Science and Society in Equilibrium

An equilibrium growth rate for science may have a much larger impact than is generally expected.

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The growth of science over the last several decades—indeed over the last several centuries—has been exponential. This in itself is not especially surprising. The growth of almost everything else connected with our society has also been exponential. What *is* somewhat surprising is the fact that science has been able to maintain for at least several decades a percent-per-year growth rate which is much larger than that of society as a whole or of most other components of society. Some argue that the rate of growth of science can and should increase, or at least not decrease from the rate of the recent past. Others have argued that the rate of growth must decrease. Some of the implications of a decrease in the growth of science are examined below.

Many authors have pointed out the distinctions among scientific research, applied research, engineering, and so on. Although all these activities are related in the technological enterprise of the nation, they are not identical. However, for simplicity, and in part because of the paucity of other than aggregated data, the entire collection of activities covered by research, development, product engineering, the teaching of science and engineering, and the administration of these activities is referred to in this article as "science." In addition, all persons engaged in these activities are called "scientists." The distinctions among these activities, as well as those among the various disciplines of science in the usual narrow sense, are ignored in this preliminary study.

Figure 1 shows the growth in the number of scientists in the United States since 1940, the growth in the U.S. population since 1940, and scientists as a percentage of the total population. Over a period of nearly 30 years the proportion of scientists in the population has increased from less than 0.5 percent to about 1.0 percent. Figure 2 shows the growth in the U.S. gross national product (GNP) since 1946, the dollar resources expended in R&D since 1953, and R&D costs as a percentage of GNP. Between 1953 and 1963 the proportion of the U.S. GNP devoted to R&D doubled, from slightly less than 1.5 percent to 3 percent.

It should be clear that no component of society can long continue to grow at a rate greater than the rate of growth of the society as a whole. Projection of the upper two curves of Fig. 1 and of Fig. 2 would imply that eventually the entire U.S. GNP would be expended on R&D and the entire U.S. population would be working as scientists. Clearly this is not going to happen. Eventually an equilibrium must be reached where the growth rate of science is no greater than the growth rate of society. As indicated in Figs. 1 and 2, there are two growth rates to be considered. One is the increase in material resources devoted to science; the other is the increase in the manpower devoted to science. That is, the equilibrium growth rate of science resources must be no greater than the growth rate of the GNP, and the equilibrium growth rate of science manpower must be no greater than the growth rate of the population. These two equilibrium growth rates need not coincide. One might be more restrictive than the other, holding science to an equilibrium growth rate in one component and to less than equilibrium in the other.

Figure 1 shows that the proportion of scientists in the total U.S. population has been growing steadily since 1940 and so far shows no sign of leveling off. In dollars spent on R&D, however, the situation is different. Figure 2 shows that, since 1964, the resources expended on R&D have leveled off to essentially 3 percent of the GNP. This raises the possibility that the growth of resources available to science is at last coming into equilibrium with the growth of resources available to society as a whole. If this is true, the consequences of this equilibrium growth deserve serious attention.

Many of the people engaged in science seem to feel that if the growth rate of science slows down so that science grows no faster than society, the impact will be only marginal. In discussions of science policy at the university level, this impact has been seen in limited terms: research grants would be somewhat more difficult to obtain, support for graduate students might diminish somewhat, but the publication problem would ease slightly. At the industrial level there has been no indication that a diminution in the growth rate of science would have any impact on the traditional division of research between universities and industry. At the national level the notion seems to be that a decrease in the growth rate of science would mean that science would go on as it has for years, though perhaps at a slightly slower pace.

This view, however, may be overly optimistic. The optimism probably arises from the fact that the growth rate of science and the direct consequences of this growth rate have become so deeply embedded in the customs and institutions of science that the significance of this growth is not fully recognized. The extent to which this fact of nonequilibrium growth has permeated and shaped science as an institution is probably not fully appreciated by the average scientist. In this article I evaluate the magnitude of the impact to be expected from a transition to equilibrium by taking a concrete example: the requirement for university science faculty members. I estimate the magnitude of the impact by showing the difference between current projections based on the assumption that nonequilibrium growth will continue at its present rate and estimated requirements based on the assumption that equilibrium was reached in 1968.

