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Once Highly Productive, Forever Highly Productive? Full Professors' Research Productivity from a Longitudinal Perspective

Highlights:

- Lifetime biographical and publication histories of 2,326 full professors examined
- A combination of administrative, biographical, and bibliometric data used
- Retrospectively constructed productivity, promotion age and speed classes
- 50% of current top productive professors – top productive throughout their careers
- Top-to-bottom and bottom-to-top transitions in productivity classes rare

Abstract

This longitudinal study explores persistence in research productivity over time. We examine the trajectories of the academic careers of 2,326 current full professors in 14 STEMM disciplines, studying their lifetime biographical histories and publication histories. Every full professor is compared in terms of productivity classes (top, middle, bottom) with their peers at earlier career stages. We used prestige-normalized productivity in which more weight is given to articles in high-impact than in low-impact journals, recognizing the highly stratified nature of academic science. Our results show that membership in top productivity classes is to a large extent determined by being in these classes earlier. Half of the current top productive full professors belonged to top productivity classes throughout their academic careers. Half of the top productive assistant professors continued as top productive associate professors, and half of the top productive associate professors continued as top productive full professors (52.6% and 50.8%). Top-to-bottom and bottom-to-top transitions in productivity classes occurred marginally. The combination of biographical and demographic data with raw Scopus publication data from the past 50 years (N=1 million) made it possible to assign all full professors retrospective to different productivity, promotion age, and promotion speed classes. In logistic regression models, two powerful predictors of belonging to the top productivity class for full professors were being highly productive as assistant professors and as associate professors

(increasing the odds by 180% and 360%). Neither gender nor age (biological or academic) emerged as statistically significant. Hiring both low-productivity and high-productivity scientists may have long-standing consequences for institutions and the national science system: after entering the system and achieving job stability, scientists in Poland (where attrition is low) usually remain in the system for years, if not decades.

1. Introduction

This study explores persistence in research productivity at the individual level over time. We examine the trajectories of the academic careers of 2,326 current full professors, including their lifetime biographical histories and their lifetime publication histories. We studied the dates of their academic promotions and their publication output between promotions over a 40-year period across 14 science, technology, engineering, mathematics, and medicine (STEMM) disciplines. Our focus is not on productivity per se but on transitions between productivity classes throughout the professors' academic careers, from the assistant professor stage to the full professor stage.

We hypothesized that the current placement of full professors in the productivity classes of top, middle, and bottom (i.e., top 20%, middle 60%, and bottom 20% of scientists in prestige-normalized productivity in each discipline) corresponds, to some degree, to their placement in productivity classes at earlier stages of their careers. We speculated that current highly productive full professors could have also been highly productive associate professors and highly productive assistant professors earlier in their careers.

Research productivity is strongly influenced by both age and academic position (Wang & Barabási 2021; Gingras et al. 2008; Kyvik & Olsen 2008). Biological age and academic age as its proxy have been widely used in academic career research and productivity studies in the past decade (Nane et al. 2017; Aref et al. 2019; Savage & Olejniczak 2021). However, in national and cross-national comparative research, data on the ages and academic positions of all scientists are difficult to obtain. Previous studies linking productivity (as well as citation impact and collaboration), age, and academic positions are available in only a few countries, such as Norway (Kyvik & Olsen 2008; Aksnes et al. 2011; Rørstad et al. 2021), the USA (Stephan 2012; Sugimoto et al. 2016), Canada (Gingras et al. 2008; Larivière et al. 2011), Italy (Abramo et al. 2011; Abramo et al. 2016), Poland (Kwiek 2015; Kwiek 2020), and Spain (Costas & Bordons 2007; Costas et al. 2010).

Several recent studies have linked academic careers, productivity, mobility, collaboration, and academic age, such as the following: Milojević (2012), who studied citing behavior in relation to age, productivity, and collaboration; Radicchi and Castellano (2013), who studied productivity; Nane et al. (2017), who predicted age using bibliometric data; Aref et al. (2019), who studied mobility; Robinson-Garcia et al. (2020), who examined task specialization in academic careers; Chan and Torgler (2020), who examined top cited scientists; Simoes and Crespo (2020), who analyzed performance data per unit of time, linking career length to productivity; and Savage and Olejniczak (2021), who studied the productivity of younger versus older scientists.

Differences in research productivity have traditionally been explained using three theories of productivity: the "sacred spark" theory, the cumulative advantage theory, and the utility maximization theory. The sacred spark theory states that highly productive scholars are "motivated by an inner drive to do science and by a sheer love of the work" (Cole & Cole 1973: 62). In other words, while certain people are particularly good at doing science, "some are not just good but superb" (Stephan & Levin 1992: 13). The cumulative advantage theory developed by Robert K. Merton (1968) holds that productive scientists are likely to be even more productive, and low-productive scientists are likely to be even less productive. This theory is related to the reinforcement theory (Cole & Cole 1973: 114), which holds that “scientists who are rewarded are productive, and scientists who are not rewarded become less productive.” Finally, the utility maximization theory holds that scientists choose to reduce their research efforts over time because they may believe that other tasks are more advantageous. Stephan and Levin (1992: 35) claimed that later in their careers, scientists “are less financially motivated to do research…. [With] each additional year, the rewards for doing research decline,” perhaps because their research-driven professional reputation is already high (Kyvik 1990: 40). These three theories of productivity are complementary rather than competitive (Kwiek 2019: 27–32).

In the present study, we used prestige-normalized productivity, which combined the output indicator of research productivity with the output indicator of scholarly impact on science based on citations. Output indicators measure the knowledge produced, and impact indicators measure the ways in which scholarly work affects the research community and society (Sugimoto and Larivière 2018: 1). The weight of an article depends on its position in the global hierarchy of academic journals. In our approach, articles published in journals with, on average, a high impact on the academic community captured through the proxy of average citation numbers (in terms of Scopus journals’ percentile rank in the range from 0–99) were given more weight in calculating productivity than articles in low-impact journals because they required, on average, more scholarly effort. Our approach to productivity recognizes the highly stratified nature of academic science, in which both the quantity of publications and their standardized quality are important.

Our starting point was the current distribution of full professors by productivity classes in the four-year period from 2014–2017. They were classified as either high productivity, average productivity, or low productivity. We then examined the productivity classes to which they could be retrospectively assigned at earlier stages of their careers, that is, when they were assistant professors and associate professors. In the Polish system, only a small portion of the academic workforce reaches the stage of full professorship.

In this study, the unit of analysis was the individual researcher, not the individual publication. Although we used a combination of administrative, biographical, and bibliometric data, our study was not bibliometric in nature and is germane to academic career studies. It was not possible to perform lifetime retrospective analyses of individual scientists without having full access to raw bibliometric metadata for all publications by all individual scientists in the past 40 years. It was not possible to construct retrospective productivity classes for all scientists by discipline, career stage, and selected period without having access to each scientist’s global publication metadata. It was also impossible to determine the academic age of each scientist, which is used in addition to biological age in logistic regression models, without the ability to collect structured big data from commercial bibliometric databases, such as Scopus and the Web of Science. Our study provides an example of combining structured big data and national registry data to conduct detailed analyses of academic careers within a national (i.e., Polish) academic science system.

This paper consists of the following sections. First, we conduct an analysis of the literature on full professors and present the research questions and hypotheses. We then describe the dataset, sample, and methods applied to define academic discipline and academic age, followed by the distribution of our sample. We then discuss three key elements of our methodological approach: 1) constructing lifetime biographical and publication histories; 2) constructing prestige-normalized individual research productivity; and 3) constructing academic career classifications (i.e., productivity, promotion age, and promotion speed). We then discuss the limitations of our study. The results section consists of two main sections: 1) mobility between productivity classes from a lifetime career perspective; and 2) the odds ratios (using logistic regression models) of being in the highest and lowest productivity classes. The discussion section is followed by the conclusion section, which includes future research directions.

2. Literature Review

2.1. Research So Far

2.1.1. Literature on Full Professorship: International Insights

The research on full professors in academia can be classified by their academic position (i.e., full professor literature and all ranks literature, which includes full professors) and methodology (i.e., driven by survey data, bibliometric, administrative, and biographical data, interview data, and mixed-methods approaches). The amount of literature on all ranks outnumbers that on full professors. Both categories are outnumbered by the amount of literature on scientists without reference to academic positions, the major reason for which is the lack of access to adequate data on academic rank.

The literature on full professors includes studies of the academic profession in the United States, such as Yuret (2018), who analyzed the "paths to success" of holding full professorships based on the educational backgrounds of over 14,000 full professors from 48 top universities. Yuret showed that 70% of full professors who worked in private universities obtained their degrees from private universities, only 4% worked at universities from which they graduated, and full professors graduated significantly faster than the median PhD graduate. The findings showed that promotion to full professorship was related to high mobility, low inbreeding, and short duration to PhD graduation. Kolesnikov, Fukumoto, and Bozeman (2018) studied 227 full professors of chemistry and 148 full professors of mechanical engineering at 10 research-intensive universities to test the hypothesis that productivity is inversely correlated with impact. However, the results for the two fields were divergent: in the former, higher productivity led to lower impact; in contrast, in the latter, higher productivity consistently led to higher impact. In a USA context, Fox (2020: 1002) concluded that gender predicts academic rank: "women are less likely than men to hold higher ranks, and the gender disparity is especially apparent for the rank of professors".

Previous research in the literature on full professors included studies conducted in Israel and Norway. Weinberger and Zhitomirsky-Geffet (2021) examined diversity in scholarly performance among 663 tenured professors at Israeli universities based on distinctions between high-, average-, and low-impact scholars. The results of their linear regression analysis showed that women outperformed men in terms of scientific impact, and differences in performance showed that scholarly success and promotion in Israel may not be determined by productivity because other factors were involved (Weinberger & Zhitomirsky-Geffet 2021: 2949). Piro, Rørstad, and Aksnes (2016) studied the influence of prolific professors on the citation impacts of their university departments in Norwegian universities (N = 1,084 observations). While productivity was skewed at the level of individuals, the influence of prolific professors on their departments' citation impacts was modest.

Regarding gender discrimination in promotions to full professorships, recent evidence was found in Italy, Sweden, the USA, and Germany, albeit with inconclusive results. In Italy, Marini and Meschitti (2018) analyzed 1,161 promotions from 2013–2016 across 14 disciplinary areas using multilevel logistic regression. The results showed that men had a 24% higher probability of being promoted, although they had the same scientific output as women. The authors showed that gender-based discrimination was persistent, and it may have been linked to homophily; therefore, promotion committees composed entirely of men could favor males (Marini & Meschitti 2018: 1000). Madison and Fahlman (2020), using publication data, analyzed all promotions to full professorships in the six largest Swedish institutions from 2009–2014. Their results showed that there was no bias against women in attaining full professorships in relation to publication metrics. Furthermore, they concluded that women had been "preferentially hired" rather than discriminated against (Madison & Fahlman 2020: 16). Lerchenmueller and Sorenson (2018) studied gender gaps in career transitions in the life sciences in the USA, focusing on the recipients of the first R01 renewable grant from the National Institutes of Health (NIH). The results showed that a large share of the gender gap in science had emerged within a brief period when men and women moved from being a member of another researcher's lab to leading their own lab (Lerchenmueller & Sorenson 2018: 1015). Women had 20% lower rates in the transition from postdoctoral grants to R01 grants.

In Germany, all sociologists and psychologists were studied. Lutter and Schröder (2016) examined all sociologists working in sociology departments and showed that, compared with men, women had obtained their first permanent positions as university professors with, on average, 23–44% fewer publications. Women sociologists were likelier than men to obtain a full professorship with the same number of publications. Interestingly, the road to full professorship was found to clearly differ (Lutter & Schröder 2016: 1006–1008). In men, the strongest predictor of success was publishing in Social Science Citation Index (SSCI) journals. In contrast, in women, while SSCI articles also strongly increased their chances of obtaining a professorship, the strongest predictor was the accumulated number of academic awards. Mayer and Rathmann (2018) conducted analyses of the curriculum vitae (CV) of 294 German full professors of psychology, combining these data with data collected from the Web of Science (WoS). Using a multivariate analysis, they showed that women psychologists had different publishing patterns; instead of submitting papers to competitive journals (i.e., the top 10% journals in WoS), women psychologists may have been satisfied with publishing less prestigious book chapters (Mayer & Rathmann 2018: 1663). This publishing pattern may be disadvantageous for women in terms of recognition and prestige, even though all observations were of successful females who had already been promoted to full professors in their field. Lutter, Habicht, and Schröder (2022) examined gender differences in achieving a tenured professorship in German psychology based on the profiles of 2,528 scholars. Assuming that the "race for tenure" started with the first publication, they rejected the female devaluation theory, which suggests that women's career achievements are devalued in relation to those of men. They found no systematic evidence of gender bias: productivity, as determined by the number of WoS articles, was particularly beneficial for women, and women accumulated as many awards as men, and they profited as much from them as men (Lutter et al. 2022: 8).

