Doctoral Feedback into Higher Education

An analytical model can guide the development of policies and programs.

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Many persons and groups, both public and private, are seeking ways to strengthen science and engineering education in this country. Often these persons or groups try to develop policies and programs based upon factual information regarding the numbers, characteristics, and deployment of scientific and engineering personnel. Almost as often, the facts, even though they may comprise voluminous statistics, do not serve adequately to clarify and quantify the particular issues involved. We believe that the main reason for this shortcoming is a lack of unifying concepts for distilling the essential facts and portraying them quantitatively, in a form that policy makers can use effectively.

In this article we derive policy guides relevant to one class of problems, those that involve relations among numbers of academic degrees awarded and numbers of persons engaged in educating and training the degree recipients. We represent the process of degree production by means of a feedback model, shown in Fig. 1, that abstracts, in fundamental form, certain quantitative elements of the process. After analyzing the model dynamically, we graph the results to depict alternative policies as alternative paths drawn from a point, which represents an existing condition, to a curve, which represents a set of future possible conditions. Although the analytical method we develop is applicable to the production of degrees at any academic level and in any field of learning, we apply it here only to degrees at the doctoral level and in the fields of science and engineering.

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We do not offer predictions or value judgments. We do not attempt to say how many degrees should be given or how many faculty members will be needed in the future. Rather, in this study, we aim only to develop a tool for helping policy-makers see more clearly the likely consequences of programs they may recommend.

The Feedback Model

Our model, an analog of the educational feedback process, is made up of elements of two kinds: boxes, representing pools of persons distributed according to functions they serve, and lines, representing flows of persons into and out of the pools.

In the analog (Fig. 1), box E contains all the doctoral scientists and engineers who serve relevant educational functions and box P contains all other doctoral scientists and engineers, those engaged in professional activities other than higher education. The letters E and P algebraically represent the numbers of doctorates in the respective boxes.

Because the analog represents *functions* rather than structures, the boxes do not correspond uniquely to groups of organizations or to sectors of the economy as usually defined. Box E, for example, is not congruent with the sector called Colleges and Universities: not all doctoral scientists and engineers employed in colleges and universities are engaged directly in the educational function, and some educational endeavor is carried on by persons employed in sectors other than Colleges and Universities. Even though most of the numerical data we use derive from surveys made with reference to organizations or sectors, we adapt the data to measure the behavior of the model according to functions.

We consider several different definitions of the educational function. Under one definition, for example, box E represents only persons who teach; under another definition, E represents all persons who teach or do academic research or both. Each such different definition relates to a different facet of educational policy. Further, we use this model to represent the educational feedback process not only in the aggregate but also in certain segments, such as particular academic fields, or groupings of fields.

The lines that connect the boxes represent flows of several kinds. Out of box E each year flow a certain number, rE, of persons who have received doctoral degrees during the year. Thus, the production ratio, r, is the number of doctorates awarded during one year, divided by the number of doctoral scientists and engineers performing educational functions in that year. We consider several different definitions of r, corresponding to different definitions of E, as mentioned.

The feedback ratio, b, is the fraction of degree recipients who, within 1 year after receiving the degree, enter employment in some capacity pertaining to the educational function. For the most part, but not always, depending upon the policy problem studied, b relates directly to employment in colleges and universities. In any case, brE is the absolute number of new doctorate recipients fed back into the educational function within 1 year.

The attrition rate, a, is the annual number of scientists and engineers with doctorates who leave professional employment, expressed as a fraction of the number employed. This attrition is attributable to death, retirement, or shifting to entirely different occupations (*1*).

Finally, the transfer rate, c, is the net annual number of persons who transfer from educational to noneducational activities, expressed as a fraction of the number of persons engaged in education (*1*). Because persons can transfer in either direction, the transfer rate can have either a negative or a positive value. Apparently the value of c in recent years has been positive for some fields of science and negative for others.

Limitations of the Model

This model is about the simplest one that can give a meaningful, first-order approximation of the process relating numbers of doctorate recipients to numbers of doctorate producers. The model of course has several limitations, including especially the ones we now discuss.

1) The model ignores the *input* of students into education. In Fig. 1, the dashed line entering at the left of box E represents this input, which is not explicitly involved in our analysis. We measure the flow of students only at the *output*, where rE is the number of persons who complete their education for the doctorate during the year.

This first limitation is irrelevant as long as the output of doctorates is actually the limiting factor of the performance of the system. If, instead, doctorate production is limited by the input of students, we can obtain a valid analysis of the process only by including the input in the analytical formulation. Explicitly including the input would also make the model representative of events such as dropouts of students before they achieve the doctorate. In omitting the input we do not imply that the output is, in reality, independent of the input; but we have found that an output-limited analog suffices for studying certain important policy issues, and it is to these issues that our study is directed.

2) The E-box in this model does not distinguish between persons who have recently become engaged in the educational function (through brE) and persons who have worked in education for many years. Not all doctorate-holding faculty and staff members, regardless of the number of years they have been employed, contribute equally to the process of doctorate production. In general, however, we may expect to find a relatively stable distribution among such faculty and staff members with respect to age, number of years on the job, and amount of involvement in the educational process. As long as this distribution does not change significantly from year to year, this limitation does not invalidate the results the model can yield (*2*).

