciplines. As a response, various reference standards and normalisation procedures have been developed. Here we have used the average citation rates of the field in which the particular papers have been published. That is, the citation counts are matched to the mean citation rate per

publication of the particular fields/subfields the papers are assigned to (using Thomson Reuter's journal-based field delineations).
The indicator is subsequently calculated as the ratio between the citation rate of the articles and the average subfield citation rates and multiplied by 100. For example, an index value of 150 would mean that the articles are cited 50 % more frequently than the average. The method adopted here is commonly applied in similar bibliometric performance analyses (see for example Moed, 2005; van Raan, 1996). We have calculated citation indexes for each article separately and this is the basis for the average normalised citation score (cf. Lundberg, 2007). The measures of number of citations are based on "whole counting" of publications, i.e. with no fractional attribution of credit (all authors get full credit). This is the counting methods that most commonly are being applied in bibliometric studies.
We analysed the citation rates at an overall level and in terms of the age, gender and academic positions of the persons included. The unit for the analyses is the individual persons. This means that an average citation index has been calculated for each person (mean for all publications to which they have contributed), and based on these measures we have calculated new averages for the different categories the persons are affiliated with. This has been done in order to avoid that the analyses would be biased towards highly productive persons and fields. In other words, all persons count equally as one unit in the analysis.
When studying age differences in citation rates, one basic methodological point should be emphasized: Citations are given to papers, not to persons. Moreover, most articles are published by more than one author where researchers with various age contribute as authors. Thus, the results of the analysis need to be interpreted in the light of this fact. What can be studied is whether there are citation differences in the *oeuvre* of publications to which researchers with various age have contributed. For example, one might find that young researchers on average contribute to publications that have higher impact than the publications to which old researchers have contributed. Similar interpretations have to be applied in most citation studies. For instance, in analyses of the performance of a research institute, only one of many authors of a paper may be affiliated with the particular institute.

Results

In the first part we present the results of the study on scientific productivity. Typical for productivity distributions, the production of publications is very skewed at the individual level (Kyvik, 1991). Of the 11,519 persons, 46 per cent have published only one or two publications during the time period, while a small proportion of the population are very prolific. Figure 1 shows the average number of publications per person per year for five-year age groups. Since the study includes persons with various positions, even technical and administrative personnel who are "publicationally" active are included. The persons have here been classified in two categories: scientific personnel comprising the "core" scientific and scholarly personnel (persons with positions as PhD students, post doctors, associate professors and professors) and other personnel (comprising technical and administrative personnel, medical doctors, adjunct professors and other scientific positions.
As expected the average productivity is much higher for the scientific personnel than for the group of other personnel. The productivity of both groups of personnel is increasing by age, reaching a peak late in the career, and declining thereafter. For the scientific personnel, the highest productivity number is found for the 50-54 and 55-59 age groups using whole counts measures. Using fractional measures and article equivalents the peak is "delayed" by one period and the maximum is reached for the 55-59 and 60-64 age groups. The reason for this difference is that the older personnel tend to publish publications with fewer co-authors. Overall, the age productivity differences are very large – for example, while persons between 30 and 35 years old publish 1.2 article equivalents per year, the corresponding number for the

55-64 age groups is 3.8. Although the publication rates are declining as the researchers become older, the persons above 70 are still more productive than persons below 40. The persons above 70 are mainly emeritus professors who have formally retired (only the persons who are still active researchers are included, i.e. have published at least one publication). It should be noted that this group of persons is rather heterogeneous and the extent they are still involved in research may vary. Some are very active and spend much time on research, others are only occasionally doing research.

There are less age productivity differences for the group of other personnel, particularly when looking at the fractionalized indicators. The number of articles equivalents is increasing from 0.8 for the 25-29 age group to 1.8 for the 64-69 age group.