2.1.2. All Ranks Literature: International Insights

Regarding the all-rank literature, in which full professors are examined among other academic ranks, research on productivity, ranks, and age was conducted in Finland, Italy, Norway, the Netherlands, Poland, and the USA. Puuska (2010) focused on ranks, productivity, and different types of publications by 1,417 Finnish professors. The results showed that full professors were the most productive: the "higher the more productive" principle applied to all academic ranks, and male scholars were more productive than female scholars for all publication types (Puuska 2020: 428-430). Full professors were also more productive than lower ranks in the soft sciences, where solo research is important, and therefore the impact of leading large research grants is marginal (see Kwiek & Roszka 2022a). In several male-dominated fields, female full professors were shown to be more productive than male full professors, which may indicate that in these fields only exceptionally productive women are appointed to full professorships, whereas in other fields, possibly less merit in research is required for women in this rank (Puuska 2010: 435).

In the Italian context, Abramo et al. (2011) examined the links between individual productivity and academic ranks for all Italian university researchers active in the hard sciences. Their study included 10,764 full professors. The results showed that the productivity distribution across the ranks was not pyramidal but uniform, only slightly shifting in favor of full professors. The share of full professors with at least one publication and with at least one citation in the period studied was higher than for the lower ranks. Full professors showed the highest productivity, but "top scientists" (i.e., the upper 10%) were evenly concentrated among the three ranks (Abramo et al. 2011: 927). Abramo et al. (2016) also examined two other dimensions related to productivity: collaboration and impact from the perspective of academic rank. First, they examined the north–south divide in Italian higher education, in which full professors in the north are more productive than full professors in the south. Second, they studied the propensity to collaborate internationally across different ranks. The findings showed that full professors were, on average, more inclined to collaborate internationally and less inclined to collaborate nationally compared with lower ranks (Abramo et al. 2013: 2288–2298). Finally, they studied highly productive academics (2,135 star scientists). The results showed that almost six in ten (57.8%) were full professors and were usually male (Abramo et al. 2009: 143). They demonstrated that in the case of non-stars, or the remaining 90% of scientists, gender differences in productivity were practically nonexistent. Especially significant for our context of full professorships, female full professors were found to be more productive than male full professors if only 90% of the population of scientists were examined and the upper 10% (i.e. star scientists) were excluded from the analysis (Abramo et al. 2009: 154).

In a Norwegian context, Aksnes, Rørstad, Piro, and Sivertsen (2011) addressed the question of whether female researchers were less frequently cited than male researchers, based on 8,500 Norwegian researchers. Based on the results, they attributed gender differences in citation rates to differences in productivity; they showed a cumulative advantage effect of increasing publication output on citation rates. Full professors obtained a lower-than-average citation index despite their high productivity index; by far, the highest indexes in both categories were obtained by postdocs, both male and female (Aksnes et al. 2011: 632). The same authors (Aksnes et al. 2013) also studied the impact of mobility on productivity and citation rates by comparing mobile and non-mobile Norwegian scientists. The results showed that the differences between mobile and non-mobile full professors were not statistically significant. However, mobile full professors were the most productive group (Aksnes et al. 2013: 219).

Finally, in the USA and Dutch contexts, in a survey-based study of 607 highly prolific scientists, Fox and Nikivincze (2021) showed that, compared with the rank of assistant professor, the rank of full professor was a strong and positive predictor of being highly prolific. Interestingly, in the presence of rank, gender was not associated with being highly prolific. Consequently, rank emerged as a "conduit in the relationship between gender and being prolific". They concluded that "being prolific is a senior professors' game" (Fox & Nikivincze 2021: 1250). Based on survey results from 453 economists at Dutch universities, van Dalen (2021: 1691) demonstrated that full professors substantially differed from lower ranks in their perceptions of the publish-or-perish principle. They perceived the positive side of this principle more intensively compared with the lower ranks, and, unlike the latter, they perceived virtually no negative aspect of the principle.

The life cycle perspective has rarely been used to examine academic careers. Only three studies have viewed scientists from this perspective. Lörs and Mühleck (2019) analyzed gender differences in transitions between enrollment in studies and first postdoc positions. The results showed that performance played a minor role in professional decision-making, and the men and women differed in their reasons for starting or stopping their academic careers. Horlings and Gurney (2013) examined 43 eminent physicists, combining their CV data with their metadata of over 18,000 publications. They examined how individual scientists built their personal research portfolios at various stages of their academic careers. Kawaguchi, Kondo, and Saito (2016) examined the use of research time during the life cycle in Japanese universities. They found that the amount of research time decreased, and the amount of administrative time increased over the lifecycles of the academics.

Finally, and most significant for our study on productivity from a life cycle perspective, Abramo et al. (2016: 318), in their study of Italian full professors, concluded, "As age increases, there is a high decline in full professors' productivity." However, professors appointed at a young age were likelier to maintain and increase their productivity than colleagues promoted at a later age (Abramo et al. 2016: 318). A "negative monotonic relationship" between age and research performance was found to accompany a "positive relationship between seniority in rank and performance" (Abramo et al. 2016: 301). In their bibliometric study of Spanish National Research Council scientists, Costas et al. (2010) concluded that the productivity of top- and medium-performing scientists increased or remained stable with age, and that the productivity of low-performing researchers tended to decrease with age (Costas et al. 2010: 1578).

2.2. Research Questions and Hypotheses

The six research questions and hypotheses provided in Table 2 were based on the previous studies analyzed in Section 2.1. and prior knowledge of the Polish academic science sector. The hypotheses pertain to persistence of high productivity (H1) and low productivity (H2) over time; and persistence of high productivity at the beginning and towards the end of academic careers (H4); as well as disciplinary differentiation (H3) and gender differentiation (H5) in mobility between productivity classes, and individual vs. organizational features (H6) in logistic regression analysis estimating odds ratio of belonging to top and bottom productivity classes. An overaching research question is about changes in productivity from a life-cycle perspective: have current top performing full professors always been top performing while current low performing full professors – always low performing?

Table 2. Research Questions, Hypotheses, and Summary of Results.

Research Questions	Hypotheses	Support
RQ1. What is the relationship between currently high productivity and high productivity in the two earlier stages of an academic career?	**Persistence of *high* productivity over time** **H1:** Currently highly productive full professors were, in a significant proportion, highly productive associate professors, and highly productive associate professors were, in a significant proportion, highly productive assistant professors.	Supported
RQ2. What is the relationship between currently low productivity and low productivity in the two earlier stages of an academic career?	**Persistence of *low* productivity over time** **H2:** Currently low-productive full professors were, in a significant proportion, low-productive associate professors, and low-productive associate professors were, in a significant proportion, low-productive assistant professors.	Supported
RQ3. What is the relationship between productivity trajectories during a life cycle and academic disciplines?	**Disciplinary differentiation** **H3:** Mobility between productivity classes varies by discipline.	Supported
RQ4. What is the relationship between current productivity and productivity at the beginning of an academic career?	**Persistence of productivity throughout the academic careers** **H4:** Current full professors belong, in a significant proportion, to the same productivity class at the beginning and at the end of their academic careers.	Supported
RQ5. What is the relationship between productivity trajectories over a life cycle and gender?	**Gender differentiation** **H5:** Mobility between productivity classes varies by gender.	Supported
RQ6. What is the relationship between individual and organizational attributes and belonging to the top and bottom productivity classes?	**Individual characteristics versus productivity classes** **H6:** Individual characteristics better determine a scientist's odds ratios of belonging to the highest and lowest productivity classes compared with organizational characteristics.	Supported

3. Data, Methods, and Sample

3.1. Dataset and Sample

The data used in this study were collected from the Polish Science Observatory database (see Kwiek & Roszka 2021a: 4-6), from a national administrative and biographical register of all Polish scientists (N = 99,935), and from the Scopus bibliometric database (2009–2018, N = 380,000 publications). The final number of articles was 158,743, and they were published by 25,463 unique authors with Polish affiliations. The Observatory database was then enriched with publication metadata collected from Scopus, which were obtained through a collaboration agreement with the ICSR Lab, which is a cloud-computing platform provided for research purposes by Elsevier (N = 1,000,000 publications from 1980–2021 by authors with Polish affiliations). We used information about the entire academic output of individual authors based on their Scopus IDs in the database. Our final sample included full professors in 14 STEMM disciplines (N = 2,326).

3.2. Defining Academic Disciplines and Academic Age

We defined individual attributes in the sample of 23,543 scientists in all academic positions and disciplines and every full professor in the 14 STEMM disciplines in our final sample. In the All Science Journal Classification (ASJC) system of disciplines used in Scopus, a journal publication has one or multiple disciplinary classifications. The dominant discipline of each full professor was determined based on all publications (type: article) included in their individual publication portfolios for the period from 2009–2018 (the modal value is the most frequently occurring value). When there was no single value, the dominant discipline was randomly selected from among the most frequently occurring disciplines.

Our dataset included the professors' dates of birth and the dates on which every full professor received three scientific degrees—doctoral degree, habilitation degree, and professorship—which were used as proxies for assistant, associate, and full professors, respectively. We obtained the dates of the first publication indexed in Scopus using the application programming interface (API) protocol, which is a set of programming codes that enable data transmission between one software product and another provided by Scopus. The gender of all scientists with at least a PhD degree is included in the data provided by the national registry of scientists, and in this study, it was treated as a binary variable.

3.3. Full Professors: Discipline and Age Distribution

The distribution of our final sample was as follows: about three-fourths of full professors were men (see Table 1); about one-third worked in 10 research-intensive IDUB institutions (IDUB is a Polish research excellence initiative from 2020–2026); about two-thirds were aged more than 60 years and about a half were aged from 65–70 years. In our sample, 16% were young (under 55 years) full professors: 2% aged 40–44 years, 4.8% aged 45–49 years, and 9.2% aged 50–54 years. The three disciplines with the largest number of full professors were medical sciences (MED), agricultural and biological sciences (AGRI), and engineering (ENG). About half of all Polish full professors in our sample were publishing in these three disciplines. The largest share of female full professors in larger disciplines was in biochemistry (BIO), MED, and AGRI (about one-third). The lowest share was in physics (PHYS) (5.5%), mathematics (MATH) (6.3%), and ENG (5.8%). The distribution by biological age and gender are presented in Figure 1. The distribution of female scientists was equal across ages, while the distribution of male scientists was steeper. The distribution by age was more similar than expected. The gender distribution of the full professors in our sample was close to their gender distribution in the population over the past five years (GUS 2021).

Table 1. Structure of the sample of all Polish internationally visible university full professors by gender, age group, and STEMM discipline.

		Female scientists			Male scientists			Total		
		n	row %	col %	n	row %	col %	n	row %	col %
Age groups	Total	551	23.7	100.0	1775	76.3	100.0	2326	100.0	100.0
	up to 50	48	24.9	8.7	145	75.1	8.2	193	100.0	8.3
	51 - 60	164	27.2	29.8	438	72.8	24.7	602	100.0	25.9
	61 - 65	145	22.3	26.3	505	77.7	28.5	650	100.0	27.9
	65-70	194	22.0	35.2	687	78.0	38.7	881	100.0	37.9
IDUB	IDUB	130	16.7	23.6	650	83.3	36.6	780	100.0	33.5
	Rest	421	27.2	76.4	1125	72.8	63.4	1546	100.0	66.5
Academic discipline	AGRI	119	33.9	21.6	232	66.1	13.1	351	100.0	15.1
	BIO	66	37.9	12.0	108	62.1	6.1	174	100.0	7.5
	CHEM	41	25.2	7.4	122	74.8	6.9	163	100.0	7.0
	CHEMENG	9	21.4	1.6	33	78.6	1.9	42	100.0	1.8
	COMP	14	14.4	2.5	83	85.6	4.7	97	100.0	4.2
	EARTH	13	11.3	2.4	102	88.7	5.7	115	100.0	4.9
	ENER	6	19.4	1.1	25	80.6	1.4	31	100.0	1.3
	ENG	18	5.8	3.3	292	94.2	16.5	310	100.0	13.3
	ENVIR	57	35.6	10.3	103	64.4	5.8	160	100.0	6.9
	MATER	37	23.1	6.7	123	76.9	6.9	160	100.0	6.9
	MATH	9	6.3	1.6	133	93.7	7.5	142	100.0	6.1
	MED	138	36.4	25.0	241	63.6	13.6	379	100.0	16.3
	PHARM	14	66.7	2.5	7	33.3	0.4	21	100.0	0.9
	PHYS	10	5.5	1.8	171	94.5	9.6	181	100.0	7.8

Note: STEMM disciplines included in the study: AGRI, agricultural and biological sciences; BIO, biochemistry, genetics, and molecular biology; CHEMENG, chemical engineering; CHEM, chemistry; COMP, computer science; EARTH, earth and planetary sciences; ENER, energy; ENG, engineering; ENVIR, environmental science; MATER, materials science; MATH, mathematics; MED, medical sciences; PHARM, pharmacology, toxicology, and pharmaceutics; and PHYS, physics and astronomy.