3) The model is defined only for *linear* behavior. The quantities a, b, c, and r are treated as constant coefficients, at least on the average, over any interval of years analyzed, and E and P are taken as multipliers to the first power (not squared, for example). Although the system, in practice, may not behave linearly, we can gain useful understanding of its operation by starting with linear analysis, which we can apply sequentially, if necessary, to subintervals of time over which the behavior does remain essentially linear. Our objectives in this study can be reached without adding the complications of variable coefficients and nonlinear analysis.

4) The model does not directly represent measures of quality. The quality of education is of course a matter of primary concern, and much of educational policy necessarily is directed toward the improvement of faculties, curricula, and facilities, and toward other measures needed to insure first-rate education. In certain respects, however, quality does relate to numbers, as, for example, through the number of doctorate-holding faculty members available to educate and train graduate students. In this sense the production ratio r bears upon the assessment of quality. If the value of r is rising rapidly in some particular field of science, the policy-maker should ask whether teachers in that field can rapidly increase the number of doctoral candidates they handle without impairing the quality of the education. On the other hand, a rapidly diminishing value of r in a particular field might signal the possibility of increasing the average number of doctoral candidates supervised by a faculty member.

Mathematical Analysis

We analyze the behavior of the feedback model by using difference equations to derive expressions for E and P as functions of a, b, c, and r. The expressions include the initial values, E_0 and P_0, observed in a starting year $k = 0$, and yield the values of E_k and P_k, reached in the kth year.

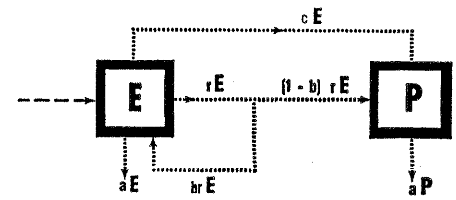

Fig. 1. The feedback model.

To set up the difference equations, we adopt a unit interval of 1 year, and we relate values of E and of P in the year $k + 1$ to their values in the preceding year:

$$E_{k+1} = (1 + br - a - c)\,E_k$$
$$P_{k+1} = (1 - a)\,P_k + [(1 - b)\,r + c]\,E_k.$$

This pair of simultaneous difference equations has the unique solution:

$$E_k = (1 + br - a - c)^k\,E_0 \qquad (1)$$

$$P_k = (1 - a)^k P_0 + \left[(1 + br - a - c)^k - (1 - a)^k\right]\left[\frac{(1 - b)r + c}{br - c}\right]E_0. \qquad (2)$$

The sum of Eqs. 1 and 2 gives the total number of doctoral scientists and engineers in year k.

In order to make the behavior of the feedback system more apparent, we rewrite Eqs. 1 and 2, using a set of system parameters defined as follows:

production growth rate,

$$\alpha = r\left[b - \frac{a + c}{r}\right]; \qquad (3)$$

damping factor,

$$\beta = \frac{1 - a}{1 + \alpha}; \qquad (4)$$

equilibrium ratio of P/E,

$$\gamma = \frac{1}{b - c/r} - 1. \qquad (5)$$

In terms of these parameters, Eqs. 1 and 2 can be written, respectively:

$$E_k/E_0 = (1 + \alpha)^k \qquad (1a)$$

$$P_k/P_0 = (1 + \alpha)^k\left[\frac{\gamma + (P_0/E_0 - \gamma)\beta^k}{P_0/E_0}\right]. \qquad (2a)$$

Similarly, the total number of doctorates in year k can be written:

$$(P_k + E_k)/(P_0 + E_0) = (1 + \alpha)^k\left[\frac{(1 + \gamma) + (P_0/E_0 - \gamma)\beta^k}{1 + P_0/E_0}\right]. \qquad (6)$$

The relations expressed by Eqs. 1*a* and 3 are illustrated graphically in Fig. 2, which shows a set of curves

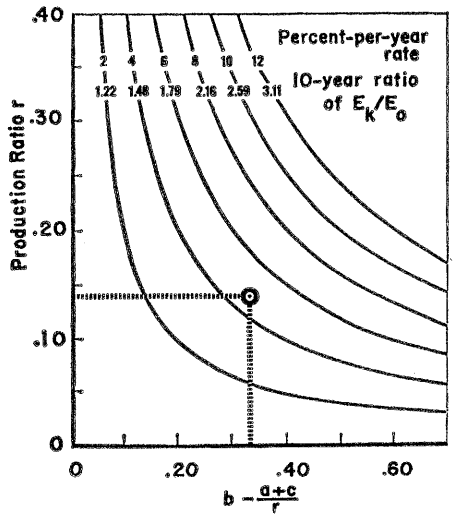

Fig. 2. Curves of production growth rate, expressed as percent-per-year rate of growth and as 10-year ratios of E_k/E_0.

calculated for values of α ranging from 0.02 to 0.12. Corresponding percentage values are marked on the curves, as are the associated values of the ratio E_k/E_0 for a period of $k = 10$ years. The percent-per-year rate of growth, 100 α, by analogy, is the "compound interest" rate at which the "principal" increases from E_0 to E_k in k years. Further, within limitations we have discussed, the same growth rate applies to doctorate production, which increases from rE_0 to rE_k in k years.

An illustrative datum point is shown in Fig. 2 at the values $r = 0.14$ and

$$b - \frac{a + c}{r} = 0.34.$$

By interpolation, we find that this point represents an annual growth rate of about 4.7 percent and a ratio of 1.6, or 60 percent increase, in 10 years.