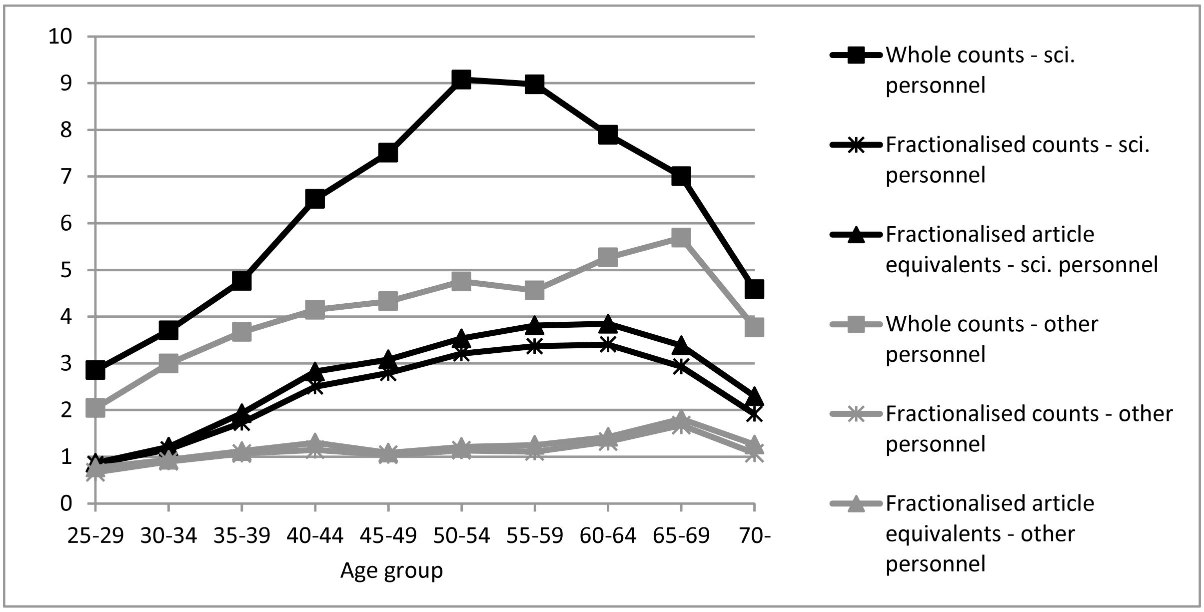

Figure 1. Average number of publications per person per year, by age group and group of personnel.

Previous studies have shown that the productivity of publications at individual levels tends to increase within the hierarchy of academic positions (Kyvik, 1991; Bordons et al., 2003), where professors are the most prolific personnel. We have therefore analyzed how the productivity varies with age within the categories of academic positions, cf. Figure 2. Our study also shows that the professors are by far the most productive persons. Next follows associate professors, post doctors while the PhD students and the medical doctors have the lowest productivity of the personnel groups shown in the figure.

Interestingly, the age profiles differ substantially from the average profiles shown in Figure 1. The professors have the highest productivity at a young age and the annual number of publications declines substantially during the career. For the associate professors the age profile shows less variation by age: There is a peak for the 35-39 age group and the productivity declines as the researchers get older.

It may seem surprising that these patterns are quite different from the average productivity profile. The reason is that PhD students and post-doctors are in a majority in the young age groups and accordingly influence significantly on the average for these groups. The proportion of professors in the population analyzed is increasing by age and is highest for the older age groups. Therefore the productivity of this group influences more on the overall average for the older age groups. In addition, only the most successful scientists have obtained a professorship at a young age and this is probably an explanation for the very high productivity level of the young professors.

