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A STUDY OF PROCEDURES OF SELECTING AND CHANNELIZING SCIENTISTS FOR RESEARCH AND DEVELOPMENT

Part III.—Cyclic Variations in Output

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An attempt is made in this paper to make a fresh analysis of the productivity of scientists by studying the yearly variation of output of individual scientists. A sample of nine recognized Pakistani scientists has been taken, and the plot of yearwise research output of each one shows maxima and minima with a period of nearly six years. The data are then collected agewise into two groups, and the mean output for each group is found to show these cycles even more clearly.

The cycles for different groups can be brought into excellent agreement by bringing into coincidence the years of taking the Ph. D. The overall mean output curve shows the highest productivity between the ages of 36 and 46. A similar plot of the output of two relatively prolific Pakistani scientists shows maximum productivity from the age of 28 to over 43. Thus, the most probable range for greatest productivity is from 32±4 years to 45±1 years of age.

It is further concluded that (i) the output of scientists shows a six-year cycle, and they would do well to change their fields once every six years and their location once every twelve years, giving a turn-over rate of 8% per annum, and (ii) appointments to senior managerial positions in science should preferably be made after the age of 45 years, so as to allow the scientists' maximum productivity to be utilized in the laboratory.

Introduction

In the earlier series of papers,[1,2] an attempt has been made to correlate academic excellence with scientific activity, and some measures for career planning at the intermediate F.Sc. level were proposed. The problem of selecting a good active scientist to fill a senior laboratory post or a supervisory post is a rather more complex one, which requires a great deal of sifting and the consideration of a variety of factors. One usually extrapolates from the previous record on to the probable future activity and productivity of the scientist. While it would be erroneous to assume that a prolific scientist is necessarily the best one for every job, yet the quantity of the research output is a significant criterion. Related with this is the question of when to change one's job or at least one's field[3] of activity, which has a direct bearing on the optimum rate of "turn-over" for a healthy organization. Accordingly, there has been considerable interest during recent years in trying to chart the probable quantum of research output of a scientist in relation to age, and the available data in one field have been analysed to produce a mean graph ("Some thoughts in creativity") of output[4] against age, which is of the type shown in Fig. 1. This graph shows a fairly rapid rise in output with a peak near the age of 33, followed by a relatively slow decline in output. This average graph for a large number of electronics specialists indicates that a fair percentage of scientists do become *relatively* inactive soon after the age of 45. However, two noticeable features of this graph are:

(i) that there is a definite continuance of the creative activity into very high age groups, such as the 50s or 60s, and

(ii) that there is some indication of a small-scale periodicity in the output, as might have been expected because many individuals produce good work by fits and starts.

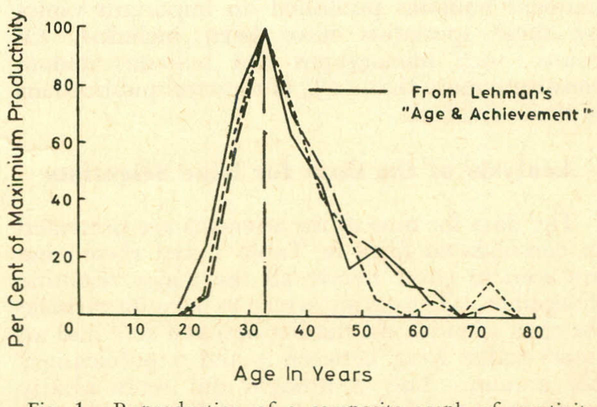

Fig. 1.—Reproduction of a composite graph of creativity as a function of age, based on contributions to electrical development and on papers published in the Proceedings of Institute of Radio Engineers in the years between 1930 and 1953. The maximum is found at 33 years of age.

It, therefore, appears worthwhile to examine the yearwise research output of certain selected senior scientists, in order to (a) determine whether any small-scale periodicity exists in an individual's output, and (b) find how much correlation there is (from scientist to scientist) of maximum output with the ages or perhaps with years of post-doctoral work. A brief analysis of this type is presented in the present paper, for a sample of eleven Pakistani scientists.