Over the past few years the need for science staffs in colleges and universities has been examined in a number of reports. The authors of a number

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of these reports have expressed concern that there would not be enough qualified persons available to fill the required staff positions, or that some lowering of quality would be required (*1–4*). In one study (*4*), optimization theory was applied to the problem of allocation of new Ph.D.'s between teaching and research, with the objective of achieving a maximum value for a specified welfare function which involved both the level of available scientific knowledge and the amount of education being provided to society. The authors of these reports (after analyzing the number of science staff members required and comparing these requirements with the number of new graduates available, particularly new Ph.D.'s) generally conclude that, at best, the situation will not deteriorate below the current situation, but that it is more likely that both the teacher-student ratio and the Ph.D.-total faculty ratio will decline, resulting in a decline in educational quality. A typical statement of numbers of staff members required is shown in Table 1.

In one of the most thorough studies (*3*), Consolazio states explicitly an assumption which is made in all the studies, even if not explicitly stated. This assumption is that students will continue to present themselves for education in science and engineering at rates which are essentially projections of the rates that have obtained in the past. Another assumption is implicit in all these studies. This is that the demand for science graduates will continue at rates which are essentially projections of the rates that have obtained in the past. Consolazio recognizes the importance of this assumption (*3*, p. 211) but does not investigate it specifically.

The computations given below are based on specific denial of the validity of this assumption and on adoption of the assumption that demand for science graduates will be limited to the numbers required to maintain equilibrium growth of science, equilibrium with growth of resources and equilibrium with population growth being considered separately.

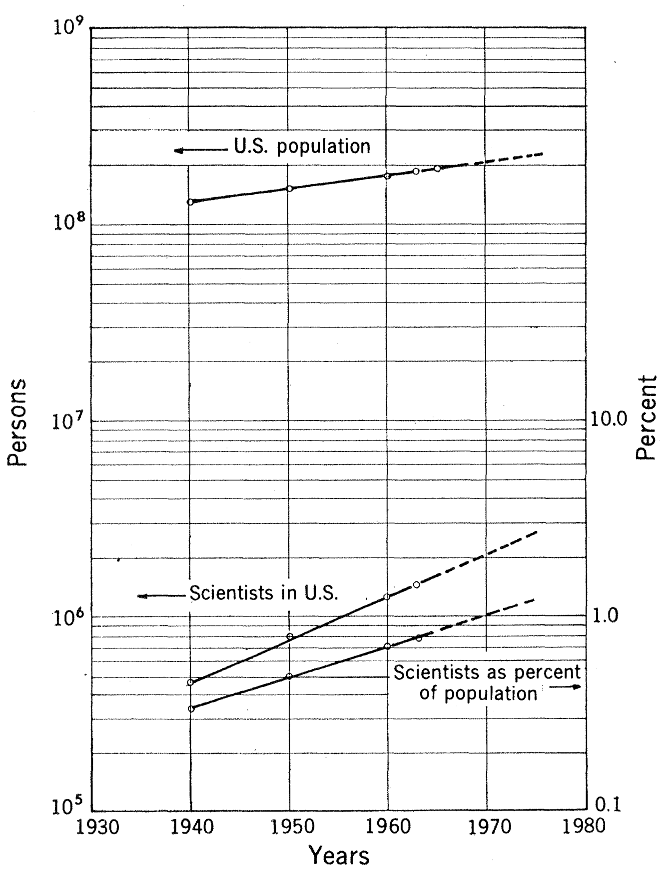
The Size of Science

The number of scientists engaged in the practice of science is described to a first approximation by Eq. 1. This model is much simpler and more highly aggregated than that used by Reisman (*5*) but is adequate for the present purpose.

$$N_n = N_0 + \sum_{j=1}^{n} P_j + \sum_{j=1}^{n} I_j - \sum_{j=1}^{n} E_j - \sum_{j=1}^{n} D_j \quad (1)$$

Here N_n is the number of scientists in the nth year; N_0 is the number in some reference year; P_j is the number of holders of science degrees produced by American universities in the jth year; I_j is the number of persons who enter science in the jth year without a science degree from a U.S. university; E_j is the number of scientists leaving science for work in other fields in the jth year; and D_j is the number of scientists who die or retire in the jth year. (The symbols are discussed and evaluated below.)