The meaning of Eqs. 2a and 6 becomes clearer when we examine them in the light of the following equation:

$$P_k/E_k = \gamma + (P_0/E_0 - \gamma)\beta^k. \qquad (7)$$

If the initial ratio P_0/E_0 is equal to the equilibrium ratio γ, then the second term in the right-hand member of Eq. 7 vanishes, and P_k/E_k is simply equal to γ in all years. However, if the initial ratio differs from the equilibrium ratio, the system is "disturbed," so to speak, by the second term in the right-hand member of Eq. 7, and this disturbance dies out over a period of years, at a rate determined by β, the damping factor.

The equilibrium ratio is determined by three variables, b, c, and r (as long as a remains the same for both boxes). If the values of these variables have remained constant over a period of many years, the doctorates have become distributed between E and P in some fixed ratio, which represents a stable, equilibrium condition of the system. As long as the system is in equilibrium, the numbers of persons in the P-box and in the entire system increase proportionately at exactly the same rate as the number in the E-box does. We can see this behavior in Eqs. 2a and 6, in which the second term inside the square brackets, like the second term in the right-hand member of Eq. 7, vanishes and thus takes out the time-dependent factor β^k, leaving the bracketed expression equal to unity. Contrarily, if the system is not in equilibrium, the magnitudes of E and P vary at different rates, in a complicated fashion, and the growth of the entire population, $E + P$, cannot be expressed by any simple, exponential percent-per-year rate of growth.

In the study of policy issues, these system parameters can provide useful foresight. They help us to "look inside the black box" to see what the system is likely to do in the future in the way of producing and distributing doctorates. Even with a quite limited set of measured values we can make some predictions concerning rates and directions of change. If we should find that the system is not now operating in equilibrium, we could tell whether P is increasing or decreasing in relation to E, and at what rate. Then, if we wished to do so, we could recommend policies that would affect the values of b, r, and c in such a way as to shift the trend toward a more "desirable" distribution of doctorates.

Measuring the Variables

The utility of a model depends considerably upon the availability of measured values of the variables involved. In this study we have obtained several such values by combining and analyzing data, both published and unpublished, collected from sources cited in the references.

Table 1 summarizes overall values of the variables for 1961, the most recent year for which we have been able to compile a set of reasonably accurate data. These values relate to all fields of science and engineering combined, to all colleges and universities combined, and to all types of activity combined. Subsequent sections of this article give measurement details and particular values of the variables for individual fields, for certain academic segments, and for various activities, such as teaching, research, and development.

In 1961, about 7.1×10^3 (rE) persons in the United States received doctoral degrees in engineering and science—here "science" includes mathematics, physical and biological sciences, and social sciences (not including history) (*3*, p. 12; *4*). Also in that year, about 95×10^3 persons already held doctoral degrees in these same fields and were engaged in professional work.

About 50×10^3 [as measured on a full-time-equivalent basis (*5*)] of these doctoral scientists and engineers were employed in colleges and universities. In using this figure for the value of E in Table 1, we assume that the number of persons in colleges and universities who are not engaged in educational work is approximately offset by the number of persons in other institutions, such as research foundations, who do some educational work.

From these values for E and rE we obtain the value 0.14 for the production ratio r. At first sight, this value may appear surprisingly low. Why should seven doctorate-holding educators, on the average, produce only one new doctorate each year? The answer is that they also do many other things, including teaching many hundreds of thousands of students in science and engineering courses at all academic levels.

Values of b, the feedback ratio, vary considerably among different fields, and also depend strongly upon the type of activity undertaken by the new doctorate recipient when he is "fed back." Some of these recipients, for example, hold postdoctoral fellowships, and therefore serve the educational function in a certain restricted sense only. When we exclude these fellowship holders from the count, but include all other activities, we get an overall value of 0.48 for b in 1961. (See footnote to Table 1.) Thus, for all fields combined, about half of the new doctoral scientists and engineers have their first employment in colleges and universities.

The illustrative datum point shown in Fig. 2 is located in accordance with the values given in Table 1 and therefore represents the actual operating point for the system in 1961. If the doctorate-producing system should continue to operate at this point during a period of several years, the average rate of increase in staff members with doctorates would amount to about 4.7 percent per year, as we have already noted. As long as r remains constant, this same growth rate applies also to the number of new degrees produced. If the doctorate output after 1961 should increase at a rate greater than 4.7 percent per year (as indeed it has been doing), then the operating point would move up to some new position, located on the curve that corresponds to the higher rate.

Attrition Rate

Table 1 shows an estimated attrition rate, a, of 0.02 for doctoral scientists and engineers in the United States in 1961. This figure, determined mainly from demographic data, combines four separately estimated components: 0.009 for death, 0.006 for retirement, 0.002 for transfer to other occupations, and 0.003 for conversion of the first three component figures to full-time-equivalent counts.

To measure the attrition attributable to death, we use tables of survival rates (*6*), we assume that the median age at which persons receive doctoral degrees is 31 years (*7*; *8*, p. 13), and we estimate attrition for each age group separately. For example, persons born in 1928 reached age 31 in 1959, and on the average they would have received their doctorates in that year. Of the group who received the doctorate in 1959, the number who died in 1961 equals the number surviving in 1960 minus the number surviving in 1961. More specifically, in this example we take the survival-per-thousand value for persons born in 1928 and reaching age 32, we subtract the survival-per-thousand value for persons born in 1928 and reaching age 33, and we multiply this difference by the number, in thousands, of science and engineering doctorates awarded in 1959.