Sources of Data

The following analysis utilises the published research work of eleven Pakistani scientists in various fields, two of whom can probably be classified as "prolific", while the others were sufficiently productive to be proposed and elected for Fellowship of the Pakistan Academy of Sciences in recent years. (This largely avoids the vexing question of the quality of their research publications, which are screened by the Council of the Academy before the elections.) The data consists of the number of research publications in various years, and has in some cases been kindly provided by the scientists concerned themselves, and in other cases through the courtesy of PANSDOC and the Pakistan Academy of Sciences. Although the specializations of the various scientists and their ages are given in this paper, their names are being withheld as a matter of courtesy, even though specialist readers may in some cases be able to identify them from their work. Four of the eleven scientists work in Government research organizations, while the other seven are in Universities or other teaching institutes. While predominantly the output has been taken to include original research papers, nevertheless in many cases scientific monographs and international/national bulletins published on important topics by these specialists have been included. Of course, such monographs and bulletins seldom constitute more than 10% of the total publications of the individual.

Analysis of the Data for Nine Scientists

The data for nine of the scientists are presented in consolidated form in Table 1 and these nine are seen to cover nearly all the major scientific disciplines. The output is seen to be quite variable for each scientist, fluctuating between zero and an upper value lying between 3 and 7 publications per annum. This is brought out more clearly by plotting the data in graphical form in Fig. 2(a) and (b) for the first four and the next five rows of Table 1, respectively, including data before 1940 for Nos. 8 and 9. The actual annual output is plotted as crosses in Fig. 2, but in order to exa-

Table 1.—Synopsis of Yearly Research Output of Nine Senior Pakistani Scientists for Twenty-Six Years from 1941–1966.

No.	Year of birth & specialization	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
1.	Soil Science born 1918	—	1	—	—	—	1	0	0	0	0	0	1	0	4	3	6	1	2	3	2	2	1	0	0	2	1	
2.	Biochemistry born 1919	—	—	—	—	—	1	1	0	0	2	3	0	2	5	4	4	1	2	2	5	3	3	2	3	2	4	
3.	Phys-inorg. chem. born 1910	—	—	—	—	—	0	0	0	0	1	0	0	0	0	2	5	3	2	2	1	2	2	1	3	4	1	
4.	Applied biology born 1919	—	—	—	1	2	1	0	1	2	0	1	0	1	0	1	0	0	0	0	1	1	3	5	2	1	5	
5.	Botany born 1916	—	—	—	—	—	0	0	0	0	0	0	1	5	2	3	1	1	0	1	2	1	1	1	3	2	3	3
6.	Org. chemistry born 1921	—	—	—	—	—	0	0	0	0	2	0	2	2	3	5	0	3	0	2	0	0	1	1	0	0	0	0
7.	Soil engineering born 1920c	—	—	—	—	—	0	0	1	1	1	1	2	2	2	1	4	3	1	2	5	7	4	1	1	2	1	0
8.	Physics born, 1910	3	1	—	—	—	0	1	1	0	0	0	1	0	1	2	1	1	0	0	1	2	2	0	1	0	0	0
9.	Inorganic chem. born 1911	1	—	2	2	1	0	0	0	0	3	1	0	2	0	1	2	0	1	0	0	1	0	0	1	0	0	1
	Total of serial Nos. 3, 8 & 9	4	1	2	2	1	0	1	1	0	4	1	1	2	1	5	8	4	3	2	2	5	4	1	5	4	1	(~3)
	Total of serial Nos. 1, 2 and 4 to 7	0	1	0	0	2	3	1	2	3	5	5	6	12	16	17	15	9	5	10	15	14	13	10	9	9	13	(~10)