Estimates of the number of scientists in the United States were obtained as follows. A National Science Foundation



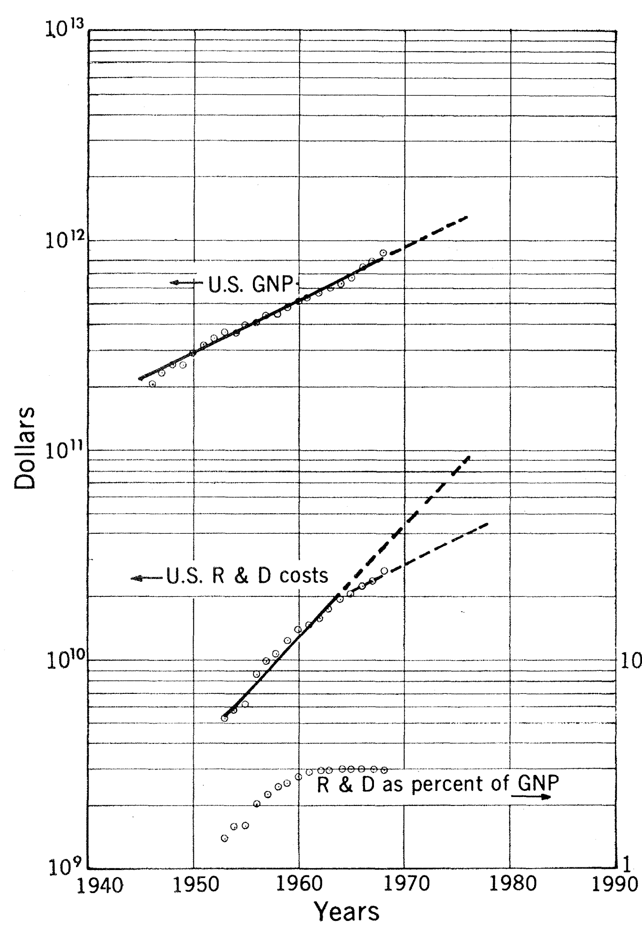


Fig. 1 (left). (Scale at left) U.S. population since 1940, and number of scientists in the United States since 1940, as defined in text. (Scale at right) Scientists as a percentage of the population [data on population, from (*9*); data on scientists, from (*7*)]. Fig. 2 (right). (Scale at left) U.S. gross national product since 1945, and U.S. R&D costs since 1953. (Scale at right) R&D costs as a percentage of GNP [data on GNP, from (*10*) (to 1966) and from preliminary estimates (1967 and 1968); data on R&D costs, from (*6*) and from congressional appropriations for 1968].

study (*6*) gives the numbers of scientists engaged in R & D during the period 1953 to 1968. These numbers are reflected in Fig. 1. Another NSF study (*7*) indicates that in 1960 7 percent of all scientists held the Ph.D. degree, the remainder having lesser degrees. The proportion has apparently increased since then, but precise current figures seem not to be available. The annual summary, *American Science Manpower,* issued by the National Science Foundation indicates that about 40 percent of all scientists in the National Register of Scientific and Technical Personnel hold the Ph.D. Since the register does not include engineers and is based on responses to surveys by professional societies, it is undoubtedly biased in an upward direction. The report of the Committee on Utilization of Scientific and Engineering Manpower, of the National Academy of Sciences (1964), shows less than 2 percent of engineers holding the Ph.D. For the computations given below, it is assumed that 10 percent of all scientists (including engineers) hold the Ph.D. The figures given in (*6*) also indicate that, for every scientist engaged in R & D, there are two more engaged in production, university teaching, administration, and other science-related activities. It is assumed here that this proportion will hold true in the future.