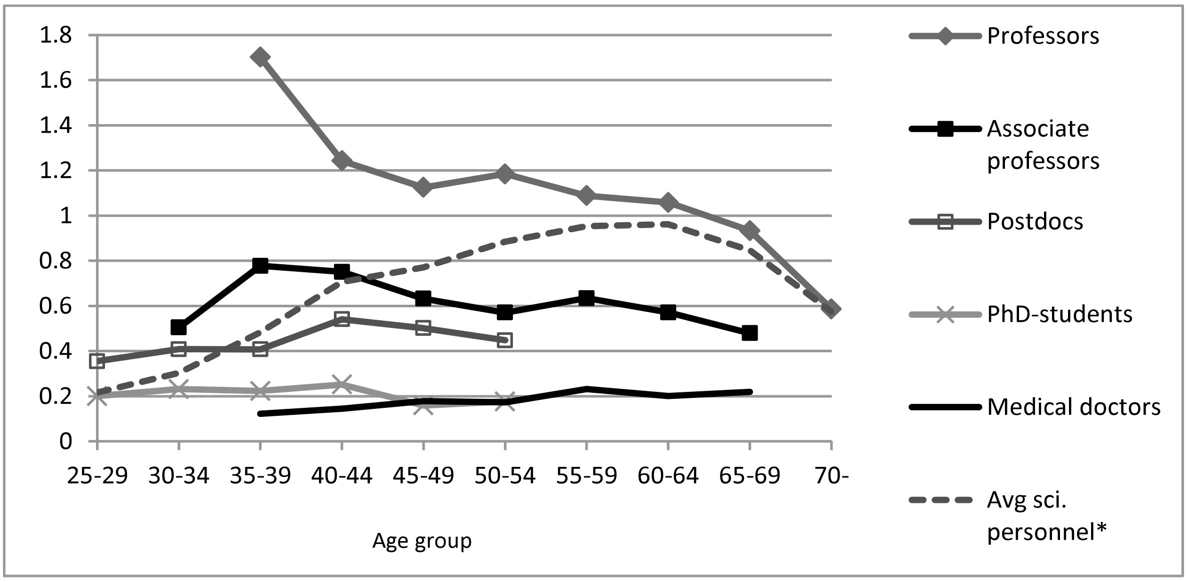

Figure 2. Average number of publications (fractionalized article equivalents) per person per year, by age group and group of personnel.

*) Includes PhD students, post doctors, associate professors, and professors.
Only age groups with more than 25 persons are shown in the figure.

In Figure 3 we have shown the publication productivity of the scientific personnel by scientific domains. There are quite large differences between domains in terms of average productivity measured as fractionalised article equivalents, but all show a similar age pattern of rise and decline. The humanities and the social sciences have the highest productivity levels. However, when using whole counts (not shown in the figure) the productivity numbers are much higher in the natural sciences, technology and medicine than in the humanities and social sciences (cf. (Aksnes et al., 2010). Despite similarities in the age patterns, there are also notable differences. For example, scholars in the humanities and the social sciences remain productive for a longer time period. In these domains, researchers in the age between 65 and 69 are still very productive.

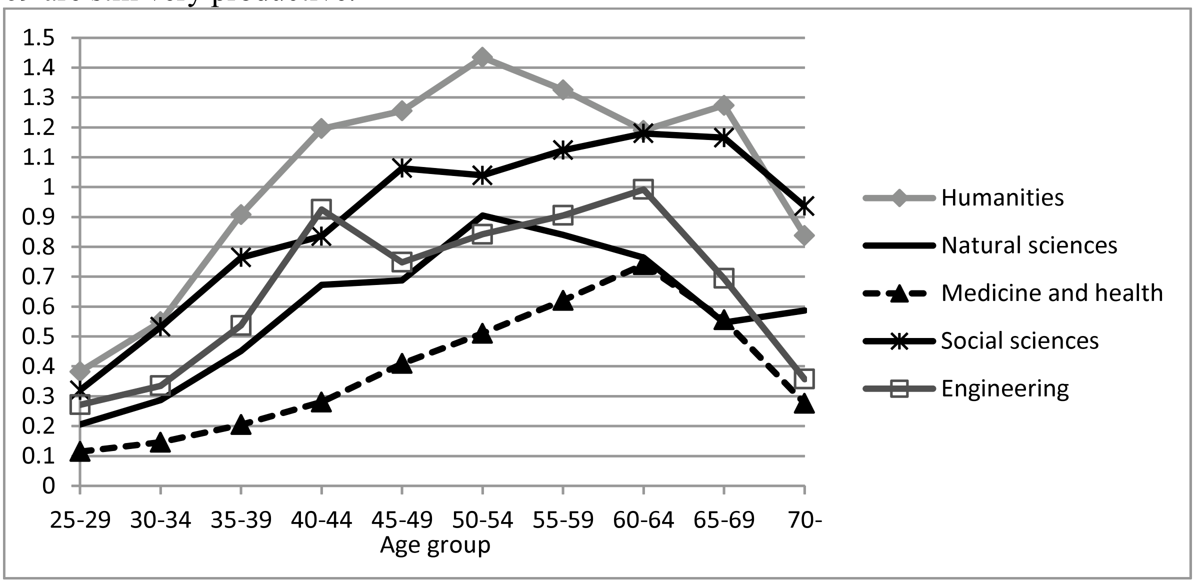

Figure 3. Average number of publications (fractionalized article equivalents) per person per year, by age group and domain, scientific personnel.*

*) Includes PhD students, post doctors, associate professors, and professors.

