НАУКОМЕТРІЯ

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Classification of Individual Age-Phase Dynamics Profiles of Researchers' Scientific Activity

In the present study, investigations of the relationship between scientists' age and their publication activity are discussed in the context of the Age-Phase Dynamics (APhD) model of scientific activity and performance. Evaluation of APhD-profiles of several renowned scientists from different historical periods, each conducting research in their individual discipline are investigated and presented here as derived from the scientists' bibliographies. Examples of general APhD graphs as well as their variations reflecting various subjective circumstances and external conditions during the scientist's career are shown. The possibility of further integration of scientist's personal APhD-profile within the publication profiles of small research groups and laboratories or large groups of scientists (meso level), as well as a combination of these group profiles with citation indices are discussed.

Introduction

One of the central problems in evaluation of research activity and performance at the individual level is the relationship of publication productivity and quality of scientific publications to the age of scientists. Despite the progress achieved in this field, the topic remains actively researched and debated [1–13]. In the present study, investigations of the relationship between scientist's age and their publication activity are discussed in the context of Age-Phase Dynamics (APhD) model of scientific activity [14–17]*.

D. Pelz and F. Andrews [14] were first to describe a bimodal dependence between productivity and age of the scientists. They divided the life cycle of scientific activity into several periods characterized by alternating peaks and valleys of scientific productivity of researchers starting at the age of 30–35 years. They also highlighted a number of factors responsible for the saddle-shape curves of age dynamics of the scientist's research performance, in particular, changes in the nature of scientific activity, "creative" in younger years versus "productive" and "tutorial" in adulthood as well as changes in personal motivation. R. Merton and H. Zuckerman [19] referred on the age stratification in science in terms of the sociology of science. M. Fox [20] interpreted the discovered by D. Pelz and F. Andrews wave-like pattern to be a consequence of authors' including in the analysis not only the major works of the scientist but a wide spectrum of other publications, including articles, patents and applications,

* Selected thesis of this paper were recently presented by the authors at the 14th International Society of Scientometrics and Informetrics Conference in Vienna, Austria [18].

books, reports, presentations as well as manuscripts. Nontheless, D. Pelz and F. Andrews obtained the same characteristic relationships not only based on the number of printed publications, but also when "unpublished reports" and "peer reviews" categories were included. D. Pelz also observed a bimodal pattern in the case of age-dependence in the number of citations for psychologists and other scientists [14b, p. 291]. Later, B. Malitsky [15, p. 88–101] defined the theoretical basis of the model proposed by D. Pelz and F. Andrews, reformulated and further developed it to become the "principle of phase dynamic development of researcher's scientific activity"*. Some recent studies have shown a different pattern of scientist's productivity in the beginning, the middle, and the end of the career [5], as well as correlation between collaboration with other scientists and productivity at various age phases of researcher's scientific activity [12, 13].

In our opinion, the age-phase dynamics approach integrates the elements of econometric models and models of human capital in terms of the sociology of science. Application of the age-phase dynamics methodology can be a useful tool in order to study and evaluation of the efficiency and effectiveness of research activities at the micro and meso level.

Method

This work presents preliminary results of age phase dynamics analysis (APhD-analysis) of the personal scientific bibliographies of eight distinguished scientists that conducted research in a variety of scientific disciplines and during different historical periods. Data of an APhD-analysis for German and Russian physical chemist, 1909 Nobel Prize laureate in Chemistry Wilhelm Ostwald (1853–1932); Russian and Ukrainian geochemist Vladimir Vernadsky (1863–1945); Ukrainian scientist in the field of material science, the President of the National Academy of Sciences of Ukraine, Boris Paton (born 1918); Ukrainian mathematician and cybernetician, Viktor Glushkov (1923–1982); British chemist Thomas S. West (1927–2010); Ukrainian economist Gennady Dobrov (1929–1989); French, 1991 Nobel Prize laureate in Physics, Pierre-Gilles de Gennes (1932–2007); and American, 2001 Nobel Laureate in Physiology/Medicine, Leland H. Hartwell (born 1939) are presented. Their biographical details are fairly well known.