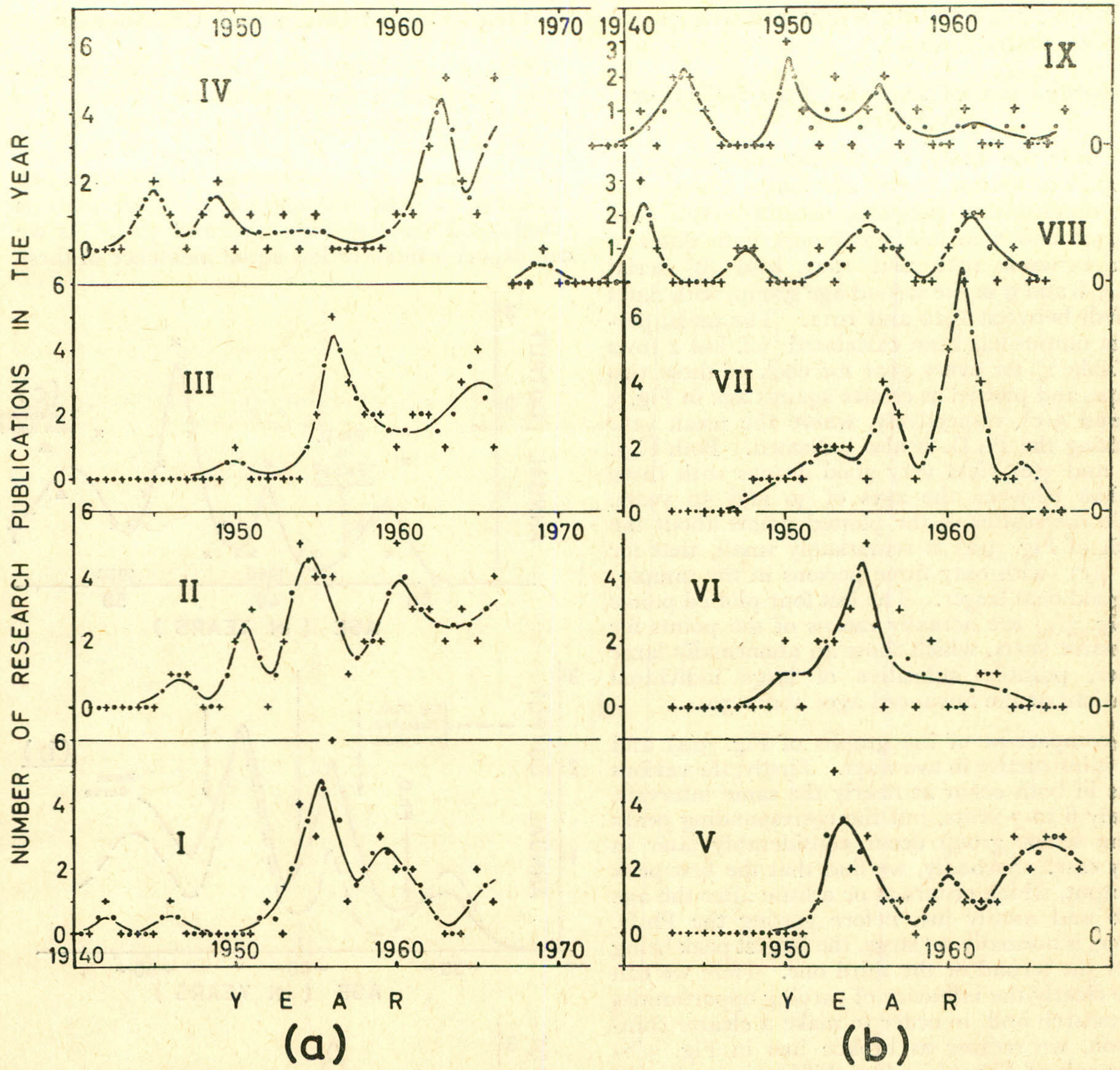

Fig. 2.—Plots of the year-by-year research outputs of nine recognized Pakistani scientists (tabulated in Table 1), with smooth curves drawn through the means of successive years, which are shown as small solid circles. A pattern of 3 to 5 maxima and minima is found in each case, the period of one cycle varying from 5 years to 7 years.

mine the data for any regular trends, the means of successive crosses have been plotted as small solid circles. These solid circles clearly indicate a pattern of maxima and minima in each case.

Accordingly, the full lines show the best graphs drawn through these solid circles. An examination of Fig. 2(a) shows clear evidence of the presence of 3 to 4 cycles of maxima and minima in the output of each scientist. The period of any one cycle varies from 4 to 7 years, but the mean periods obtained for the four scientists from Fig. 2(a) are 5.8 years, 5.0 years, 6.8 years, and 5.6 years. These yield an *overall mean* value of 5.8 ± 0.4 years for the output periodicity of these *four scientists*.