The entire calculation is expressed by the equation

$$N_{1961} = \Sigma(S_n{}^m - S_n{}^{m+1})D_y, \qquad (8)$$

Table 1. Overall values of variables for 1961, based on full-time-equivalent counts of the numbers of persons involved.

Variable	Value
E	50×10^3
P	45×10^3
rE	7.1×10^3
r	0.14
b*	.48
c	−0.001
a	.02

* Excludes postdoctorate fellowship holders; see Table 5, which also excludes them, and Table 4, which includes them.

in which N_{1961} is the number of science and engineering doctors who died in 1961; $S_n{}^m$ is a survival rate—the number of persons per thousand who were born in year n and were surviving at age m years; and D_y is the number, in thousands, of science and engineering doctorates awarded in year y. The summation is taken over the following values: y, from 1960 to 1920; n, from 1929 to 1889; m, from 31 to 71. This calculation yields 840 deaths of science and engineering doctors in 1961, or 0.009 of the 95×10^3 such doctors living in that year.

We estimate retirements in a similar way, using an average retirement age of 65 years. For every thousand persons born in 1896, 701 reached (in 1927) the median doctoral age of 31 years, and 402 reached (in 1961) the retirement age of 65 years. The fraction of these individuals who were 31 years old in 1927 and who reached retirement age 34 years later is 0.575 (402 divided by 701). We multiply this fraction by 976, the number of science and engineering doctorates granted in 1927, and get 561 for the estimated number of retirements in 1961. This number equals 0.006 of the 95×10^3 total (*9*).

Our estimate of 0.015 for the attrition resulting from both death and retirement agrees reasonably well with estimates, given elsewhere (*10*, p. 14), which indicate that about 1.5 percent of all engineers and 1 percent of all scientists leave the field each year as a result of these causes. Relative to "all" scientists and engineers, those who hold doctorates start their professional careers later, on the average, and work about 20 percent fewer years before reaching retirement age. A corresponding correction, weighted for the relative numbers of scientists and engineers, brings the attrition figures cited into approximate agreement with our estimate.

Some doctors of science and engineering transfer away from professional work in their fields before they retire, and thereby add another component to the attrition. We have found no direct measure of this component. For all scientists and engineers, the transfer attrition has been estimated to lie between ½ and 1 percent (*10*, p. 15). If doctors alone were considered, presumably the attrition would be less, because doctors generally have a heavier investment in education and a stronger commitment to their field than nondoctors, and are in greater demand for faculty positions. Such considerations lead us to estimate a value of about 0.002 for the transfer attrition for doctors.

All the components discussed above are based upon the number of different persons involved, regardless of the fraction of time they spend in professional work. The full-time-equivalent effort they contribute is less than full-time effort for all the persons involved (see *5*). For example, some of the older persons who are counted as full-time workers actually work less than full time, owing to illness or to personal activities outside their regular employment. The difference increases the full-time-equivalent attrition rate by about 0.003, bringing the combined attrition rate up to about 0.02, the figure we use.

Transfer Rate

In order to measure the transfer rate, c, we conducted a pilot study of the movement of doctoral scientists into and out of colleges and universities between 1960 and 1962 (*11*). From questionnaires filled out for the National Register of Scientific and Technical Personnel, we obtained the responses of persons who had registered both in 1960 and in 1962 and had provided usable data, in both years, with respect to employer and field of specialization.

The resulting sample covers about 45×10^3 persons, approximately half of all persons holding doctorates in science and engineering in 1960. Within this sample, about 46 percent of the persons were employed in educational institutions. The absolute number was larger by 35 in 1962 than in 1960. This difference yields a net annual transfer rate of about −0.09 percent; the minus sign, in our feedback analysis, means a net flow back into the E-box. In view of statistical and definitional uncertainties involved, we use the rounded figure $c = -0.001$ as a reasonable estimate of the overall value (see Table 1).

The National Register, designed for selective coverage, includes a large fraction of the nation's natural scientists but only a small and uncertain sample of social scientists and engineers. These last two categories contain about one-fourth of all scientists and engineers, as defined in this article. Nevertheless, the Register data give us a preliminary indication of variations in transfer rate among different academic fields. The results are as follows: $c = +0.001$ in the physical sciences (engineering is not included); $c = -0.003$ in the life sciences, apart from the social sciences; and $c = +0.006$ in the single field of mathematics.

Variations as large as these can produce significant effects upon the behavior of the system. In the doctorate-production growth rate, illustrated in Fig. 2, c adds algebraically to a in its effect upon the location of the operating point. In the equilibrium ratio, defined in Eq. 5, the value of c is multiplied by $1/r$, which amounts to multiplication by a factor of 5 or 10 for many cases studied. Especially if c is positive in some cases and negative in others, ignoring its effect can lead to serious errors in conclusions drawn from the feedback model. Therefore, the continuing study of transfers is of considerable importance (*11*).