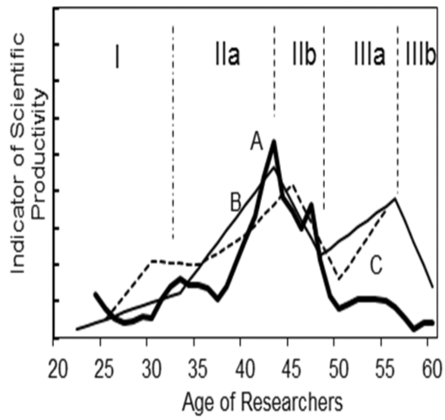
The sources of input data were the published personal research bibliographies of the scientists [24–32]. The main criteria for selection of bibliographies for analysis were all-inclusive coverage of publications and the availability of their bibliometric data. Unpublished materials, reports, electronic and media publications were not included. References in the analyzed bibliographies were confirmed in

* These conclusions are based on the results of extensive research conducted between 1971 and the end 1989 under the UNESCO international research project "International comparative study on the management, productivity and effectiveness of research teams and institutions" (The ICSOPRU Project, 1971–1989) [21]. The study conducted according to the same methodology for each of seventeen countries carried out through direct interviews with leaders of research teams and institutions as well as surveys of thousands of researchers including more than 1,500 scientists in the Ukrainian S.S.R. [22, 23].

"Scopus" and "Google Scholar" scientometric databases.

Results and Discussion

Figure 1 shows a general pattern of APhD of researcher's scientific activity. The productivity curves in each phase of scientific activity life-cycle clearly indicate the most common type of scientific activity (movement of knowledge) and the nature of scientific and organizational functions of scientists (performing, guiding, mentoring, training, consulting) in the corresponding period of their career (see table in Fig. 1).



Types of Knowledge Movement	Phases of Development of Scientific Activity				
	I	IIa	IIb	IIIa	IIIb
Accumulation	+	+	+		
Production		+	+	+	
Transmission			+	+	+

Fig. 1. Age dynamics of publications of T.S. West [28] (A) in comparison with productivity obtained for groups of scientists by B. Malitsky [15, p. 95, Fig. 11] (B) and by D. Pelz and F. Andrews [14b, p. 285, Fig. 57] (C). The scientific productivity indicator axis is approximated.

The indicated general pattern of APhD graphs may be complicated by the influence of various non-systemic factors that reflect subjective circumstances (e.g. psychological characteristics, personal motivations) and external conditions during the scientist's career, in particular, the nature of the research (e.g. theoretical or experimental, research or development), the field of science, the change of scientific focus, degree of scientific communication and cooperation, affiliation of scientific institutions, following the principle of "Publish or Perish", and so forth may alter the pattern. Figure 2 illustrates the differences in the types of individual APhD-profiles of the selected group of scientists as related to some of these nonsystemic factors.