Previous studies have shown large gender differences in scientific productivity ((Aksnes et al., 2011; Kyvik & Teigen, 1996). For the scientific personnel we therefore analyzed how the average productivity varied according to gender and domain, cf. Figure 4 a and b. These results show that for almost all age groups and domains men are more prolific than women. Female scientists tend to publish generally between 20–40 per cent fewer publications than their male colleagues. The productivity of both men and women is increasing by age, reaching a peak in the 50–64 age groups, declining thereafter.

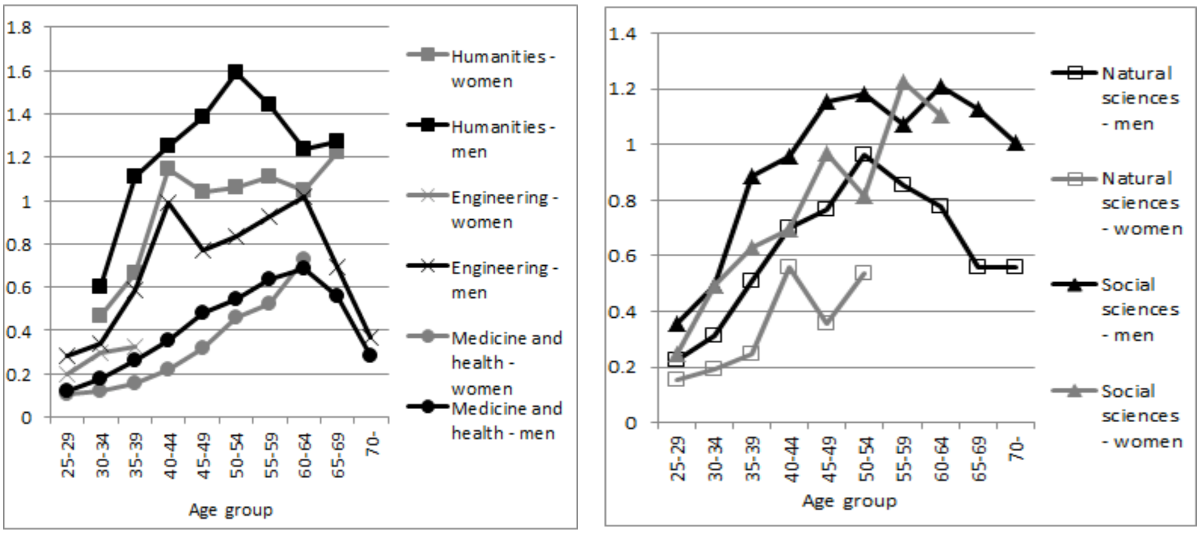

Figure 4 a and b. Average number of publications (fractionalized article equivalents) per person per year, by age group, gender and domain, scientific personnel*

*) Includes PhD students, post doctors, associate professors, and professors.
Only age groups with more than 25 persons are shown in the figure.

We then analyzed how the citation rates varied by age. As expected we find large individual variety and skewed citation distributions. Overall, 59 per cent of the persons obtained a relative citation index below 100 and 41 per cent above 100. Moreover, 13 per cent of the personnel were highly cited with a citation index above 200 and 11 per cent were very poorly cited or not cited at all (relative citation index 0-10). Interestingly, it appears that the average citation rate declines with the age of the scientists. A statistical analysis of the entire data set of 8456 persons shows that age and relative citation index are negatively correlated, although the correlation is rather weak. The Pearson correlation coefficient is - 0.039, significant at the 0.01 level.
In order to simplify the data set, the individuals were classified in age groups by five-year periods and an average citation index was calculated for each age group. The results are shown in Figure 5. Since the citation distribution is skewed and the average values are strongly influenced by a small group of highly cited persons, we have also calculated the medians for each age group. Both the average and the median citation index increase from the first to the second age group. The median shows the most distinct age pattern. With the exception of the 55-59 age group, the median is declining with age, and the decline is particularly strong for the personnel above 60 years. The average shows a less distinct pattern with more fluctuations, probably because of varying influence of highly cited persons. However, also for this parameter we see a strong decrease for the oldest groups of scientists. Thus, from the analysis it can be concluded that persons above 60 are significantly less cited than their younger colleagues. We have also analyzed the citation frequency at the level of

gender and for both men and women we find declining citation rates towards the end of the scientific career (cf. Aksnes et al., 2011).
In Figure 5 we have also shown the corresponding figures for one particular group of the scientific personnel – the professors (due to small numbers of professors in the youngest age groups, these figures have been omitted). Here, we see that the median citation index has an even stronger and continuous declining trend. The median is highest for the 35-39 age group, while the average peaks for the 40-44 year old scientists. Again, these results needs to be interpreted against the fact that we are using cross-sectional data and only the most successful scientists are able to obtain a professorship at a young age.