Production Ratio

In order to determine the production ratio r, we need to know the number (rE) of doctorates produced and the number (E) of doctoral scientists and engineers who perform the educational function. A National Science Foundation study (*12*) of 306 institutions awarding graduate degrees in science and engineering provided data from which we derived the number of staff members with doctorates employed in colleges and universities in 1961 (*13*). Of all scientists and engineers employed by colleges and universities, more than four-fifths, measured on a full-time-equivalent basis, are employed by these 306 institutions. Using this sample, we estimated the total number of academic scientists and engineers and their distribution by academic field. Then, in order to determine the proportion of staff members who held doctorates, we examined the catalogs of a sample of typical institutions and applied the proportion found in these sample institutions to the total number of scientists and engineers employed by colleges and universities. The results agree closely with other estimates (*14*) and yield the overall value $r = 0.14$.

Different definitions of E, corresponding to different academic segments and functions, give different values of r. Not all institutions of higher education grant graduate degrees. Also, the modern university campus consists not of a single entity but, rather, of several types of organizational components. Therefore, we distinguish between "colleges" and "universities," and also between "doctorate-granting universities" and "doctorate-granting universities proper." This last-named category excludes research centers and agricultural experiment stations which operate under federal contract, and therefore includes fewer staff members with doctorates than are found in "doctorate granting universities." Finally, we introduce the category "graduate schools of doctorate-granting universities proper," which covers all graduate academic units in the university, including medical and dental schools, but excludes the federal-contract centers and stations mentioned above.

The type of work activity, also, affects the definition of E, and thereby the value of r. In the educational system, doctoral scientists and engineers do many kinds of work, including teaching, basic research, applied research and development, and administration. Some persons divide their time among different activities. Therefore, we use full-time-equivalent numbers to measure the relative amounts of effort devoted to these activities.

In Table 2, the figures in parentheses are the numbers, in thousands, of science and engineering doctors (in full-time equivalents) for 1961, distributed by the type of activity and by academic segment. The figure immediately above each figure in parentheses is the corresponding value of r, based upon $rE = 7080$, the number of science and engineering doctorates granted in 1961.

Of the total of 50×10^3 doctorate-holding scientists and engineers of Table 2, about 41×10^3 worked in universities that grant doctorates. Of this latter number, about four-fifths, or 34×10^3 persons, were working in doctorate-granting institutions proper, a category which includes schools of medicine, dentistry, public health, engineering, and arts and science. About one-fifth of the 41×10^3 were working in federal-contract research centers and agricultural experiment stations, and were engaged primarily in research and development. Graduate schools accounted for some 21×10^3, equivalent to about two-thirds of the staff members with doctorates in doctorate-granting universities proper and to about half such staff members in doctorate-granting universities.

Distributions by type of work activity, also, are shown in Table 2. Of

Table 2. Values of the production ratio r—number of doctoral degrees granted per doctorate-holding staff member—for all fields of science and engineering in 1961, tabulated by type of activity and by academic segment. The numerator of r in all cases is 7080, the number of doctoral degrees in science and engineering granted in 1961. The denominator in each case is the figure shown in parentheses, the number (in thousands) of doctorate-holding staff members expressed in full-time equivalents.

Type of activity	Academic segment			
	Graduate schools of doctorate-granting universities proper*	Doctorate-granting universities proper*	Doctorate-granting universities	All colleges and universities
Teaching	1.0 (7)	0.37 (19)	0.35 (20)	0.26 (27)
Teaching + basic research	0.39 (18)	0.23 (31)	0.22 (32)	0.18 (40)
Teaching + all research and development	0.35 (20)	0.21 (33)	0.18 (39)	0.15 (47)
All activities†	0.34 (21)	0.21 (34)	0.17 (41)	0.14 (50)

* Excludes research centers and agricultural experiment stations operating under federal contract.
† Includes administration, community activity, and public service.

the total 50×10^3 doctoral scientists and engineers, an estimated 27×10^3 were engaged directly in teaching, 13×10^3 were engaged in basic research, 7×10^3 in applied research and development, and 3×10^3 in administration, community activities, and public service. In Table 2 these figures are added as components of successively larger categories.

At doctorate-granting universities, the staff members with doctorates devoted about equal amounts of time to teaching and to research and development. In these institutions, about 20×10^3 (full-time-equivalent) of the staff members with doctorates engaged in teaching and 19×10^3 engaged in research and development.

The graduate schools account for a major part of the effort in basic research. Such research occupied 11×10^3 of the staff members with doctorates at graduate schools in 1961, or about 85 percent of the 13×10^3 engaged in basic research in all colleges and universities combined.

All the distributions discussed are reflected in r. Because inclusive categories are used, the values of r decrease in order with successive categories of academic segment (from left to right in Table 2), and with successive categories of activity (from top to bottom). The largest value of r shown is 1.0; this value means that the number of doctorates produced during the year was about equal to the full-time-equivalent number of faculty members with doctorates in the graduate schools of doctorate-producing universities.

The availability of r values tabulated in this way enables the policy-maker to examine the feedback process in relation to several relevant questions concerning the employment and utilization of doctoral scientists and engineers in the academic sector of the economy. Effects he can study quantitatively include, for example, the relative concentration of the doctorate-holding population in the doctorate-granting universities and the proportioning of efforts between teaching and research in institutions of different kinds.