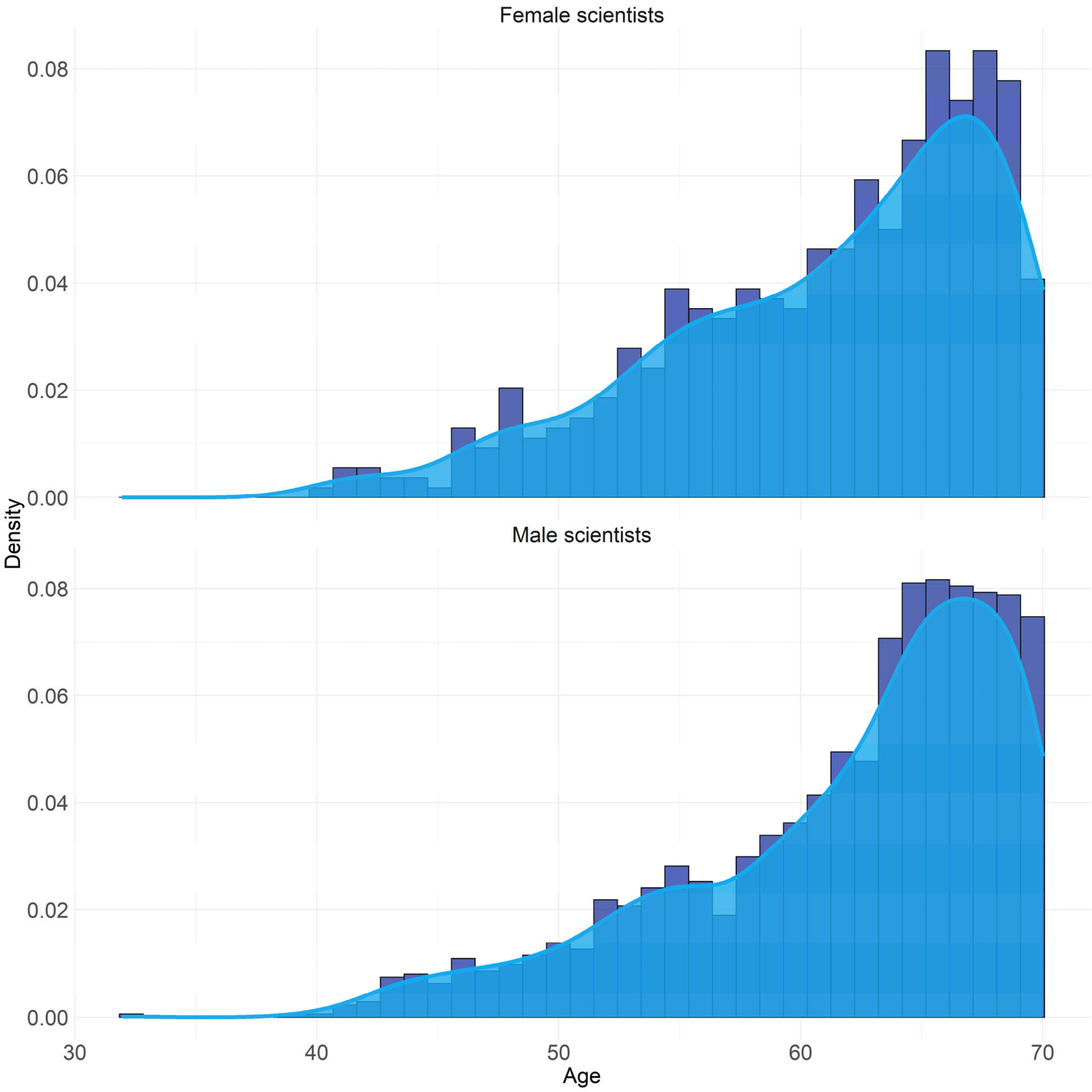

Figure 1. Distribution of biological age: kernel density plot, full professors in 14 STEMM academic disciplines combined, by gender.

3.4. Methodological Approach

3.4.1. Constructing Lifetime Biographical and Lifetime Publication Histories

The Laboratory of Polish Science database created for this study included the complete publication histories of all Polish scientists working in the higher education sector as of November 2017, holding at least a PhD degree, and having at least one publication in the Scopus database. The database includes the publication and citation metadata on all publications by each scientist in each stage of their scientific career. The database included data on 14,271 assistant professors, 7,418 associate professors, and 3,774 full professors in STEMM and non-STEMM disciplines.

However, we focused only on a subsample of full professors, which enabled us to trace their individual biographical histories and individual publication histories in the earlier stages of their careers. Only full professors could be compared in three earlier stages. An analogous analysis could have been performed in a subsample of all current associate professors, but in this case, their academic output would have been compared in only two earlier stages. The analysis of full professors included a long period of scientific activities lasting several decades. A full professorship represents the culmination of an academic career: we retrospectively examined the academic career classes of full professors who had been working for 20–40 years. The compilation of complete lifetime biographical histories (i.e., dates of birth and dates of subsequent academic promotions) and complete lifetime publication histories (i.e., detailed data on publications, collaborations, mobility, and citations), spanning entire academic careers, allowed us to retrospectively analyze the transitions between productivity classes over time of the full professors in our sample.

In this study, we applied a longitudinal approach to analyzing the transitions between the productivity classes of the full professors over their careers, from the year in which they received their PhD degrees to 2017. We analyzed the productivity of individual scientists as they aged and moved up the academic ladder. Each publishing scientist within their unique biographical history (based on dates) and unique publication history (based on publication metadata) was characterized by transitions between productivity classes compared with their peers in the same discipline and at the same career stage.

3.4.2. Constructing Prestige-Normalized Research Productivity

Empirically, the productivity of a researcher at a given stage in their academic career was reflected in the number of all publications (i.e., publication type: article) published by that stage divided by “4” to maintain the comparability of the productivity counts over four-year periods. This approach reduced potential differences between the first years after each promotion, when productivity may decrease, and the years just before a new promotion, when productivity may increase, as shown in an earlier study on Polish researchers (Kwiek 2015). As in other countries, the productivity of some scientists may vary during their careers.

We divided the academic careers of the full professors in our sample into three stages based on distinct opening and closing dates, and we constructed lifetime productivity profiles and productivity profiles in their three career stages. We used a full counting approach instead of a fractional counting approach in which single-authored and multiple-authored publications were counted equally. We used the prestige-normalized publication number rather than the raw publication number.

Prestige-normalized individual research productivity better reflects workloads and their effects in the form of publications in the scientific community compared with raw or non-normalized productivity. Measuring journal prestige is closely related to the Polish system of evaluating scientists and scientific units and to the indicators used in the “Excellence Initiative – Research Universities” (IDUB). Articles in highly prestigious journals require, on average, a greater workload and have, on average, greater resonance in the world of science, as captured through citations. In Scopus, the prestige rank of a journal is determined annually by the journal's placement in the CiteScore ranking system, which is prepared annually for all journals indexed (e.g., 40,562 in 2022). In our study, the most intuitive in the CiteScore family of metrics was the journal percentile rank. Percentile ranks are based on values in a range from 1–99, in which the highest prestige is the 99th percentile. Highly prestigious journals in each field tend to be in the 90–99th percentile. For example, *Research Policy,* the *Journal of Informetrics,* and *Nature Communications* are in the 97th percentile of Scopus journals. In this approach, publications in more prestigious journals count more in productivity calculations compared with publications in less prestigious journals within each discipline.

In a non-normalized approach to productivity, based on raw publication numbers, an article published in any journal would receive a value of 1. In contrast, in the prestige-normalized productivity approach applied in the present study, an article in a journal with a percentile rank of 97 received a value of 0.97, while an article in a journal with a percentile rank of 30 received a value of 0.3, and articles published in journals with percentile ranks of and below 10 received a value of 0.1. A prestige-normalized approach to individual research productivity allows for a fair measurement of scholarly effort in STEMM disciplines in which vertical journal stratification is a fact of life. For instance, in plant science, counting publications in *Nature Plants* (99th percentile) and *Plants* (56th percentile) in the same way would disregard individual scholarly efforts invested in research. Each discipline has specific top-tier journals, and "the tyranny of the top five" (Heckman & Moktan 2018) is applicable far beyond economics.

3.4.3. Constructing Academic Career Classes: Productivity, Promotion Age, and Promotion Speed

In this study, we applied the notion of climbing the academic ladder, which defines an academic career that spans several decades. Current full professors have previously been first assistant professors and then associate professors. They remained for a specific number of years at each stage of their academic careers. In each stage, they demonstrated specific productivity—that is, a certain number of publications in a four-year reference period.

We assigned seven academic career classes to each full professor (see Figure 2): three productivity classes, two promotion age classes, and two promotion speed classes. The current and past productivity classes were the top, middle, or bottom—that is, the upper 20%, middle 60%, or lower 20%, respectively, in a prestige-normalized and discipline-normalized approach separately within each of the 14 STEMM disciplines. The promotion age classes were young, middle, or old associate professors and young, middle, or old full professors. That is, the upper 20%, middle 60%, or lower 20%, respectively, in terms of promotion age expressed in full years. The promotion speed classes were fast track, typical track, and slow track associate professor and fast track, typical track, and slow track full professor, that is, the upper 20%, middle 60%, and lower 20%, respectively, in terms of the transition time between subsequent promotions, also expressed in full years.

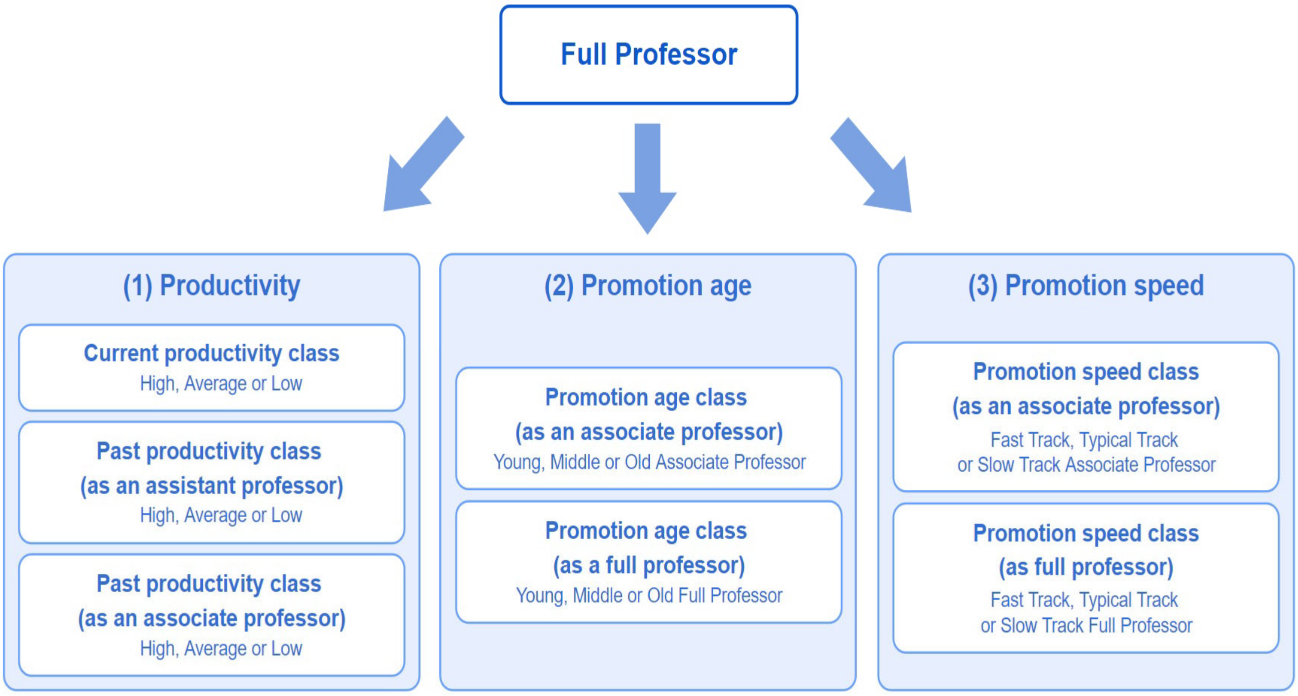

Figure 2. Classification scheme used for full professors: productivity, promotion age, and promotion speed classes.