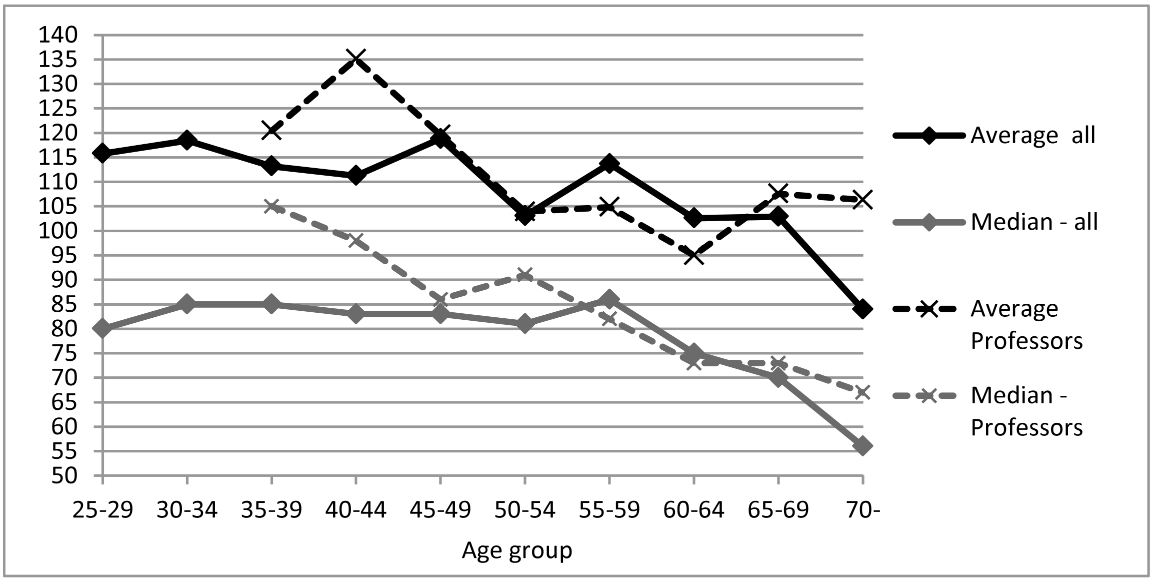

Figure 5. Average and median relative citation index by age-groups, all personnel and professors.

As a next step we analyzed how the scientists were distributed according to citation frequencies. This analysis did not reveal major differences between the age groups. However, it appeared that the share of highly cited persons (defined as persons having a citation index above 200) was higher for the younger persons, cf. Figure 6. In the age group 25-29 year, 16 per cent of the persons were highly cited, compared to only 7 per cent in the 70+ age group. Thus, this difference is likely to be a major explanation for the observed general declining citation pattern.