Table 3 shows some values of r for several different academic fields. Columns 2 and 3 give the number of doctoral degrees granted in 1961 and the full-time-equivalent number of faculty and staff members with doctorates in colleges and universities. The ratio of these numbers gives the corresponding value of r shown in column 4.

Table 3. Values of the production ratio r—number of doctoral degrees granted per doctorate-holding staff member—in science and engineering in 1961, for all activities and segments in colleges and universities, tabulated by academic field.

Academic field	Doctoral degrees granted (1000's)	Doctorate-holding staff of scientists and engineers (in full-time equivalents, in 1000's)*	r
Mathematics	0.36	3.9	0.09
Physics, astronomy, and earth sciences	.86	7.7	.11
Chemistry	1.14	7.1	.16
Engineering	1.01	4.8	.21
All physical sciences, mathematics, and engineering	3.37	24.	.14
Biological sciences + agricultural and health sciences†	1.80	14.	.13
Psychology	0.87	3.6	.24
Social sciences	1.04	8.5	.12
All life sciences	3.71	26.	.14
All fields of science and engineering	7.08	50.	.14

* Values rounded to two significant figures. † We were unable to obtain the data needed to separate agricultural and health sciences from biological sciences.

The physical sciences, mathematics, and engineering combined accounted for 3.37×10^3 doctoral degrees in 1961, and the life sciences accounted for 3.71×10^3. Each of these two major divisions has a production ratio of $r = 0.14$, a value which is identical with the overall value.

Individual values of r vary over a considerable range. The largest, 0.24, for psychology, is 2.5 times the smallest, 0.09, for mathematics. Many factors affect the distribution of values of r among academic fields—for example, the nature of the graduate work required to obtain the doctorate, the extent to which the field attracts graduate students, and the amount of undergraduate teaching expected of the graduate school faculty. The value of r probably also reflects the relative amount of financial support available for student fellowships and for research grants in the field. Such factors suggest ways in which the behavior of the system may be modified or adapted to meet new needs.

Feedback Ratio

In this section we report values of the feedback ratio, b, derived from survey data obtained by the National Academy of Sciences–National Research Council (*3*, p. 48; *15*).

We give values of b for different academic fields and types of activity, and for a series of years, 1957 through 1962. Owing to limitations in the data available, we do not distinguish among different types of academic institutions or among different academic segments into which the individuals with doctorates feed. If an individual's first employer, after he receives the doctorate, is a college or university, we count him as feeding back into the E-box, no matter what part of the college or university employs him.

Table 4 shows values of b, tabulated by type of activity and by academic field, for 1962, the earliest year for which data are available which permit calculation of the feedback ratio for different types of activity. All the values shown are derived from full-time-equivalent numbers of persons engaged in the type of activity indicated (*16*). The basic data cover a sample of 6608 doctoral-degree recipients, about 84 percent of all science and engineering doctorates granted in 1962. Therefore, these values of b can be used with considerable confidence to represent the feedback in the actual system.

We divide the feedback ratio into five additive components: b_r, for research and development; b_t, for teaching; b_f, for fellowships; b_o, for other, a category which includes administration and professional services; and b_n, not specified, a category which accounts for the survey respondents who gave insufficient information. Although, in general, b_t is the largest feedback component and b_o is the smallest, the relative magnitudes of the components vary widely. The amount of feedback is significantly smaller ($b = 0.44$) for the physical sciences, mathematics, and engineering fields than it is for the life sciences ($b = 0.56$). Among the individual fields shown, mathematics and the social sciences have the largest values of b and engineering and chemistry have the smallest. The feedback ratio for chemistry would have been even smaller had it not been for the high feedback into fellowships ($b_f = 0.20$). Only one other field, biological sciences, shows as large a feedback for fellowships.

Among different fields, wide variations are seen in b_t/b_r, the ratio of feedback for teaching and feedback for research and development. This ratio is largest, by a factor of 4 or 5, for mathematics and the social sciences, the fields that have the largest overall feedback ratio. This behavior is not surprising, because these fields are to a considerable extent service fields; that is to say, they provide courses taken by large numbers of undergraduate students who are not majoring in these fields. The categories of (i) physics, astronomy, and the earth sciences and (ii) the agricultural and health sciences have the smallest b_t/b_r values—about equal to or less than unity. The proportionately larger number of persons going into research in these fields probably is related to the large amount of research support available.

The feedback ratios reflect relative magnitudes of need, demand, and competition for doctoral scientists and engineers among the several employing sectors of the economy. Thus, a large feedback ratio may indicate a high need and demand by colleges and universities and a low demand by other employers; or it may indicate a low ability of other employers to compete with colleges and universities under prevailing conditions. Conversely, a small feedback ratio may indicate a low demand by colleges and universities, or a low ability of colleges and universities to compete, under prevailing conditions of demand, with other employers. These relationships show themselves, for example, in the relatively low feedback for chemistry, a field in which industrial opportunities abound, and in the high feedback for mathematics, a field in which academic opportunities are relatively numerous.

Recent trends in the feedback ratio are of considerable interest, especially in view of the expanding national needs for scientists and engineers during the past several years. Table 5 shows a time series of values of the doctoral feedback ratio b, for 1957 through 1962, tabulated by academic field.