At each stage of their careers, the full professors were more or less productive. They changed their productivity classes in relation to their colleagues in the same discipline and remained at the same stage of their academic career and in the same academic position. Our study compared "apples with apples" rather than "apples with oranges". The scientists were consistently compared at the same stage of their careers within the same historical period and within the same discipline. The scientists may have been nominally progressively more productive over time and progressively more productive at successive stages of their careers. However, in comparative terms, they may have been less productive than their peers at these stages. Our methodological approach thus did not consider nominal increases and decreases in individual productivity over time; instead we focused on increases and decreases in individual productivity compared with peers.

3.7. Limitations

The present study has several limitations related to the data and methodology. First, our sample included all scientists who were internationally visible through their research in Scopus from 2009–2018; consequently, non-publishing (and non-publishing internationally) scientists were not included in the sample. However, the percentage of scientists in STEMM disciplines who published internationally was high; moreover, it increased over time, and it was much higher than in non-STEMM disciplines (Kwiek 2020).

Second, this research combined (near perfect) administrative and biographical data collected from a national registry of scientists with (much less perfect) bibliometric data at the individual level. Therefore, we combined data on "real individuals" with national identification numbers with metadata on publications by "individual Scopus IDs" rather than "real scientists." Our Observatory of Polish Science was constructed through a deterministic and probabilistic record linkage between two original data sets that differed in nature. For the past two decades, it has been widely debated to what extent bibliometric data are biased linguistically, geographically, and disciplinarily (Shang et al. 2021; Boekhout et al. 2021). However, sources other than raw Scopus (or the raw Web of Science Core Collection) datasets could not be used to construct full publication histories of all scientists within a national science system. No other source of publication metadata has been available about Polish scientists from the past 40 years.

Third, in this study, academic age used in the logistic regression analyses was a proxy for biological age (biological age was used too). However, as we have shown elsewhere (Kwiek & Roszka 2022b) in a study on 25,000 Polish scientists, the use of academic age as a proxy for biological age is fully justified in STEMM disciplines. The correlations between the two age types in these disciplines ranged from 0.75–0.90 We used recently available (2020) institutional affiliations of scientists rather than their earlier affiliations; however, previous research showed that the rate of academic inbreeding in Poland is high, and the majority (over 90%) of full professors have never changed their institutions, except for temporary international mobility. Finally, our study shows a "success bias": its sample includes only full professors i.e. those who go to the top of academic hierarchies.

4. Results

4.1. Mobility between Productivity Classes from a Lifetime Career Perspective

The research questions concerned the persistence of productivity classes of full professors from a lifetime career perspective: Have current top-performing full professors always been top-performing? And have current low-performing full professors always been low performing?

Figure 3 shows the lifetime career trajectories of 2,326 full professors in 14 STEMM disciplines combined (TOTAL). Their productivity was classified as top, middle, or bottom (20%, 60%, or 20%, respectively) in three periods: between becoming assistant professors and becoming associate professors (left column); between becoming associate professors and becoming full professors (middle column); and after becoming full professors (right column). Our focus was on the mobility of top productivity classes and bottom productivity classes in the three stages of an academic career. The results are shown in Sankey diagrams.

The majority of highly productive scientists (Top) remained highly productive compared with their peers in the same discipline and within the same academic position, which is shown in thick left-to-right horizontal flows (as shown in Figure 3). More than half of the highly productive scientists moved from the top class to the top class in the first (52.6%)

and second stages of their academic careers (50.8%). Only about 2.3% moved to the low-productivity class in the first period, and only about 5% moved to the low-productivity class in the second period. These exceptional cases of top-to-bottom mobility in productivity classes are shown as thin descending flows from the top classes to the bottom classes (Figure 3). The mobility from the bottom productivity classes to the top productivity classes in the first and the second periods was limited. In Figure 3, upward mobility is shown as thin ascending flows from the bottom classes to the top classes: 8.5% and 2.9%, respectively. Extreme mobility between productivity classes (top-to-bottom and bottom-to-top) was characteristic of only 100 scientists of 2,326.

The Sankey diagrams also show the ongoing mobility between middle-performing classes (Middle) and top-performing classes (Top). Although the majority of professors assigned to the middle-performing class remained in the same class, some moved up, and some moved down. The data on possible combinations of mobility in this case are shown in Table 2: the first panel shows the data on mobility from assistant professors to associate professors, the second panel shows mobility from associate professors to full professors, and the third panel describes the subsample used (all special cases can be identified at an individual level, and further discussed).

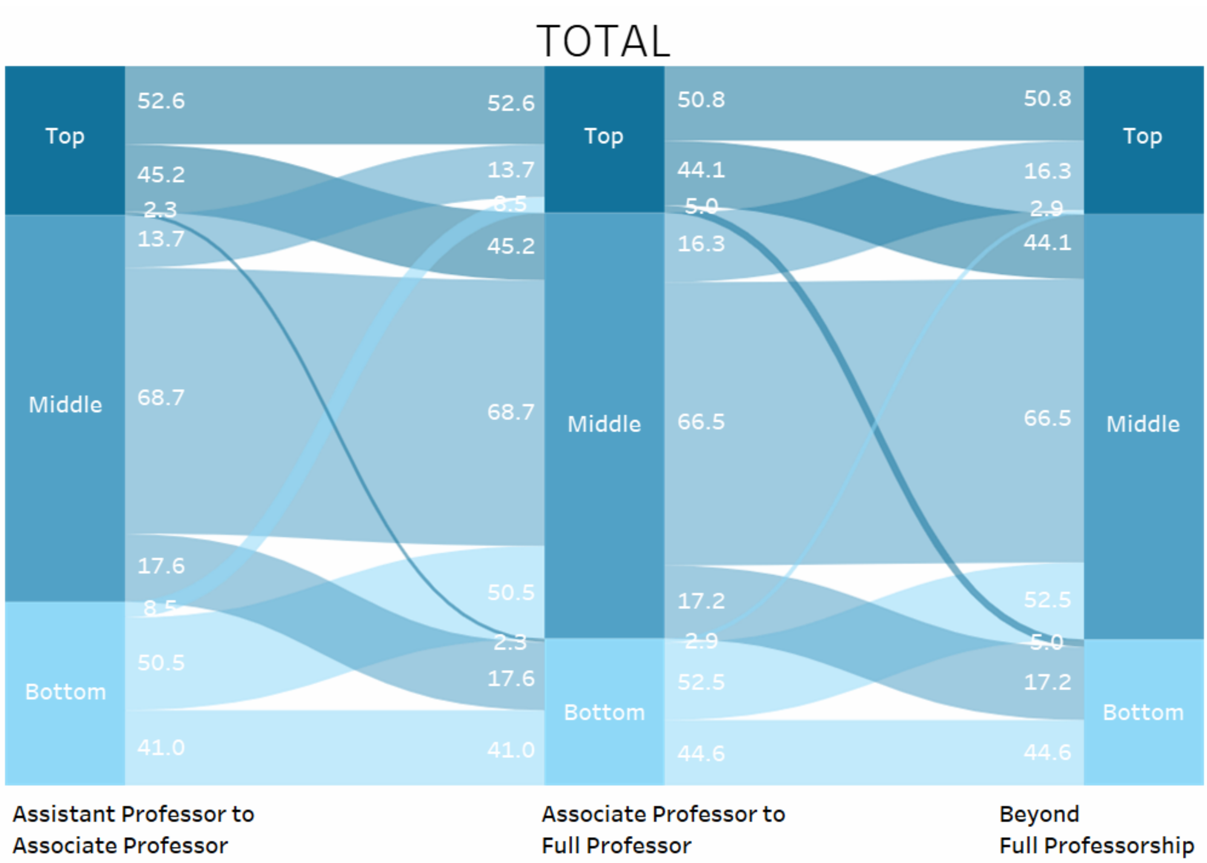

Figure 3. Sankey diagram of retrospectively constructed mobility between productivity classes in the three stages of an academic career. All STEMM disciplines (TOTAL) are combined, and only current full professors are shown. Top (upper 20%), middle (middle 60%), and bottom (lower 20%) productivity classes are shown in percentages of 100% (or rounded) in each of the three classes. The bottom class in the left column is larger than 20%,

and the middle class is smaller than 60%; the cutting-off points did not permit a different division into classes. N = 2,326

Table 2. Mobility between productivity classes in the three stages of academic careers.

Transition from source academic position	Transition from productivity class	Transition to target academic position	Transition to productivity class	Number of scientists in transition	Number of scientists in each productivity class	%
Assistant Professor	Bottom	Associate Professor	Bottom	245	598	41.0
Assistant Professor	Bottom	Associate Professor	Middle	302	598	50.5
Assistant Professor	Bottom	Associate Professor	Top	51	598	8.5
Assistant Professor	Middle	Associate Professor	Bottom	222	1260	17.6
Assistant Professor	Middle	Associate Professor	Middle	866	1260	68.7
Assistant Professor	Middle	Associate Professor	Top	172	1260	13.7
Assistant Professor	Top	Associate Professor	Bottom	11	485	2.3
Assistant Professor	Top	Associate Professor	Middle	219	485	45.2
Assistant Professor	Top	Associate Professor	Top	255	485	52.6
Associate Professor	Bottom	Full Professor	Bottom	213	478	44.6
Associate Professor	Bottom	Full Professor	Middle	251	478	52.5
Associate Professor	Bottom	Full Professor	Top	14	478	2.9
Associate Professor	Middle	Full Professor	Bottom	238	1387	17.2
Associate Professor	Middle	Full Professor	Middle	923	1387	66.5
Associate Professor	Middle	Full Professor	Top	226	1387	16.3
Associate Professor	Top	Full Professor	Bottom	24	478	5.0
Associate Professor	Top	Full Professor	Middle	211	478	44.1
Associate Professor	Top	Full Professor	Top	243	478	50.8
Full Professor	Bottom			475	475	100
Full Professor	Middle			1385	1385	100
Full Professor	Top			483	483	100

The results showed that mobility between productivity classes differed substantially between disciplines. We examined in detail two of the three disciplines with the largest number of full professors (i.e., MED and ENG) and a discipline in which the patterns of top-to-top and bottom-to-bottom mobility were the most stable from a comparative cross-disciplinary perspective (i.e., MATH). MATH showed the highest stability among the top productivity classes. MATH has been frequently studied because of its unique features, such as the lowest collaboration rate among STEMM disciplines and the lowest share of female scientists (e.g., Mihaljević-Brandt et al. 2016).