For the computations, the following relation is used:

$$P_j = pT_{j-1} \qquad (2)$$

Here T_j is the number of full-time–equivalent (FTE) university staff members engaged in teaching science, in R & D related to teaching, and in administration of both during the jth year. The factor p is the number of graduates produced per FTE staff member. An NSF study (*2*) gives detailed estimates of this productivity factor for various fields of science and for various academic levels. For the computations, an overall average figure has been taken across all fields of science: for B.S. degrees, $p = 1.230$; for Ph.D. degrees, $p = 0.087$.

I_j, the number of persons who enter science in the jth year without science degrees from U.S. universities, includes those who hold degrees of any kind from non-U.S. universities and those who hold nonscience degrees from U.S. universities. An NSF study (*8*) indicates that these individuals constitute approximately 15 percent of those entering science. However, in the computations, I_j is taken equal to zero.

Table 1. Requirements for science staff in universities, 1964–1975. [From (*2*)]

Year	Number of full-time–equivalent (FTE) staff members (in thousands)
1965	164.0
1966	191.4
1967	210.9
1968	214.8
1969	224.6
1970	243.5
1971	258.4
1972	275.8
1973	289.6
1974	305.6
1975	324.6

That is, it is assumed that all new entrants to science will be holders of science degrees from U.S. universities.

In the computations, the following relationships are used:

$$E_j = eN_{j-1} \qquad (3)$$

where e is the fraction who leave per year. From (*7*), we find that e is about ½ percent. Also

$$D_j = dN_{j-1} \qquad (4)$$

where d is the fraction who die or retire per year. From (*7*) and (*8*) we find that d is currently about 1 percent. However, if we assume steady-state conditions and an average career of 40 years, we find that d would be slightly less than 2.5 percent. This value is used in the computations.

In the next sections the total number of scientists in 1975 is estimated on the basis of assumed external constraints, and the required number of FTE university staff members in the sciences is computed.

If Science Is Limited by GNP

The number of FTE university staff members required is first computed on the assumption that the growth of science is no faster than the growth of the GNP. It is assumed that R & D will continue to receive 3 percent of the GNP (the 1968 proportion) through 1975. Projecting the GNP at the growth rate it exhibited between 1953 and 1968, we find that in 1975 the GNP will be approximately $1250 billion, and in 1976, approximately $1300 billion.

From (*6*) we learn that the average annual cost of a scientist engaged in R & D in 1965, including salary, equipment, subprofessional support, and overhead, was $41,000. If this same cost figure holds true in the future, there will be 915,000 scientists engaged in R & D in 1975 and 952,000 in 1976. Thus, there will be 2,745,000 scientists in the United States in 1975 and 2,856,000 in 1976. From Eq. 1, we have

$$N_{76} = pT_{75} + N_{75}(1 - 0.025 - 0.005) \qquad (5)$$

(the subscripts indicate the years). Solving this equation, we find that the number of FTE university staff members required in 1975 to produce the net increase of 111,000 scientists required in 1976 is 157,195. However, if 10 percent of the new scientists produced are Ph.D. holders, then the number of FTE university staff members required will be 222,241. This number of FTE staff members will produce not only the required number of Ph.D. holders but also a surplus of holders of lesser degrees. Both of these estimates are considerably lower than the estimate of 324,600 of Table 1.

If Science Is Limited by Population

The number of FTE university staff members required is next computed on the assumption that the growth of science is no faster than the growth of the U.S. population. In 1968 scientists represented not quite 1 percent of the U.S. population. It is assumed that in the future the proportion of scientists will remain stable at 1 percent of the U.S. population. From (*9*), Series D, we obtain a figure of 214,384,000 for the U.S. population in 1975. Series D assumes a growth rate of about 1.1 percent per year; thus the 1976 population will be 216,739,000. Hence the number of scientists in the U.S. will be 2,143,840 in 1975 and 2,167,390 in 1976. According to Eq. 5,

$$N_{76} = pT_{75} + N_{75}\,(1 - 0.025 - 0.005)$$

Solving this equation, we find that the number of FTE university staff members required in 1975 to produce the net increase of 23,550 scientists required in 1976 is 71,435. If 10 percent of the new scientists required are Ph.D. holders, the number of FTE university staff members required will be 100,995. Again, these staff members will produce the required Ph.D.'s and a surplus of lesser degree holders as well. These estimates are significantly lower than those calculated for the GNP-limited case and lower than the estimates of Table 1.