Figure 2(b) shows the corresponding output plotted yearwise for the remaining five scientists, and these graphs again provide evidence of the cyclic variation, the periods being 6.2 years, 5.8 years, 5.3 years, 6.6 years, and 6.0 years, respectively. The mean value of the period obtained from these five is 5.9 ± 0.3 years, which agrees satisfactorily with the figure of 5.8 ± 0.4 years obtained for the four scientists in Fig. 2(a). We can thus conclude that there is a quite definite cycle of mean period 5.8 ± 0.3 years in the activity of all the nine scientists, whose research output has been analyzed above.

Examination of Data in Two Different Age Groups

In order to study the possible correlation of the cyclic pattern with age, the data of Table 1 has been divided into two lots, viz. (a) serial Nos. 1,2,4,5,6 and 7 in one age group, with dates of birth between 1916 and 1921, and (b) serial Nos. 3, 8 and 9 in the second age group, with dates of birth between 1910 and 1911. The mean per-capita output has been calculated (cf. last 2 rows of Table 1) for every year for each of these two groups, and plotted as crosses against age in Fig. 3 (a) and 3(c), respectively, where the mean year of taking the Ph.D. is also indicated. Both Figs. 3(a) and 3(c) yield very good graphs with three maxima between the ages of 30 and 50 years. While the scatter of the plotted points about the graph of Fig. 3(a) is remarkably small, that for Fig. 3(c) (with only three persons in the sample) is a good deal larger. The last four plotted points in Fig. 3(c) are actually means of the points for successive years, which show an abnormally large scatter, possibly indicative of large individual variations at the advanced ages above 50.

A comparison of the graphs of Fig. 3(a) and 3(c) is instructive in two ways. Firstly, the various peaks in both occur at nearly the same intervals, namely 6 to 7 years, but the corresponding peaks in the senior group occur considerably later in every case. Secondly, we find that the first peak of output, which occurs at or a little after the age of 30 and mostly just before getting the Ph.D. degree, is normally *not* large, the largest peak being either the second or the third one. Here we can trace clearly the influence of varying opportunities for research and, in order to make a clearer comparison, we redraw as broken line in Fig. 3(b) the graph of Fig. 3(c) after shifting it to the left (lower ages) by 4 years, which brings their years of taking their Ph.D. into coincidence.

We now see the contrast between the behaviour of the 2nd and 3rd peaks. The younger group of Fig. 3(a) got the opportunity of doing doctoral and post-doctoral research soon after passing their M.Sc. during the post-War years 1946-50, and consequently the subsequent six-year period from 1952 to 1958 was extremely productive, thus making the 2nd peak of Fig. 3(a) the highest, with an output of 3 publications per annum. On the other hand, the senior group had to plod along during the War years, which coincided with their second peak period, which is therefore relatively low, while their third peak (corresponding to the post-War years) is high, going upto 2.4 publications per annum.

Mean Output Curve and Conclusions

Thus, a significant delay in the ready availability of research opportunities or facilities can shift the main maximum of output from the 2nd peak (before 40) to the 3rd peak (after 40). At the same time, it is interesting to note that the total output from the ages of 25 to 50 years is roughly the same in Figs. 3(a) and 3(c). As we can expect a more or less equal incidence of these