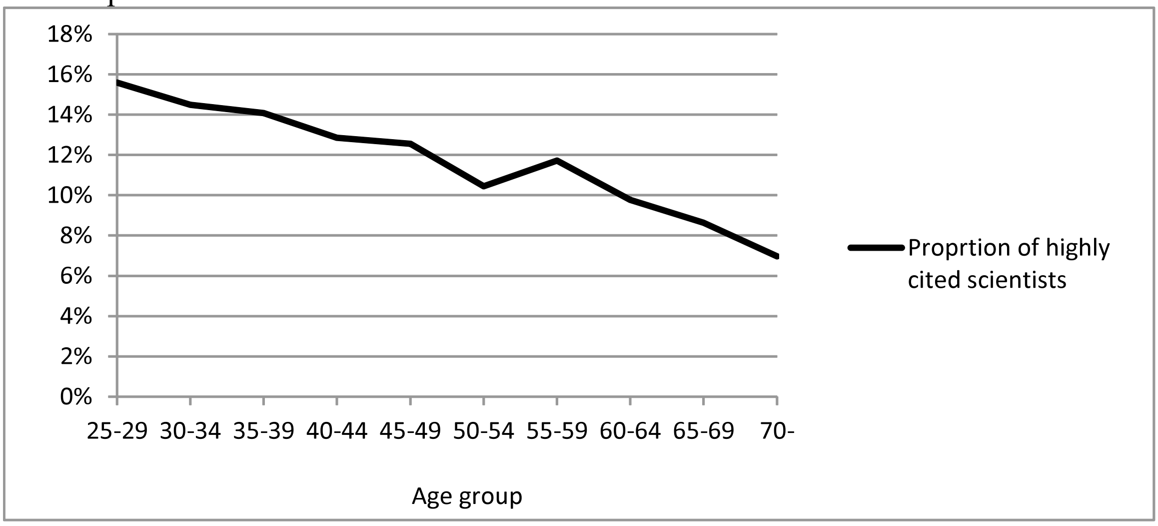

Figure 6. Proportion of highly cited* scientists by age-groups, all personnel

*) Relative citation index above 200.

The analysis is based on Norwegian scientists. As holds for all nations, Norway has a particular citation profile and obtains high citation rates in some disciplines and less high in others. This national profile might influence on the results of our analysis. We have therefore analyzed how the citation rates vary by age within the various disciplines. In order to simplify this analysis we have aggregated the data into three age groups: young scientists less than 40 years old, middle age scientists, 40 to 59 years, and old scientists more than 60 years old. The results are given in Table 2.

Table 2. Average relative citation index by age-groups and disciplines/domains, all personnel.

Discipline	*<40*	*N*	*40-59*	*N*	*> 60*	*N*
Biology	135	466	124	275	120	86
Biomedicine	108	928	114	664	110	198
Chemistry	106	232	94	93	71	53
Clinical medicine	109	446	110	811	101	279
Computer sci/informatics	110	188	83	92	67	16
Engineering	102	438	94	186	79	86
Geosciences	153	182	150	132	121	48
Humanities	61	76	100	127	43	50
Mathematics	113	125	110	64	127	36
Other	107	64	134	98	82	26
Physics	128	357	110	133	111	79
Psychology/psychiatry	163	139	114	204	80	67
Social medicine	116	102	127	225	116	49

The analysis shows that in 9 of 13 disciplines/domains the old scientists are less cited than their younger colleagues. In most cases the citation rate is substantially lower. In three disciplines the citation index of the old personnel is equal or almost equal to the second ranking group. In only one category (mathematics) the old scientists are the most highly cited personnel. The young scientists are the most highly cited personnel in 7 of 13 categories and the middle aged scientists obtain the highest citation rate in 5 categories. Thus, in the majority of the fields the young scientists are most highly cited, but there is no unambiguous patterns when it comes to age for obtaining the highest citation rate.

We also analyzed whether differences between the age groups could be found for variables that generally have been shown to be positively correlated with citations rates: average number of authors per publication, proportion of international co-authorship and proportion of review articles (see e.g. Aksnes, 2003). However, for all these variables we did not find large or systematical differences between the age groups (figure not shown).

Discussion

Numerous previous studies have analyzed productivity at individual levels. It has been shown that the productivity of publications per person may depend on various factors such as gender, age academic position and rank, availability of research funds, teaching loads, equipment, research assistants, workload policies, department culture and working conditions, size of department and organizational context (Dundar & Lewis, 1998; Kyvik, 1993; Ramesh & Singh, 1998). In this study the main focus has been on the relation between age and publication and citation rates.

The productivity analysis has shown that there are large age differences in the annual productivity levels, and for the population as a whole, we find an inverted U-shaped publication pattern. The pattern is uniform across variables such as research areas and gender, although the average productivity of publications is lower for women than for men in all the age groups. When analyzing the issue at the level of academic positions, we do, however, find a more heterogeneous picture. The professors are by far the most prolific persons. This category of academic personnel has the highest productivity at a young age and the annual number of publications declines substantially during the career. Still, this needs to be interpreted against the fact that we are using cross-sectional data and only the most successful scientists have been able obtain a professorship at a young age.

Our study is based on data on Norwegian scientists. While representing a large-scale study, the question remains whether our findings have general validity. Our overall results on the relation between age and productivity of publications are in accordance with many previous studies on this issue (e.g. Cole, 1979; Fox, 1983). Thus, there is additional empirical support that the pattern identified does not only hold for Norwegian scientists and that the curvilinear relationship between age and productivity can be considered to have a more general validity.