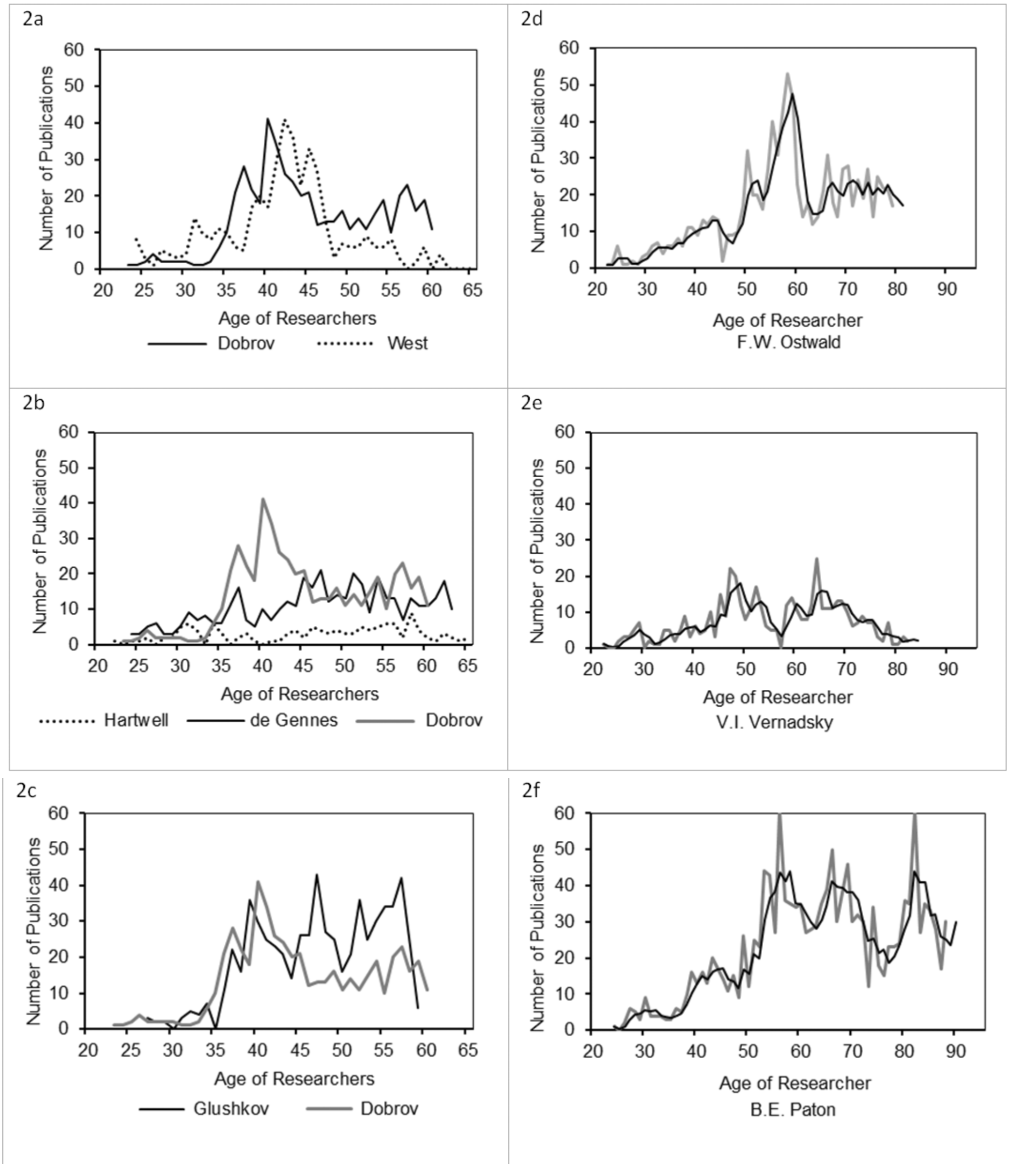


Fig. 2. APhD-profiles of publications of T.S. West [28], G.M. Dobrov [29], L.H. Hartwell [31, 32], P.-G. de Gennes [30], V.M. Glushkov [27], F.W. Ostwald [24], V.I. Vernadsky [25], and B.E. Paton [26]. The references indicate the sources of the bibliographic data. Graph of the number of publications of B.E. Paton (Fig. 2f) does not reflect the patents. APhD-curves of publications of G.M. Dobrov in Figures 2b and 2c are shown for comparison. The light curves in Figures 2d, 2e, and 2f reflects the absolute numbers of publications, and the dark curves are the trends for linear filter (w = 3 years).

As it can be seen, the typical "saddle-shaped" form of age-related patterns of change in the scientific productivity, as described in [14–16], is more or less common to all these examples. At the same time, some specificity in individual APhD-profile is obvious. Figure 2b shows the differences in the types of APhD as related to the research field of science: physics (P.-G. de Gennes), molecular biology and genetics (L.H. Hartwell), as well as economics and sociology of science (G.M. Dobrov). Figure 2c reflects the sequential change of priorities in the appropriate time interval depending on the kinds of scientific and technological activities of the scientist (V.M. Glushkov): theoretical research – the first peak, applied research and development – the second peak, development and innovation - the third peak. Figures 2d and 2e shows APhD of prominent scientists of late XIX - early XX centuries, W. Ostwald and V.I. Vernadsky, when scientific papers were published mainly by individuals rather than by research groups and collaborators. Figure 2f illustrates the wave-shape pattern of APhD-profile in unique case of B.E. Paton, when scientist' career spans more than 70 years.

Theoretically it is possible to imagine a variety of relationship types between scientists' age and their publication activity. Analysis of the results allows us to take the APhD model shown in Fig. 2a as the basic pattern. It reflects the most common regularity of evolution of scientific productivity of a scientist as he ages. From our point of view it is permissible to interpret all other types as special cases of this model as a combination and interdependence of objective and subjective factors, their shapes, direction, and intensity of the relationships.