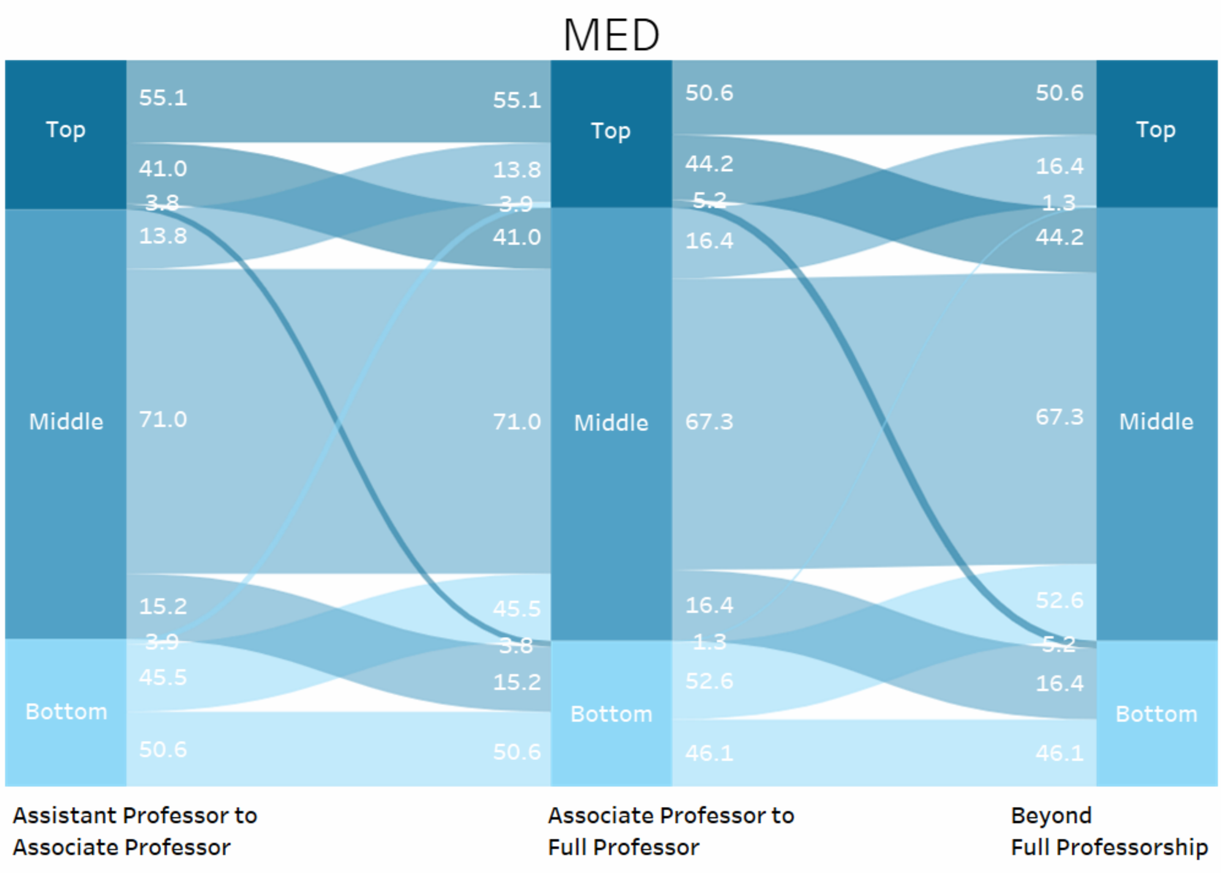

Figure 4. Sankey diagram of retrospectively constructed mobility between productivity classes in the three stages of academic careers. MED and current full professors only. N = 379

The MED case (Figure 4) presented a clear pattern of productivity class mobility: its top-to-top and bottom-to-bottom mobility was high, and its top-to-bottom and bottom-to-top mobility was limited over entire academic careers. More than half of highly productive assistant professors (Top) became highly productive associate professors (Top); and more than half of low-productive assistant professors (Bottom) became low-productive associate professors (Bottom) (55.1% and 50.6%, respectively; see thick flows in Figure 4). The mobility pattern was similar for the two stages of academic careers. The majority of highly productive associate professors (Top) became highly productive full professors (Top), and almost half of the low-productive associate professors (Bottom) became low-productive full professors (Bottom; 50.6% and 46.1%, respectively). Extreme productivity class transitions (top-to-bottom and bottom-to-top) were rare, which is shown by very thin flows linking top and bottom productivity classes in both periods of their academic careers. Extreme transitions were experienced by 3.8% (downward) and 3.9% (upward) of assistant professors and by 5.2% (downward) and 1.3% (upward) of associate professors.

The patterns of productivity class mobility in ENG (Figure 5) were similar for highly productive scientists but varied for low-productive scientists. The persistence of highly productive scientists was high, whereas the persistence of low-productive scientists was limited. For example, although about half of highly productive assistant and associate professors continued to be highly productive in the next stages of their careers, 35% and 43.5% of the low-productive scientists continued to be low productive (Figure 5).

In the MATH discipline (Figure 6), the persistence of highly productive assistants and associate professors was very high. Two-thirds of scientists in the top productivity classes remained in these classes: 69% of highly productive assistant professors continued to be highly productive associate professors, and 65.5% of highly productive associate professors continued to be highly productive full professors. The likelihood that low-productive associate professors would enter the class of highly productive full professors was slim (3.4%).

Other disciplines were characterized by different intensities of upward and downward mobility (Figure 7). In some disciplines, no highly productive assistant professor dropped to the bottom productivity class. Upward mobility from a bottom class to a top class was rare or nonexistent (e.g., CHEM chemistry). In other disciplines, no highly productive assistant professor and no highly productive associate professor dropped to the bottom productivity class, and upward mobility to a top class was nonexistent for associate professors (e.g., computer science [COMP] and earth and planetary sciences [EARTH]). In other disciplines, while no top-to-bottom mobility in productivity classes was observed, bottom-to-top mobility was notable (e.g., energy [ENER] and physics and astronomy [PHYS]). Moreover, the results showed variations by gender within disciplines in which higher proportions of women than men remained in the top productivity classes, as shown in Table 3.

Figure 7 shows all possible transitions in all disciplines not described above. The stability of top-performing classes was high and ranged from 34.4%–69.0% for assistant professors who became associate professors and 20%–65.5% for associate professors who became full professors. The share exceeded 50% in most disciplines in the first case and in half of the disciplines in the second case. Further details on mobility are shown in Table 3.

We also conducted a comparison of productivity classes in the first and last stages of the academic career: assistant professor and full professor. In the previous paragraphs, we described the transitions between the productivity classes of current full professors between the three retrospectively constructed career stages. Here, we address the stability of their productivity classes at the starting point and at the point of arrival (Mobility: Two academic career stages, Table 3, right panel).

Almost half of the current highly productive full professors had been highly productive assistant professors 20–40 years earlier (46.8%). However, the results showed an interesting gender disparity: the percentage of female scientists who continued to be highly productive throughout their careers was considerably higher than the percentage of male scientists who continued to be highly productive throughout their careers (48.1% vs. 42.5%) (Table 3, right panel). Cross-disciplinary and gender differences were substantial: for instance, all (100%) highly productive male full professors were highly productive assistant professors 20–40 years earlier in the two most male-dominated disciplines, MATH and PHYS (compared with females at 46.4% and 44.4%, respectively). The principle "once highly productive, forever highly productive" held for all cases of Polish male mathematicians, physicians, and astronomers (current full professors).

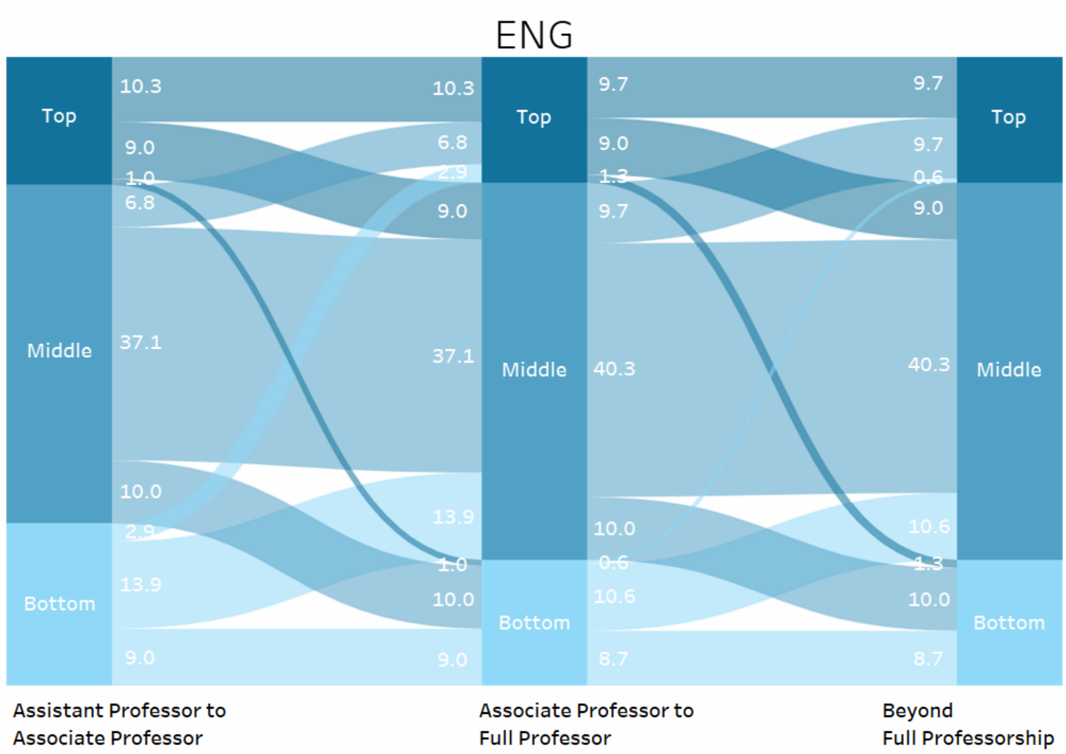

Figure 5. Sankey diagram of retrospectively constructed mobility between productivity classes in the three stages of academic careers. ENG and current full professors only. N = 310

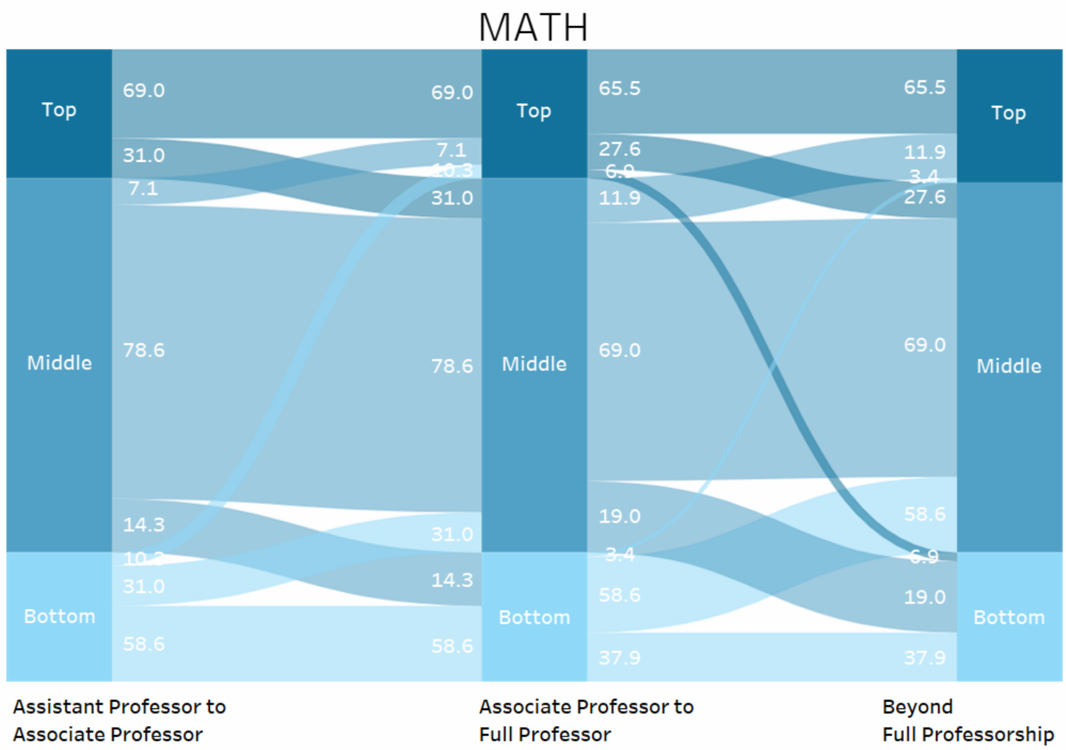

Figure 6. Sankey diagram of retrospectively constructed mobility between productivity classes in the three stages of academic careers. MATH and current full professors only. N = 142.