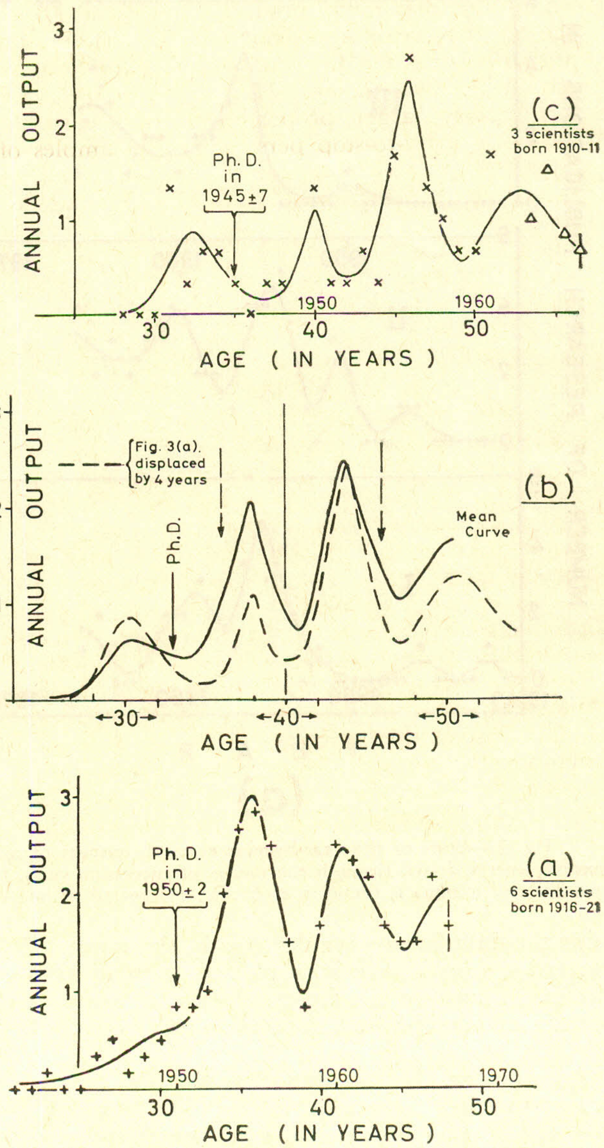

Fig. 3.—Groupwise plots of the mean yearly research output in two age groups; the mean year of taking the Ph. D. is indicated by the vertical arrow for each group. The broken line in Fig. 3(b) show the curve of Fig. 3(c) displaced by 4 years, while the full-line curve is the mean of this and the curve of Fig. 3(a). The broken vertical arrows mark the region of maximum productivity in this mean output curve.

two types of careers in research, the most probable curve of output would be close to the mean of Fig. 3(a) and (c). This mean is plotted in Fig. 3(b) as the full line, and we note that the 2nd and 3rd peaks are now nearly equal, so that the period of maximum creativity for the average scientist can be taken to extend from the ages of 36 ± 2 up to 46 ± 2, as shown by the broken arrows marking the drop to half the peak value. This result differs a good deal from that of Fig. 1, in which the maximum productivity extends from age 27 to 44 years approximately, and the reason probably lies in the different natures of the samples used in the two studies. Thus, there may well be a relatively larger proportion of the early-to-start and early-to-stop persons in the samples of Fig. 1, who may even have switched to other careers after a short spell of research. The present analysis, on the other hand, deals with the more important case of the career of each individual scientist, who by definition, has made a career of science.

At this stage, it is worthwhile making a comparison of the mean output curve of Fig. 3(b) with the graphs of annual output of the two more or less prolific scientists (both Fellows of the Pakistan Academy of Sciences) mentioned earlier. Accordingly, the data for these two are plotted in Fig. 4 with a reduced vertical scale, the upper graph being for the chemist and the bottom one for the physicist. In both these, the second, third and fourth peaks are very high, the 2nd and 4th being the largest in one case and the 3rd in the other, but the age at this 3rd peak is somewhat different from those of Fig. 3(a) and 3(b) showing that the pattern of scientific output of these most highly productive scientists may be displaced significantly towards lower ages. However, a reasonable comparison of the various peaks can be effected if we again use the year of taking the Ph.D. as a common starting point. Accordingly, we first plot in Fig.4(b) the mean of the two individual curves of Fig. 4(a) and (c), which are already plotted with the years of taking the Ph.D. in coincidence. The mean curve smooths out some random fluctuations, and we clearly see four progressively increasing peaks at intervals of 6 years, the third and fourth peak, at 35 and 41 years of age, respectively, being nearly equal in height. This mean curve can now be compared peak-by-peak with the mean curve of Fig. 3(b), provided we again place the years of taking the Ph.D. in coincidence. The only outstanding difference in the natures of the two mean curves is that the output of the more prolific scientists continues to rise even after the third peak, instead of beginning to fall progressively, sometimes even after the second peak. The period of maximum productivity in which the productivity is greater than half the peak value, is (now) seen to extend from about 28 years of age to over 43 years, which compares with Fig. 1 and the figures of 36 years to 46 years of age found in Fig. 3(b). This yields an overall mean of 32 ± 4 years to 45 ± 1 years as the period of maximum creativity or productivity of any one scientist, the upper limit being independent of whether he be an early or a late starter.