Interestingly, however, a recent study – also based on Norwegian data – did hardly find any differences in productivity between various age groups, with the exception of those less than 35 years of age (Kyvik & Olsen, 2008). In contrast, two similar Norwegian surveys conducted 9 and 19 years earlier showed that older staff published less than their younger colleagues (Kyvik, 2003). Based on these results, the authors suggested that the previously observed decline in productivity with increasing age is due to generation effects rather than aging effects. In other words, that the differences can be related to the fact that the persons belong to different generations with different life experiences, abilities and norms for publishing behaviour.

Our results are contradictory to those found in the paper by Kyvik & Olsen (2008) – even when both studies are based on Norwegian data. There are, nevertheless, important differences between the two studies. Our study is based on a much larger dataset than the Kyvik & Olsen study (11,500 compared to 1,200 persons). We are using register databases, while the results of the Kyvik & Olsen study are based on a questionnaire survey and non-verified self-reported number of publications. Finally, different time periods are being analysed: 2005-2008, vs. 1998-2000. Thus, the results of two studies are not directly comparable. In addition, as we only have dataset from one time-period, we are not able to examine possible generational effects. Nevertheless, due to the methodological differences described above, our results can be considered to have higher reliability than those of the Kyvik & Olsen study. As the findings of the latter study are in opposition with most other previous studies as well as ours, the deviating results might possibly be due to sampling errors and/or random variations.

The analysis of citation rates has shown a less distinct age pattern. The most notable finding is that citation rates tend to decline towards the end of the scientific career where the oldest researchers are less cited than their younger colleagues. Moreover, the proportion of highly cited persons is highest among younger scientists and declines by age. This is a major explanation for the observed general decline in citation rates. When analyzing the citation rates at the level of gender and academic positions we also find that the older persons perform less well. Moreover, this holds in the large majority of the disciplines analyzed. For the young and middle aged scientific personnel the citation rate is quite stable, and in contrast to the productivity rates we do not find a curvilinear pattern.

Kyvik (1991) has argued that "there seems to be a rather widespread opinion that older scientists are unproductive or out of touch with research frontiers. Gerontocratization of the university faculties has been a common concept – and one with negative connotations" (p. 154). There is some support for this opinion in our data. However, it is important to emphasise that although the productivity declines for the older scientists, they are still more productive then their youngest colleagues. The fact that the oldest persons have the lowest citation rates and there are few highly cited older persons might be interpreted to support the claim that these persons are out of touch with the research frontier. We have analysed the current publication output of the scientists, and although their former production might have been more highly cited, this do not hold for their recent articles.

As described in the introduction, the previous studies on the relationship between age and citation rates and other indicators of scientific achievements have not provided consistent results. However, in the majority of studies, the older persons fair less well when it comes to these measures. This also holds for the persons included in our study. Possible explanations might be that the older persons are not as creative as they were in their younger days, they are occupied with yesterday's problems and out-dated methods, they have problems with coping with scientific development and their research become obsolete. Still it needs to be emphasized that citations have many limitations as measures of scientific contribution (Aksnes, 2006) and can only provide indications for drawing such conclusions. It is also important to stress that our findings holds for the aggregate. At the individual level there are very large variations both in the productivity and citation rates of the persons.

Our study involves cross-sectional data. We do not have time series data to analyze the effect of age on productivity and citation rates longitudinally. A cross-sectional methodology is generally regarded to have more weaknesses than a longitudinally study (Allison & Stewart, 1974; Stephan, 1996). No doubt, a longitudinally study would have provided interesting complementary results. However, due to the fact that the norms for publication behaviour have changed during the recent decades (e.g. by an increasing number of authors per publication and number of publications per person (Kyvik & Olsen, 2008), it would be difficult to disentangle the effects of aging from these changes in the publication system.

Conclusions

This study, based on 11,500 persons, has shown that in terms of publication frequency, there are large age differences among researchers. In according with many previous studies on this issue, we find an inverted U-shaped publication pattern. The citation rates show less variation by age. The most important finding is that the oldest researchers are less cited than their younger colleagues. Moreover, the proportion of highly cited persons is highest for the younger persons and declines by age.

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