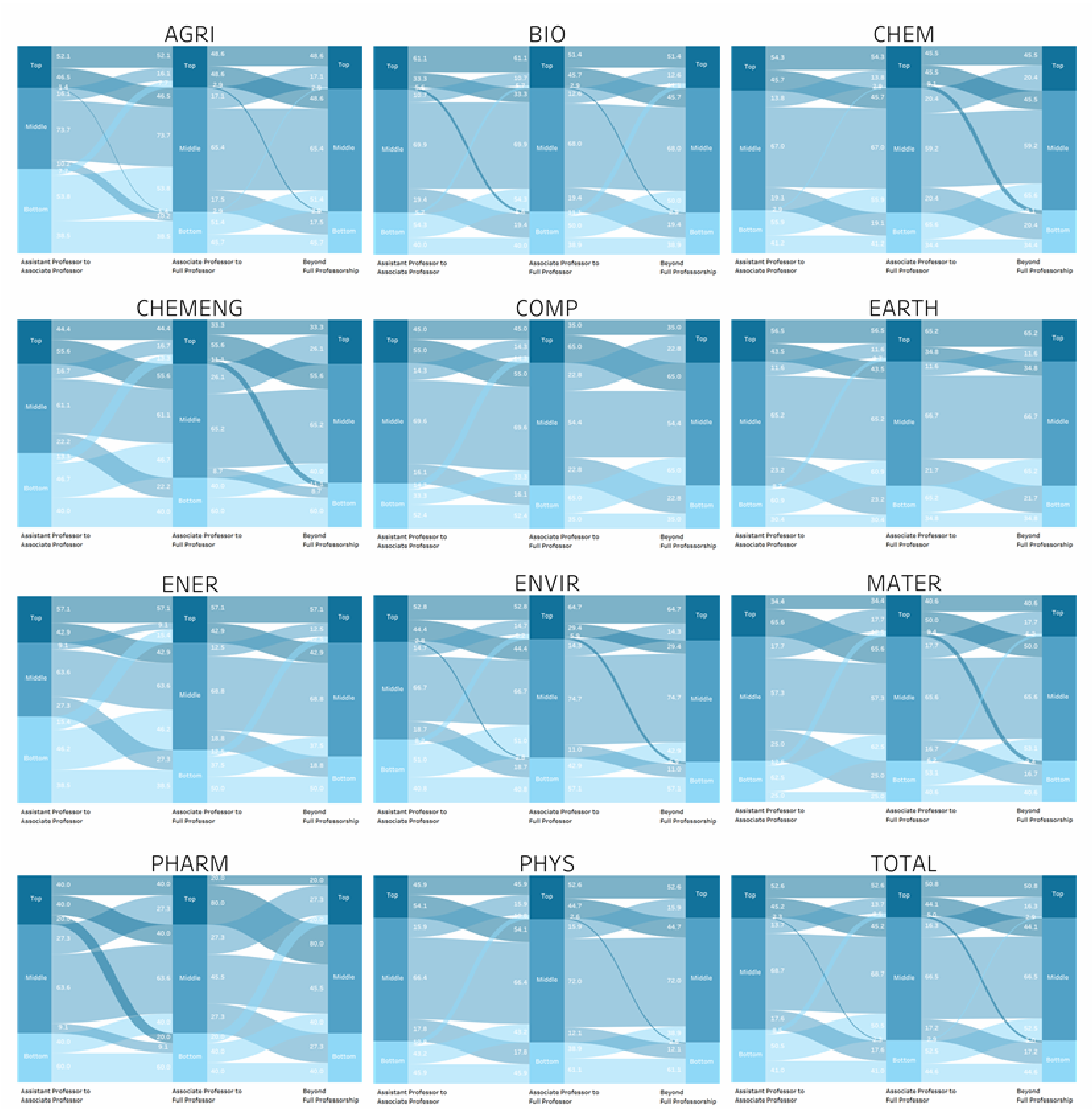

Figure 7. Overview: Sankey diagrams of retrospectively constructed mobility between productivity classes in the three stages of academic careers. Eleven STEMM disciplines and all disciplines combined (TOTAL), current full professors only.

We further classified the full professors in our sample, dividing them into 10/80/10 instead of 20/60/20 productivity classes (Table 4), as in the entire study (Table 3). Highly productive scientists belonged to the upper 10% in productivity distribution, and low-productive scientists belonged to the bottom 10%. The mobility patterns were slightly different: stability in the bottom and top classes was slightly lower, as shown in the bottom-to-bottom and top-to-top transitions in the left panels in Tables 3 and 4. However, if we focused on comparing the point of departure and the point of arrival only, as shown in the right panels in Tables 3 and 4, the gender disparity was even higher in the 10/80/10 division of the productivity classes. Compared with male scientists, female scientists showed consistently higher rates of top-to-top mobility and similar rates of bottom-to-bottom mobility .

The results showed a striking difference in the gender of scientists who remained in the top productivity class in the transition from associate professor to full professor: half of female scientists compared with 25% of men scientists (60.0% of females in MED, 66.7% in CHEMENG, and 76.9% in MATH). In the same productivity class from the point of departure to the point of arrival: 43.1% of female scientists vs. 28.3% of male scientists (about 60% in BIO, ENVIR, and ENER). These cross-gender differences in mobility patterns were strong in the 20/60/20 division into productivity classes but even stronger in the 10/80/10 division.

4.2. Logistic Regression Models

In this subsection, we examine odds ratio estimates of belonging to top and bottom productivity classes for current full professors and, retrospectively, for them at earlier stages of their academic careers to belong to these two classes (in the same disciplines, N = 2,326). The individual-level variables included gender, biological age (expressed in full years), academic age or the number of years since the first publication (expressed in full years), and biological age at which the doctorate, habilitation (or postdoctoral degree), and full professorship were awarded. The individual-level variables included also classifications drawn from our general classificatory scheme (Figure 2): current and past productivity classes, promotion age classes, and promotion speed classes. The only organizational-level variable was the research intensity of the employing institution (IDUB vs. the rest of the institutions).

The logistic regression models used to estimate the odds ratios of entering the class of most productive scientists (top 20%, Models 1–3, Table 5) clearly showed structural similarities in the predictors for the earlier stage of assistant professors and the stage of associate professors and their marked dissimilarities from the stage of full professors. For the satges of assistant and associate professorship, the important determinants of membership in the top 20% of productive scientists were related to age, both biological and academic. Biological age in both cases had a negative effect, and it had a significantly stronger effect on associate professors than on assistant professors. An increase in biological age by one year reduced the probability of entering the class of highly productive assistant professors by 20–25% (with 95% confidence interval for the coefficient between 0.753% and 0.796%). Among the associate professors, this decrease reduced the likelihood by up to one-third (31%, 0.665–0.724%). An increase in academic age (and thus publication experience, or the number of years since the first publication) by one year among the assistant professors resulted in an average increase of 12.2% in the probability of success (9.8%–14.8%), while among associate professors, the average increase was only 2.1% (0.2%–4.1%).

Table 3. Retrospectively constructed selected mobility between productivity classes (top to top, bottom to bottom) in the three stages of academic careers. Current full professors only, all STEMM disciplines combined. The 20/60/20 division: top class (upper 20%), middle class (middle 60%), and bottom class (lower 20%) in percentages, 100% (or rounded) in columns. N = 2,326

	Mobility: Three academic career stages (Assistant Professor → Associate Professor → Full Professor)												**Mobility: Two academic career stages (Assistant Professor → Full Professor)**					
Discipline	Mobility 1 (Bottom to Bottom): from Assistant Professor Bottom class to Associate Professor Bottom class			Mobility 2 (Bottom to Bottom): from Associate Professor Bottom class to Full Professor Bottom class			Mobility 3 (Top to Top): from Assistant Professor Top class to Associate Professor Top class			Mobility 4 (Top to Top): from Associate Professor Top class to Full Professor Top class			Mobility 5 (Bottom to Bottom): from Assistant Professor Bottom class to Full Professor Bottom class			Mobility 6 (Top to Top): from Assistant Professor Top class to Full Professor Top class		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
AGRI	33.3	41.1	38.5	56.2	42.6	45.7	52.2	52.1	52.1	26.9	61.4	48.6	35.4	31.6	32.9	39.1	50.0	46.5
BIO	46.2	36.4	40.0	40.0	38.1	38.9	46.2	69.6	61.1	37.5	63.2	51.4	30.8	31.8	31.4	23.1	52.2	41.7
CHEM	-	43.8	41.2	75.0	28.6	34.4	50.0	56.5	54.3	27.3	54.5	45.5	50.0	25.0	26.5	41.7	52.2	48.6
CHEMENG	-	42.9	40.0	100.0	55.6	60.0	33.3	50.0	44.4	33.3	33.3	33.3	100.0	21.4	26.7	33.3	16.7	22.2
COMP	50.0	53.3	52.4	16.7	42.9	35.0	-	45.0	45.0	33.3	35.3	35.0	-	13.3	9.5	-	30.0	30.0
EARTH	-	33.3	30.4	33.3	35.0	34.8	66.7	55.0	56.5	33.3	70.0	65.2	50.0	33.3	34.8	-	60.0	52.2
ENER	75.0	22.2	38.5	66.7	40.0	50.0	100.0	50.0	57.1	100	50.0	57.1	50.0	55.6	53.8	100.0	50.0	57.1
ENG	50.0	34.2	35.0	33.3	44.1	43.5	100.0	48.3	50.8	40	49.1	48.4	25.0	30.3	30.0	33.3	45.0	44.4
ENVIR	39.1	42.3	40.8	46.2	63.6	57.1	41.7	58.3	52.8	62.5	65.4	64.7	26.1	50.0	38.8	58.3	50.0	52.8
MATER	-	32.0	25.0	-	40.6	40.6	62.5	25.0	34.4	37.5	43.8	40.6	-	32.0	25.0	62.5	33.3	40.6
MATH	75.0	56.0	58.6	-	42.3	37.9	100.0	67.9	69.0	50	66.7	65.5	-	40.0	34.5	100	46.4	48.3
MED	54.5	47.7	50.6	55.2	40.4	46.1	56.7	54.2	55.1	37.5	60.0	50.6	51.5	40.9	45.5	46.7	62.5	56.4
PHARM	75.0	-	60.0	33.3	50.0	40.0	50.0	33.3	40.0	25	-	20.0	50.0	-	40.0	-	33.3	20.0
PHYS	-	47.2	45.9	-	62.9	61.1	100.0	44.4	45.9	33.3	54.3	52.6	-	47.2	45.9	100.0	44.4	45.9
Total	**41.2**	**40.9**	**41.0**	**47.0**	**43.9**	**44.6**	**54.9**	**51.9**	**52.6**	**35.8**	**56.7**	**50.8**	**34.0**	**34.2**	**34.1**	**42.5**	**48.1**	**46.8**

Note. - = no observation (no full professor in this class)

Table 4. Retrospectively constructed selected mobility between productivity classes (top to top, bottom to bottom) in the three stages of academic careers. Current full professors only, and all STEMM disciplines combined. The 10/80/10 division: top class (the upper 10%), middle class (the middle 80%), and bottom class (the lower 10%) in percentages, 100% (or rounded) in columns. N = 2,326

	Mobility: Three academic career stages (Assistant Professor → Associate Professor → Full Professor)												**Mobility: Two academic career stages (Assistant Professor → Full Professor)**					
Discipline	Mobility 1 (Bottom to Bottom): from Assistant Professor Bottom class to Associate Professor Bottom class			Mobility 2 (Bottom to Bottom): from Associate Professor Bottom class to Full Professor Bottom class			Mobility 3 (Top to Top): from Assistant Professor Top class to Associate Professor Top class			Mobility 4 (Top to Top): from Associate Professor Top class to Full Professor Top class			Mobility 5 (Bottom to Bottom): from Assistant Professor Bottom class to Full Professor Bottom class			Mobility 6 (Top to Top): from Assistant Professor Top class to Full Professor Top class		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
AGRI	31.2	35.8	34.3	57.1	41.4	44.4	33.3	21.3	24.2	33.3	57.7	51.4	25.0	17.9	20.3	28.6	44.8	41.7
BIO	50.0	23.5	33.3	-	41.7	27.8	33.3	33.3	33.3	22.2	55.6	38.9	20.0	17.6	18.5	-	58.3	38.9
CHEM	-	31.2	31.2	20.0	35.7	31.6	100.0	20.0	25.0	20.0	45.5	37.5	-	18.8	18.8	40.0	35.7	36.8
CHEMENG	-	28.6	26.7	50.0	33.3	40.0	-	80.0	80.0	-	66.7	40.0	-	21.4	20.0	50.0	33.3	40.0
COMP	33.3	40.0	38.1	-	40.0	40.0	-	37.5	27.3	-	22.2	20.0	-	13.3	9.5	-	10.0	10.0
EARTH	-	25.0	22.7	-	36.4	33.3	-	30.0	23.1	-	50.0	50.0	50.0	25.0	27.3	-	54.5	50.0
ENER	50.0	22.2	30.8	-	100.0	75.0	-	33.3	20.0	-	50.0	50.0	25.0	33.3	30.8	-	66.7	50.0
ENG	50.0	19.7	21.2	-	43.3	41.9	50.0	36.7	37.5	33.3	35.7	35.5	25.0	18.4	18.8	-	43.3	41.9
ENVIR	30.4	34.6	32.7	75.0	50.0	55.6	12.5	33.3	25.0	60.0	50.0	52.9	4.3	30.8	18.4	50.0	57.1	55.6
MATER	-	13.3	9.1	50.0	33.3	37.5	-	12.5	12.5	44.4	42.9	43.8	-	13.3	9.1	50.0	33.3	37.5
MATH	50.0	45.0	45.5	100.0	42.9	46.7	-	30.8	26.7		76.9	66.7	-	20.0	18.2	-	50.0	46.7
MED	61.1	58.3	59.5	46.2	36.0	39.5	61.1	33.3	46.2	11.1	60.0	36.8	38.9	16.7	26.2	30.8	48.0	42.1
PHARM	66.7	-	66.7	-	-	-	50.0	-	33.3	33.3	-	33.3	33.3	-	33.3	-	-	-
PHYS	-	33.3	33.3	-	50.0	50.0	-	38.9	38.9	-	57.9	55.0	-	27.8	27.8	-	33.3	33.3
Total	**36.7**	**31.5**	**32.9**	**39.1**	**41.6**	**41.2**	**35.4**	**29.8**	**31.1**	**25.4**	**51.4**	**44.2**	**20.3**	**20**	**20.1**	**28.3**	**43.1**	**40.3**

Note. - = no observation (no full professor in this class)

Table 5. Logistic regression statistics: odds ratio estimates of belonging the the classes of highly productive full professors, associate professors, and assistant professors (the upper 20%, separately for each discipline) (N=2,326).