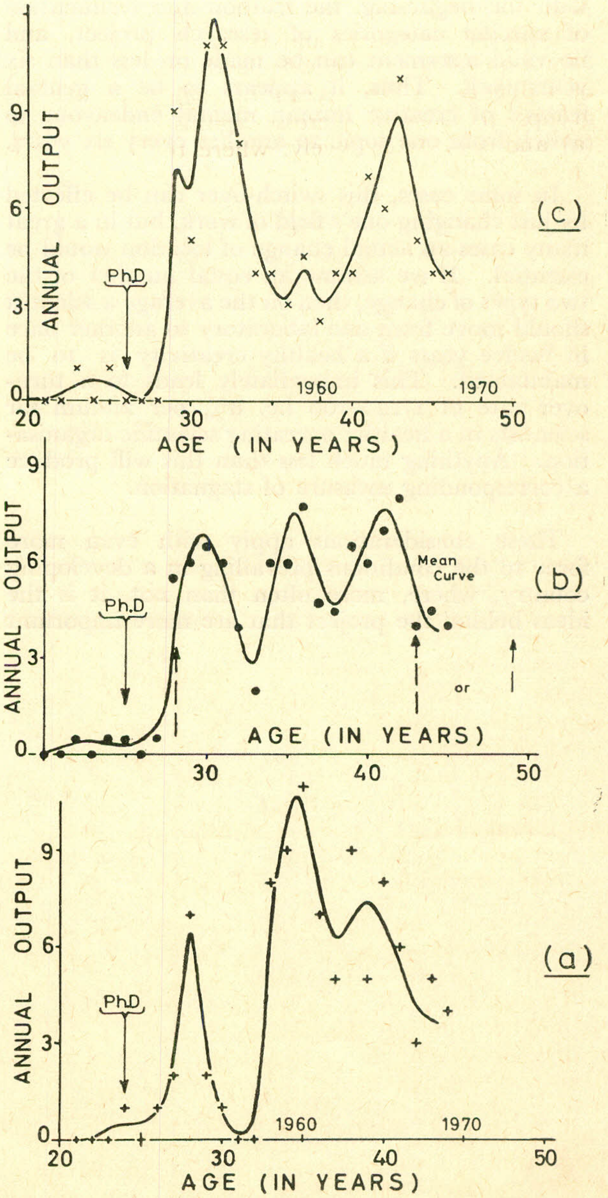

Fig. 4.—(a) and (c) show plots of the yearly output of two prolific Pakistani scientists, while (b) is the mean of the two, which is comparable with Fig. 3(b), except that the output starts earlier and is three times as much. The broken vertical arrows again delimit the region of maximum output.

We can conclude that (i) the cycles of productivity of various scientists are comparable if we use the year of taking the Ph.D. as a common starting point, (ii) the period of maximum productivity extends from the age of 32 ± 4 to 45 ± 1 years, so that incentives should be provided to keep good scientists in the labs until 45, and (iii) there is a six-year cycle in creativity for any one scientist. The various peaks and cycles in productivity can in each case be readily correlated with the beginning, the fruition and termination of specific categories of research project, and no valid assesment can be made on less than six years work. Thus, it appears to be a general feature of creative human mental endeavour to switch from one topic to another every six years.

In some cases, this switch-over can be effected by just changing one's field of work, but in a great many cases an actual change of location would be essential. If we assume an equal number of the two types of change, then on the average a scientist should move from one laboratory to another once in twelve years if a healthy creativity is to be maintained. This immediately leads to a turnover rate of $1/12 \times 100$ i.e. 8% per annum for scientists in a healthy operating scientific organisation. Anything much less than this will produce a corresponding measure of stagnation.

These considerations apply with even more force to the conditions prevailing in a developing country, where, more often than not, it is the ideas behind the project that are more important than the routine techniques of experimentation. It is of interest to note that not only is the output affected by too long a stay in a particular place or position, but the aspect of human relations also plays an important part. This is particularly true of the senior and managerial positions in scientific institutes and other governmental or public organization. One can guess that something like 6 to 12 years seems to provide a healthy rate of turnover in most such positions, with the optimum being perhaps closer to six years than to twelve. Further studies on this aspect and related considerations are desirable, as also the productivity of the prolific scientists at ages above fifty.

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