The values of b given in Table 5 do not take into account the persons who held fellowships during their first postdoctoral year. Such individuals were not included in the survey data prior to 1962. Therefore, in order to make the 1962 values consistent with values for earlier years, we adjusted the 1962 values by subtracting the number of such individuals both from the number of degree recipients and from the number of persons fed back into the E-box. This adjustment changes the 1962 value of b from 0.50 (Table 4) to 0.47 (Table 5).

The physical sciences, mathematics, and engineering show a significant rise in feedback ratio between 1957 and 1959. This rise is probably associated with the increasing national interest in graduate education in these fields, along with the increasing availability of federal funds for research in colleges and universities. Following the peak in 1959, these feedback ratios returned to about their 1957 values. The decline between 1959 and 1962 probably arises in part from the national commitment to explore the moon, and the resulting expansion of space programs in industry and in the federal government.

Contrary to certain views that have been expressed in public debate, however, the feedback ratios in the physical sciences, mathematics, and engineering are now about equal to, or greater than, the values in 1957. The fraction of new doctorate recipients going into colleges and universities has not declined. A decline is seen in the values of b for the biological sciences and for the agricultural and health sciences, but this decline may be attributable mainly to the increasing number of postdoctoral fellowships, which are not reflected in Table 5.

Depicting Policy Alternatives

Now, combining analysis with measurements, we show how the feedback model may be used to guide the making of policy. We cite actual cases as examples, and we depict certain alternatives that governmental advisers and policy-makers have faced in recent years.

Table 4. Values of doctoral feedback ratio, b, for science and engineering in 1962, for all academic segments tabulated by type of activity and by academic field. The values are based on data from about 84 percent of all science and engineering doctorate recipients during the year, and are derived from full-time-equivalent numbers of persons engaged in each type of activity. Because of rounding, the total feedback, b, may differ from the sum of its components.

Academic field	Number of degree recipients sampled	Feedback by type of activity					Total feedback to colleges and universities, b
		Research and development, b_r	Teaching, b_t	Fellowship, b_f	Other, b_o	Not specified, b_n	
Mathematics	337	0.12	0.44	0.07	0.03	0.02	0.69
Physics, astronomy, and earth sciences	792	.16	.18	.09	.01	.03	.46
Chemistry	1072	.04	.12	.20	.00	.01	.38
Engineering	1048	.10	.24	.03	.00	.02	.40
All physical sciences, mathematics, and engineering	3249	.10	.21	.11	.01	.02	.44
Biological sciences	1271	.13	.19	.20	.02	.03	.57
Agricultural and health sciences	423	.21	.14	.06	.03	.04	.49
Psychology	717	.11	.20	.07	.07	.02	.46
Social sciences	948	.09	.46	.02	.03	.04	.65
All life sciences	3359	.12	.26	.11	.04	.03	.56
All fields of science and engineering	6608 *	.11	.23	.11	.02	.03	.50

* The total number of doctoral degrees awarded in 1962 in all fields of science and engineering was 7880.

Political issues, by their very nature, involve competing values, pro or con, like or dislike. Further, dynamic systems such as the one that produces academic degrees contain many interrelated components; each depends, in one way or another, upon all the rest. When an issue of public policy concerns many persons and groups, as it usually does, and when that issue bears upon the dynamic behavior of a complex system, consideration of that issue tends to become fragmented. One voice vigorously defends or opposes a particular value judgment relating to one component of the system, while another voice champions some other value judgment that relates to a quite different component.

Table 5. Time series (1957–62) of values for the doctoral feedback ratio *b*, modified by exclusion of postdoctoral fellowship holders, tabulated by academic field.

Academic field	1957	1958	1959	1960	1961	1962
Mathematics	0.70	0.74	0.74	0.64	0.66	0.69
Physics, astronomy, and earth sciences	.43	.48	.51	.46	.45	.45
Chemistry	.23	.25	.31	.21	.24	.24
Engineering	.37	.43	.47	.42	.39	.39
All physical sciences, mathematics, and engineering	.36	.41	.45	.38	.39	.39
Biological sciences	.62	.59	.63	.58	.57	.52
Agricultural and health sciences	.63	.64	.59	.48	.51	.47
Psychology	.46	.46	.47	.44	.47	.45
Social sciences	.69	.76	.77	.67	.69	.65
All life sciences	.61	.61	.63	.56	.58	.54
All fields of science and engineering	.49	.51	.54	.48	.48	.47

Such fragmentation in the sphere of science policy is illustrated by the following statements, which are representative of competing views concerning the production and distribution of science doctorates.

1) Not enough (or too many) recipients of the doctor's degree are returning to colleges and universities for employment.

2) Each faculty member with a doctorate is, on the average, turning out too few (or too many) new doctorates.

3) Too many (or not enough) such faculty members are transferring to employment outside universities.

4) Faculty members holding a doctorate should (or should not) be encouraged to continue teaching, at least part time, beyond their retirement age.

5) Ten years from now the nation should produce two times (or x times, or only half) as many doctorates per year as it does now.

These statements relate, respectively, to five of the quantities used in our model—b, r, c, a, and α. Within the stated limitations of the model, including the assumption that E_0 and P_0 are fixed in advance, four and only four of these quantities are amenable to independent control. If we prescribe values for the first four, for example, then the fifth one, α, is fully determined, as Eq. 3 shows; there is no remaining choice. Even if we fix only one of the values, we have restricted the range of values that can be chosen for the remaining quantities.