Model	Model 1: Full Professors $R^2 = 0.254$				Model 2: Associate Professors $R^2 = 0.582$				Model 3: Assistant Professors $R^2 = 0.355$			
	Exp(B)	95% C.I. for EXP(B)		Sig.	Exp(B)	95% C.I. for EXP(B)		Sig.	Exp(B)	95% C.I. for EXP(B)		Sig.
		Lower	Upper			Lower	Upper			Lower	Upper	
Male					1.426	1.03	1.974	0.033				
Research intensive												
Biological age					0.694	0.665	0.724	<0.001	0.774	0.753	0.796	<0.001
Academic age					1.021	1.002	1.041	0.028	1.122	1.098	1.148	<0.001
Assistant_age					0.942	0.892	0.995	0.032	1.207	1.143	1.273	<0.001
Associate_age					1.475	1.404	1.549	<0.001	-	-	-	-
Full_age					-	-	-	-	-	-	-	-
Top_Assistant	2.793	2.14	3.646	<0.001	6.667	4.72	9.416	<0.001	-	-	-	-
Top_Associate	4.61	3.558	5.974	<0.001	-	-	-	-	-	-	-	-
Young_Assistant									1.739	1.232	2.455	0.002
Young_Associate									-	-	-	-
Young_Full	1.942	1.503	2.509	<0.001	-	-	-	-	-	-	-	-
Fast_Associate									-	-	-	-
Fast_Full					-	-	-	-	-	-	-	-
Constant	0.1			<0.001	46.17			<0.001	128.62			<0.001

„-" – observations structurally not applicable.

Another age-related variable that significantly affected the probability of success was the promotion age of assistant professors. The direction of change varied among different groups of scientists. Among the associate professors, an increase in doctoral promotion age had a negative effect and decreased the probability of success by an average of 5.8% (0.5%–11.8%), while among assistant professors, the direction of change was positive and high. An increase in doctoral promotion age by one year increased the probability of success by an average of 20.7% (14.3%–27.3%).

Among associate professors, the age of promotion to a doctoral degree significantly and strongly influenced the probability of success. An increase in the age of promotion by one year increased the likelihood of entering the group of the 20% most productive associate professors by about half (on average, by 47.5%; 40.4%–54.9%). This variable could not be included in the model for assistant professors because they had not yet been promoted to this stage. However, the variable (indirectly) related to age, which was important for the likelihood of being among the 20% most productive assistant professors, was among the 20% of the youngest scientists promoted to doctoral degrees. Membership in this group increased the probability of success by an average of 74% (23.2%–145.5%).

Structurally similar to full professors, among the associate professors, only inclusion in the top 20% of the most productive assistant professors strongly increased the likelihood of success. This increased the odds, on average, by a staggering 566.7% (372%–841%). Gender had a significant impact only among associate professors. Being male increased the probability by an average of 42.6%, but the spread of the confidence interval (3%–97%) suggests a cautious approach to the significance of this predictor.

Importantly, in the context of the descriptive statistics presented above, being among the most productive 20% of the full professors was dependent on being in analogous groups of highly productive scientists at earlier stages of academic careers. Thus, belonging to the class of highly productive assistant professors increased the probability of becoming a highly productive full professor, on average, by 179% (114%–265%), while belonging to the class of highly productive associate professors increased the probability of success, on average, by 361% (256–497%). The only significant predictor indirectly related to age was belonging to the class of 20% of the youngest full professors in terms of promotion age. Membership in this class increased the probability of success by an average of 94.2% (50.3%–150.9%).

Among the models used to estimate the odds ratios of belonging to the 20% of the least productive scientists (Table 6) were those in which success was to enter the group of the 20% least productive scientists in three positions: assistant professor, associate professor, and full professor. In principle, the results indicated significant characteristics similar to the previous models but with a reversed direction of influence, especially those directly or indirectly related to age. Biological age was a positive predictor of the probability of belonging to 20% of the least productive scientists. It was the most visible among associate professors and assistant professors, where each additional year of biological life increased the likelihood of success, on average, by about 23%–26.3%. It should be noted that the confidence intervals in the parameter estimates in both models overlapped, so it could be concluded that the impact of age on both groups was the same. In the case of the full professors, this influence was much lower, increasing the probability, on average, by only 5.6%.

Increasing the academic age decreased the probability of remaining among the least productive in all seniority groups. The smallest impact was observed among the full professors, where increasing the academic age by one year decreased the probability of success by 4.4%, on average. For associate professors, a similar decrease was noted, on average, by 6.7%. The decrease was the highest among the assistant professors, where each additional year of academic age reduced the probability by about 20%. It should also be noted that the confidence intervals of the parameters did not overlap, so these results could be considered statistically different from each other.

Among the assistant professors, a significant effect was also observed for the age of obtaining a doctoral degree, where each additional year meant an average decrease in the probability of success by an average of 14%. Among the associate professors, a similar result was observed for the age of obtaining a postdoctoral degree, where an increase of one year resulted in a decrease of about 16%.

Table 6. Logistic regression statistics: odds ratio estimates of belonging the the classes of low productive full professors, associate professors, and assistant professors (the bottom 20%, separately for each discipline) (N=2,326).

Model	**Model 4: Full Professors $R^2 = 0.175$**				**Model 5: Associate Professors $R^2 = 0.320$**				**Model 6: Assistant Professors $R^2 = 0.573$**			
	Exp(B)	**95% C.I. for EXP(B)**		**Sig.**	**Exp(B)**	**95% C.I. for EXP(B)**		**Sig.**	**Exp(B)**	**95% C.I. for EXP(B)**		**Sig.**
		Lower	**Upper**			**Lower**	**Upper**			**Lower**	**Upper**	
Male	1.399	1.063	1.84	0.017								
Research intensive												
Biological age	1.056	1.032	1.08	<0.001	1.225	1.19	1.26	<0.001	1.263	1.228	1.3	<0.001
Academic age	0.956	0.946	0.967	<0.001	0.933	0.921	0.944	<0.001	0.803	0.787	0.819	<0.001
Assistant_age									0.859	0.82	0.9	<0.001
Associate_age					0.838	0.808	0.869	<0.001	-	-	-	-
Full_age					-	-	-	-	-	-	-	-
Top_Assistant	0.304	0.186	0.495	<0.001	0.147	0.078	0.277	<0.001	-	-	-	-
Top_Associate	0.313	0.195	0.505	<0.001	-	-	-	-	-	-	-	-
Young_Assistant												
Young_Associate					0.591	0.402	0.868	0.007	-	-	-	-
Young_Full					-	-	-	-	-	-	-	-
Fast_Associate									-	-	-	-
Fast_Full	0.649	0.494	0.854	0.002	-	-	-	-	-	-	-	-
Constant	0.032			<0.001					0.003			<0.001

Note. – indicates that observations were not applicable structurally.

Variables not directly related to age were found to be significant only in the models of the full professors and associate professors. A large negative effect on the probability of success was found for belonging to the class of highly productive scientists at previous stages of their academic careers. Among the full professors, being among the most productive assistant professors reduced the likelihood of being among the least productive scientists by more than three times (on average, by 70%). Moreover, being in the same group of associate professors reduced the likelihood of success to the same extent. However, the greatest impact among this group of variables was observed on associate professors who previously belonged to highly productive assistant professors. Their probability of success decreased by as much as seven times on average.

In addition, a decrease in the likelihood of success was observed among associate professors who were awarded a postdoctoral degree at an early age, that is, those who belonged to the class of young associate professors (an average of 41%). However, among the full professors, the speed at which they were promoted from assistant professorships to full professorships was significant. Belonging to the class of fast-track full professors decreased the likelihood of success by an average of 35%. Gender was significant only for full professors. Males in this group were, on average, 40% likelier than women to end up in the bottom 20% in terms of productivity.

5. Discussion

The results of this study supported all six hypotheses (Section 2.2). They also supported the “sacred spark” theory of productivity (Cole & Cole 1973; Stephan & Levin 1992). Some scientists are superb at doing science from the moment they enter the academic workforce to their late career stages. About half of the highly productive full professors had always been highly productive, regardless of the trajectories of their personal lives or their external circumstances (e.g., the post-communist transition period in the Polish economy, which severely affected the academic sector). Highly productive full professors in their 60s were also highly productive when they were assistant and associate professors in their 30s, 40s, and 50s.

The results of our logistic regression models also supported previous findings that professors appointed early tended to be more productive than professors appointed later in their careers (Abramo et al. 2016). Membership in the class of young full professors increased the odds of belonging to the class of highly productive scientists by an average of 94.2%. The results did not directly support the claim that the productivity of top- and medium-performing scientists increases or remains stable with age (Costas et al. 2010: 1578), as our study focused on changing productivity classes rather than changing productivity over time. However, there are only two powerful predictors of the high productivity of full professors: membership in the class of highly productive assistant professors and the class of highly productive associate professors, which increases the odds by averages of almost 180% and 360%, respectively. The most powerful predictor of becoming a highly productive associate professor (in the sample of current full professors) was being a highly productive assistant professor, as shown by the staggering increase in odds of 570%. For highly productive assistant professors, the most powerful predictor was obtaining a PhD early in their careers.

Interestingly, in the Polish context, neither gender nor age (biological or academic) emerged as a predictor of membership in the class of highly productive full professors. However, gender was statistically significant for becoming a full professor in Germany and Italy (Mayer & Rathmann 2018; Lutter and Schröder 2016; Lutter et al. 2022; Marini & Meschitti 2018), and age was an important predictor of research productivity in the USA (Savage & Olejniczak 2021), Finland (Puuska 2010), and Italy (Abramo et al. 2011). In terms of women in science, Poland again differs from most countries studied (Kwiek and Roszka 2021b; Kwiek and Roszka 2022a).

6. Conclusions and Further Research

The patterns of mobility between productivity classes over the course of an entire academic career, from an assistant professor to a full professor and beyond, in national academic science systems may have far-reaching implications for science policies, especially regarding hiring and promotion. Hiring and tenure to both low-productivity and high-productivity scientists may have long-standing consequences for institutions and the national system in terms of the average productivity level. Research careers are usually long. After entering the system and achieving job stability, scientists in Poland (where attrition is very low) and elsewhere usually remain in the system for years, if not decades. The scientists included in this study, all of whom are currently full professors in the 14 STEMM disciplines present in the Scopus bibliometric database, have remained in the system for 30–40 years. Data on aggregate productivity at the departmental level influence university-level and national-level data. Individual hiring and promotion decisions made at the departmental level thus have long-lasting implications for productivity at the national level, spanning three to four decades.

The results of our study revealed an unexpectedly high level of immobility in the system. Membership in the productivity class during assistant professorships and associate professorships, to a large extent, determined membership in full professorship and beyond. Does the "once highly productive, forever highly productive" principle hold across STEMM disciplines? The results of this study indicate the affirmative. About half of the current full professors belonged to the same productivity class throughout their academic careers. They had remained for decades in the bottom or top productivity classes in relation to their peers and within their specific disciplines. About half of the current full professors had changed their productivity class membership by only one class in a tripartite division into top, middle, or bottom classes, with some discipline and gender differentiation.

More than half of the highly productive assistant professors became, on average, highly productive associate professors in relation to their peers in a similar period, the same academic position, and the same discipline. More than half of the highly productive associate professors became, on average, highly productive full professors (52.6% and 50.8%, respectively). Moreover, a study of direct start-to-end mobility shows that, on average, almost half of the highly productive assistant professors became highly productive full professors. They did not change their productivity class membership to a lower class throughout their academic careers (46.8%), with a large differentiation among disciplines. Similar processes of transition in productivity class membership included low-productive scientists.

The most radical changes in productivity class membership, that is, transitions from the very top to the very bottom of productivity, occurred at a marginal level, reaching 2.3% in the case of downward top-to-bottom transitions from the stage of assistant professor to associate professor and 5.0% in the case of transition from associate professor to full professor. Upward bottom-to-top transfers occurred on a similar small scale (8.5% and 2.9%, respectively). In our sample, the 2,326 full professors in the last four decades included 35 scientists who had radically changed their productivity classes downward and 65 who had moved upward. Above-average mobility was observed in the disciplines of BIO, MATH, and PHYS, while the least mobility was observed in PHARM. However, our study focused on full professors who had achieved successful careers.