We would like to point out other features of the APhD graphs that we have obtained. First, almost all of them quite clearly show the peak of the publication activity of scientists to be reached at the age of 30-35 years*. On the other hand, we observed a shift of the peaks in the second and third phases towards the greater age for the researchers, who have career for more than 40–50 years [33]. As can be seen in Figures 2d, 2e, and 2f as compared to Figures 2a, 2b, and 2c, such shift is about 10 to 15 years. A feature of the APhD-profilograms of scientific publications for W. Ostwald (Fig. 2d), V. Vernadsky (Fig. 2e) and B. Paton (Fig. 2f) is determined by continuous and simultaneous processes of production and transmission of knowledge (see table in Fig. 1) for a long scientific career. All this probably means that the age dynamics of scientific activity does not correspond to bimodal model but is indeed a polymodal process with several maxima. Thus, a hypothesis that aging may decrease research activity is not apparent on an individual level.

We currently attempt to establish classification approaches for individual APhD-profiles and to study their further integration within the publication profiles of small research groups and laboratories as well as large groups of scientists (meso level), also incorporating the interrelationship with citation indices** . The data recently published by Costas, van Leeuwen, and Bordons [5] are encouraging in this respect. Several age profiles based on a total number of publications and citations per publication (Fig. 6 and Fig. 7 in referenced article) obtained at meso level are in good agreement with typical individual APhD-profiles at micro level presented in this work (see Fig. 2a).

* Notable is that Phase 1 in the age of researcher's productivity (see in Fig. 1) is usually considered by many authors of the publications as unremarkable (see, for example [3, 5, 8]).
** Data not shown.

At the micro level, scientometric indicators are most often used during the comparative assessment of the scientific productivity and efficiency of scientists' activity (establishment of rating criterias), to make decisions on the distribution of funding for research projects, for the staffing of research groups, for the career promotion of researchers, for achievement awards, and so on. Such important decisions on the future relevance of scientific activity of a researcher or a scientific group are very sensitive assessments. The phase differences of the intensity of scientist' publication activity should be reflected in the character of scientometric indicators. From a logical standpoint, APhD approach comparison of the scientists' achievements by the number of publications and citation indices should be done in the time range of one and the same age phase. This has an essential significance for researchers rating.

Conclusions

APhD model focuses on objective assessment of the level and quality of research performance as well as on the optimal relationship between the number of scientists of different ages and their actual productivity in the corresponding phase of scientific activity. Achieving these goals requires not only an accurate measurement approach, but also a systemic modeling of the objective patterns in the life cycle of scientific knowledge, the factors and mechanisms that shape and impact scientific activity. Development of correct typology of individual APhD-profiles and their hierarchical integration, as well as evaluation of their relationship with scientometrics indicators, correlation to collaborations and productivity at various age phases of researcher's scientific activity, obviously requires special approaches, in particular, the use of modern methods of analysis and modeling of complex systems.

Further Research

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О классификации индивидуальных профилей возрастной фазовой динамики научной деятельности ученых

*Проблема зависимости продуктивности и качества научных работ от возраста ученого является одной из центральных проблем объективизации методологии оценивания эффективности научной деятельности на микроуровне. В данной работе обсуждаются результаты исследований возрастной динамики публикационной активности ученого в контексте модели фазовой динамики научной деятельности – «Age Phase Dynamics model» (APhD). Приведены предварительные данные изучения APhD-профилограмм персональных библиографий научных трудов ряда известных в мире ученых, которые вели исследования в различных областях науки и в разные исторические периоды. Обсуждаются типы модели APhD, отражающие как общие закономерности, так и особенные проявления эволюции научной продуктивности ученого с возрастом. Подчеркнута необходимость разработки корректной типологии индивидуальных APhD-профилей и процессов их иерархической интеграции, а также их взаимосвязи с наукометрическими индикаторами, корреляции между сотрудничеством и публикационной продуктивностью на различных фазах научной деятельности исследователя и др., что требует специальных подходов, в частности, использования современных методов моделирования сложных систем. Работа выполнена в рамках проекта ЕС «BILAT-UKR*AINA» «Усиление двустороннего научно-технологического партнерства с Украиной» Программы FP7-INCO-2012-2.2 (грант № 311839).*