Additional Impact

The change from nonequilibrium to equilibrium growth of science will produce significant impacts on the numbers of FTE university faculty members, as shown above. However, there are other impacts, less subject to quantitative evaluation, which are no less important.

One of the most important of these will be the change in the proportion of research done in universities and elsewhere. As the universities employ a smaller and smaller proportion of the total number of scientists, they will account for a smaller and smaller proportion of the total amount of research done. To suggest appropriate means of funding additional research outside the universities is beyond the scope of this article. Suffice it to say that new funding mechanisms will be required to pay for that research which will no longer be required in support of teaching.

Another impact will be a change in the age distribution of scientists. As the growth rate of science slows down, the median age will increase. In the most drastic case considered above, that of population-limited growth, the age distribution of scientists will tend to approach the age distribution of the work force as a whole, at least between the age limits of approximately 25 and 65. This opens considerable room for speculation about the effect of this shift in age distribution on creativity. To the extent that creativity is associated with youth, the result will be a decline in average creativity.

A reduction in the rate of expansion of science will mean a reduction in opportunities for advancement for younger scientists. There will be fewer new departments in new universities, fewer new research groups in industries, and probably fewer opportunities to start so-called "science-based companies." The average age at which scientists become department heads, chiefs of research groups, and so on, will increase. The heady pace of rapid personal advancement, which has come to be accepted without question over the last two decades, will slow down.

Presumably, despite the reduced growth rate of science, those persons who are interested in a scientific career and who have the ability to obtain a Ph.D. will continue to enter Ph.D. programs and become scientists. This probably will lead to a higher proportion of Ph.D. holders among members of the scientific work force. It may also mean that those who cannot or do not obtain the Ph.D. will be unable to obtain employment at other than the lowest levels. In addition, the comparative increase in the number of Ph.D.'s may mean that salary differentials for this degree will be reduced.

Summary

Up to the present, science staffs at U.S. universities have been required to turn out science graduates not so much to replace losses from deaths, retirements, and transfers as to provide the new scientists required by a rapidly growing scientific establishment. However, science as a component of society cannot long continue to grow at a rate exceeding the growth rate of society. The dollar resources devoted to science cannot continue to grow faster than the GNP, and the number of persons engaged in science cannot continue to grow faster than the population. Eventually science must come into equilibrium with society, and its growth rate must slow down to match the growth rate of society. When this happens, science staffs in U.S. universities will find that they are required to turn out a much smaller number of graduates, most of whom will replace losses rather than fill new posts opened by growth. The science staffs of U.S. universities are already larger than the staffs which would be required in 1975 if science came into equilibrium with society in 1968.

The transition to equilibrium will have many impacts on science in addition to its impact on university faculties. Some of the more obvious are mentioned above. Others may not be so obvious. In any case, the nonequilibrium growth of science over future generations has become an unquestioned assumption underlying many of the practices, customs, and habits of science as an institution, and of individual scientists. Many of these practices, customs, and habits may have to be modified considerably in the transition to equilibrium. Many of the modifications may be as drastic as that calculated above for universities. Because of the deep-rooted nature of the assumption of nonequilibrium growth, the nature of some of these modifications may not even be apparent until the situation has reached the crisis stage.

At this point it may be asked, How credible is the projection made above? Does it reflect a reality which we may well see by 1975? The projection was not, in fact, intended to be credible. On the contrary, a deliberate effort was made to project the worst possible case. The situation in 1975 cannot help but be better than the foregoing computations show if any forethought at all is used in developing U.S. science policy. The primary purpose of this article is to indicate that science has reached the point where science policy makers must start considering the transition to equilibrium and, in particular, must start thinking about how to cushion the shocks which will accompany this transition. The projections made were intended to indicate how serious the problems could become if the proper preparations are not made. Without adequate planning to make the transition to equilibrium as smooth as possible, however, the situation could well become as bad as that indicated above.

References and Notes

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11. The views presented in this article are my own and do not necessarily reflect the views of the United States Air Force.