The results of our study indicate the power of structured big data (in this case, the Scopus raw dataset). We examined all current Polish full professors in STEMM, but the data we used were collected from two large datasets. One was the Observatory of Polish Science, which included full biographical and administrative data on almost 100,000 Polish scientists and their 380,000 publications in Scopus from 2009–2018. The second dataset comprised Scopus metadata on one million publications in the past 50 years. What would not be possible using raw Scopus (or WoS) metadata? (1) To define *disciplines*: we examined all lifetime publications to determine the modal discipline of every full professor. (2) To measure *prestige-normalized productivity*: all publications in the lifetime publication histories of all full professors were linked to the journal prestige expressed in the Scopus journal's percentile rank, and four-year productivity was calculated accordingly. (3) To link *every article* to the three early stages of the academic careers of all full professors: only Scopus (or WoS) had all articles by all full professors during their lifetimes. (4) To establish *academic age* for all full professors: the date of the first publication, regardless of type, was necessary in regression analyses.

The combination of unequivocal biographical and demographic data with raw Scopus publication data from the past 50 years made it possible to create not only current productivity classes to which all professors were allocated but also retrospective productivity classes. Importantly, every full professor was compared in terms of research productivity as an assistant and associate professor with their exact peers, who were full professors when they were at the same earlier stages of academic careers in the same discipline. We retrospectively examined their academic careers as extensively as necessary to compare "apples with apples" and "oranges with oranges" rather than "apples with oranges" at all three stages of their academic careers.

Additionally, in applying logistic regression models, we used other retrospectively constructed academic career classes. Every current full professor was retrospectively located in promotion age classes and promotion speed classes. In the promotion age class, as associate professors and full professors, they were classified as young, middle-aged, or old. In the promotion speed class, as associate professors and as full professors, they were classified as fast track, typical track, or slow track.

In future research, we will address the question of whether productivity patterns found for Poland, could be generalized to a global context. Therefore, we will examine 300,000 older scientists defined as publishing during a period of 25–35 years to determine how they have changed their research productivity classes across 16 STEMM disciplines in 38 OECD economies. Our clearly defined sample (one discipline, one country affiliation, gender, a minimum of three articles published in the past three decades, including at least one article in the past decade) will comprise 4.9 million scientists. Specifically, we intend to rely on academic age rather than biological age, and on the four career stages retrospectively constructed using academic age (i.e., beginning, early, middle, and late career stages). Our Polish Observatory dataset is superior in its precision and accuracy, relying on data from the Polish national registry of scientists, which are not available on a global scale.

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References

Abramo, G., D'Angelo, C. A., & Murgia, G. (2016). The combined effects of age and seniority on research performance of full professors. *Science and Public Policy, 43*(3), 301–319.

Abramo, G., D'Angelo, C. A., & Caprasecca, A. (2009). Gender differences in research productivity: A bibliometric analysis of the Italian academic system. *Scientometrics, 79*(3), 517–539.

Abramo, G., D'Angelo, C. A., & Di Costa, F. (2011). Research productivity: Are higher academic ranks more productive than lower ones? *Scientometrics, 88*(3), 915–928.

Abramo, G., D'Angelo, C. A., & Di Costa, F. (2013). Variability of research performance across disciplines within universities in non-competitive higher education systems. *Scientometrics, 98*(2), 777–795.

Abramo, G., D'Angelo, C. A., & Rosati, F. (2016). The north–south divide in the Italian higher education system. *Scientometrics, 109*(3), 2093–2117.

Aksnes, D. W., Rørstad, K., Piro, F. N., & Sivertsen, G. (2011). Are female researchers less cited? A large-scale study of Norwegian researchers. *Journal of the American Society for Information Science and Technology*, *62*(4), 628–636.

Aref, S., Zagheni, E., & West, J. (2019). The demography of the peripatetic researcher: Evidence on highly mobile scholars from the web of science. In I. Weber et al. (Eds.), Social *informatics, socinfo 2019: Lecture notes in computer science* (vol. 11864). Springer.

Boekhout, H., van der Weijden, I., & Waltman, L. (2021). Gender differences in scientific careers: A large-scale bibliometric analysis. https://arxiv.org/abs/2106.12624

Chan, H. F., & Torgler, B. (2020). Gender differences in performance of top cited scientists by field and country. *Scientometrics, 125***,** 2421–2447.

Cole, J. R., & Cole, S. (1973). *Social stratification in science*. Chicago: The University of Chicago Press.

Costas, R., & Bordons, M. (2007). A classificatory scheme for the analysis of bibliometric profiles at the micro level. *Proceedings of ISSI 2007: 11th International Conference of the ISSI, Vols I and II*, pp. 226–230.

Costas, R., van Leeuwen, T. N., & Bordons, M. (2010). Self-citations at the meso and individual levels: Effects of different calculation methods. *Scientometrics, 82,* 517–537.

D'Angelo, C. A., & van Eck, N. J. (2020). Collecting large-scale publication data at the level of individual researchers: A practical proposal for author name disambiguation. *Scientometrics, 123*, 883–907.

Fox, M. F. (2020). Gender, science, and academic rank: Key issues and approaches. *Quantitative Science Studies, 1*(3), 1001–1006.

Fox, M. F., & Nikivincze, I. (2021). Being highly prolific in academic science: Characteristics of individuals and their departments. *Higher Education, 81,* 1237–1255.

Gingras Y., Larivière V., Macaluso B., & Robitaille, J. P. (2008). The effects of aging on researchers' publication and citation patterns. *PLoS One*, *3*(12), e4048.

GUS. (2021). *Higher education and its finances in 2020.* Warsaw: Main Statistical Office.

Heckman, J. J., & Moktan, S. (2018). Publishing and promotion in economics. The tyranny of the top five. *NBER Working Paper 25093*.

Horlings, E., & Gurney, T. (2012). Search strategies along the academic lifecycle. *Scientometrics,* 94(3), 1137–1160.

Kawaguchi, D., Kondo, A., & Saito, K. (2016). Researchers' career transitions over the life cycle. *Scientometrics, 109*(3), 1435–1454.

Kolesnikov, S., Fukumoto, E., & Bozeman, B. (2018). Researchers' risk-smoothing publication strategies: Is productivity the enemy of impact? *Scientometrics, 116*(3), 1995–2017.

Kwiek, M. (2015). Academic generations and academic work: Patterns of attitudes, behaviors and research productivity of Polish academics after 1989. *Studies in Higher Education, 40*(8), 1354–1376.

Kwiek, M. (2018). High research productivity in vertically undifferentiated higher education systems: Who are the top performers? *Scientometrics*, *115*(1), 415–462.

Kwiek, M. (2019). *Changing European academics. A comparative study of social stratification, work patterns*

and research productivity. London and New York: Routledge.
Kwiek, M. (2020). Internationalists and locals: International research collaboration in a resource-poor system. *Scientometrics*, *124*, 57–105.
Kwiek, M., & Roszka, W. (2021a). Gender disparities in international research collaboration: A large-scale bibliometric study of 25,000 university professors. *Journal of Economic Surveys*. Vol. 35(5), 1344-1388. doi: 10.1111/joes.12395
Kwiek, M., Roszka, W. (2021b). Gender-based homophily in research: A large-scale study of man-woman collaboration. *Journal of Informetrics*, *15*(3), article 101171. 1–38.
Kwiek, M., Roszka, W. (2022a). Are female scientists less inclined to publish alone? The gender solo research gap. *Scientometrics, 127,* 1697–1735.
Kwiek, M., Roszka, W. (2022b). Academic vs. biological age in research on academic careers: a large-scale study with implications for scientifically developing systems. *Scientometrics*, online first: April 9, 2022:
Kyvik, S. (1990). Age and scientific productivity: Differences between fields of learning. *Higher Education, 19*(1), 37–55.
Kyvik, S., & Olsen, T. B. (2008). Does the aging of tenured academic staff affect the research performance of universities? *Scientometrics, 76*(3), 439–455.
Larivière, V., Vignola-Gagné, E., Villeneuve, C. et al. (2011). Sex differences in research funding, productivity and impact: An analysis of Québec university professors. *Scientometrics, 87,* 483–498.
Levin, S., & Stephan, P. E. (1991). Research productivity over the life cycle: Evidence for academic scientists. *The American Economic Review,* March, 114–132.
Lörz, M., & Mühleck, K. (2019). Gender differences in higher education from a life course perspective: Transitions and social inequality between enrolment and first post-doc position. *Higher Education, 77,* 381–402.
Lutter, M., & Schröder, M. (2016). Who becomes a tenured professor, and why? Panel data evidence from German sociology, 1980–2013. *Research Policy, 45*(5), 999–1013.
Madison, G., & Fahlman, P. (2020). Sex differences in the number of scientific publications and citations when attaining the rank of professor in Sweden. *Studies in Higher Education,* 46(12), 2506-2527.
Marini, G., & Meschitti, V. (2018). The trench warfare of gender discrimination: Evidence from academic promotions to full professor in Italy. *Scientometrics, 115*(2), 989–1006.
Mayer, S. J., & Rathmann, J. M. K. (2018). How does research productivity relate to gender? Analyzing gender differences for multiple publication dimensions. *Scientometrics, 117,* 1663–1693.
Merton, R. K. (1968). The Matthew effect in science. *Science*, *159*(3810), 56–63.
Mihaljević-Brandt, H., Santamaría, L., & Tullney, M. (2016). The effect of gender in the publication patterns in mathematics. *PLOS ONE*, *11*(10), e0165367.
Milojević S. (2012). How are academic age, productivity, and collaboration related to citing behavior of researchers? *PLoS One, 7*(11), e49176.
Nane, G. F., Larivière, V., & Costas, R. (2017). Predicting the age of researchers using bibliometric data. *Journal of Informetrics, 11*(3), 713–729.
Piro, F. N., Rørstad, K., & Aksnes, D. W. (2016). How do prolific professors influence the citation impact of their university departments? *Scientometrics, 107*(3), 941–961.
Puuska, H.-M. (2009). Effects of scholar's gender and professional position on publishing productivity in different publication types: Analysis of a Finnish university. *Scientometrics, 82*(2), 419–437.
Radicchi, F., & Castellano, C. (2013). Analysis of bibliometric indicators for individual scholars in a large data set. *Scientometrics, 97,* 627–637.
Robinson-Garcia, N., Costas, R., Sugimoto, C. R., Larivière, V., & Nane, G. F. (2020). Task specialization across research careers. *eLife, 9*, e60586. doi: 10.7554/eLife.60586
Rørstad, K., Aksnes, D. W., & Piro F. N. (2021). Generational differences in international research collaboration: A bibliometric study of Norwegian university staff. *PLoS One*, *16*(11), e0260239.
Savage, W. E., & Olejniczak, A. J. (2021). Do senior faculty members produce fewer research publications than their younger colleagues? Evidence from Ph.D. granting institutions in the United States. *Scientometrics 126*, 4659–4686
Shang, Y., Sivertsen, G., & Zhang, L. (2021). Gender differences in research focused on the sustainable development goal of gender equity. https://osf.io/preprints/socarxiv/3fapz/.

Simoes, N., & Crespo, N. (2020). A flexible approach for measuring author-level publishing performance. *Scientometrics, 122,* 331–355.

Stephan, P. (2012). *How economics shapes science.* Cambridge, MA: Harvard University Press.

Stephan, P. E., & Levin, S. G. (1992). *Striking the mother lode in science: The importance of age, place, and time*. New York: Oxford University Press.

Sugimoto, C., & Larivière, V. (2018). *Measuring research: What everyone needs to know.* Oxford: Oxford University Press.

Sugimoto, C. R., Sugimoto, T. J., Tsou, A., Milojevic´, S., & Larivière, V. (2016). Age stratification and cohort effects in scholarly communication: A study of social sciences. *Scientometrics, 109*(2), 997–1016.

Van Dalen, H. P. (2021). How the publish-or-perish principle divides a science: The case of economists. *Scientometrics, 126,* 1675–1694.

Wang, D., & Barabási, A. (2021). *The science of science.* Cambridge: Cambridge University Press.

Weinberger, M., & Zhitomirsky-Geffet, M. (2021). Diversity of success: Measuring the scholarly performance diversity of tenured professors in Israeli academia. *Scientometrics, 126,* 2931–2970.

Yuret, T. (2018). Path to success: An analysis of US educated elite academics in the United States. *Scientometrics, 117,* 105–121.