If five different policy-makers independently choose "values" for five quantities, the conditions they collectively specify are likely to be incompatible with each other. Or, if they attempt to make their choices one at a time and report their decisions to the next policy-maker in line, the policy alternatives that remain available late in the process may be entirely unacceptable.

The feedback model offers a unified representation of all possible alternatives for each of the several components of the policy problem. We portray the alternatives by means of a set of interrelated graphs, in which each coordinate and each curve represents a single quantity. In Figs. 3 and 4, which illustrate our method, one coordinate represents the feedback ratio b and the other coordinate represents the production ratio r. The single curve in Fig. 3 (left) represents a prescribed value of the growth rate α, expressed indirectly in terms of the number of doctorates to be produced in a stated future year. The pairs of curves in Fig. 3 (middle) and Fig. 3 (right) represent alternatives in the value of the growth rate. The set of curves in Fig. 4 represents alternatives in the value of the transfer rate c for a single, prescribed value of growth rate. Other graphical combinations suggest themselves.

Each of these graphs contains a set of arrows emanating from a datum point, which represents the initial condition of the system, and ending on a curve, which represents an operating characteristic of the system. Each arrow represents an alternative path along which the system can move from its initial condition to a condition that will yield the output of doctorates associated with the corresponding curve.

In its actual behavior, the system is not likely to jump suddenly over the entire "distance" represented by an arrow, although it may do so if the distance is small, or if the system is subjected to drastic forces such as the sharp drop and subsequent sharp rise in university enrollments experienced in connection with World War II. Normally the system approaches a new operating curve by passing through several intermediate points in successive years. In that case, some of the operating points will overshoot the curve, if that curve correctly represents the *average* behavior during the entire period specified.

Correspondingly, we could project future behavior by calculating the operating points for each year separately, instead of using analytic formulas, such as Eqs. 3 and 4, derived from difference equations. We believe, however, that the unity and simplicity of presentation gained by using the equations and graphs make our method more useful for exploring policy alternatives and estimating their consequences. Then, if greater detail is needed, year-by-year calculations can be carried through.

Illustrative Examples

From 1961 to 1963 several governmental agencies and advisory bodies were conducting studies concerning the nation's needs for scientists and engineers throughout this decade. Those studies stimulated the development of our feedback analysis and yielded some of the information we draw upon to illustrate the use of the model as a policy guide.

In Figs. 3 and 4, which embody a self-consistent set of data, all initial conditions (points) relate to 1961 and all operating characteristics (curves) relate to 1970. Figure 3 (left) covers all fields of science and engineering; Fig. 3 (middle) covers one group of fields—engineering, mathematics, and physical sciences (EMP); and Figs. 3 (right) and 4 cover a single field—mathematics.

The sets of arrows shown in Fig. 3 represent alternative policies of three kinds: policy A holds the feedback ratio constant, on the average, throughout the period considered; policy C holds the production ratio constant; and policy B is a mixed strategy in which both the feedback ratio and the production ratio are allowed to vary.

In Fig. 3 (left) the operating curve corresponds to the production of 12.4×10^3 doctorates in science and engineering in 1970. This is a "projected" number based upon trends shown during past years (*17*). The arrows originate at the 1961 operating point $b_o = 0.48$, $r_o = 0.14$, and move to the operating curve along three different paths, which represent three alternatives.

1) *Policy A*. The feedback ratio b is held constant at 0.48, in which case the value of r must increase from 0.14 to a value that averages slightly over 0.15 throughout the decade.

2) *Policy B*. Both r and b increase in such a way that $b = 0.54$ and $r = 0.15$, on the average, throughout the decade.

3) *Policy C*. The production ratio r is held constant at 0.14, in which case the value of b must increase from 0.48 to a value that averages 0.60.

Figure 3 (middle) relates to doctorates in the fields of engineering, mathematics, and physical sciences. This example shows two operating curves, corresponding respectively to 5.9 and 7.5×10^3 doctorates in these fields in 1970. The number 5.9×10^3 is an average of two independent projections—5.7×10^3 by the Office of Education and 6.1×10^3 by the National Science Foundation—which are subparts of the corresponding projections discussed in connection with Fig. 3 (left) (*17*). Thus, 5.9×10^3 is a reasonable value for the "projected" number of doctorates in these fields in 1970, the number expected if trends observed up to 1961 continue in effect during the decade. In contrast, the number 7.5×10^3, associated with the upper curve in Fig. 3 (middle), represents a "recommended" goal put forth by the President's Science Advisory Committee (*18*).

In Fig. 3 (middle) all the arrows originate at the 1961 operating point for doctorates in engineering, mathematics, and physical science, $r_o = 0.14$, $b_o = 0.39$. Arrows A, B_1, and C represent alternative policies designed to achieve the "projected" 5.9×10^3 doctorates in these fields, and arrow B_2 represents a policy designed to achieve the "recommended" 7.5×10^3. These policies are as follows.

1) *Policy A*. The feedback ratio is held constant at 0.39; then r must increase to an average value of 0.17.

2) *Policy B_1*. Both r and b vary simultaneously up to the values $r = 0.15$ and $b = 0.48$, averaged over the decade.

3) *Policy C*. The production ratio is held constant at 0.14; then b must increase up to an average value of 0.60.

4) *Policy B_2*. Both r and b increase up to the average values $r = 0.16$, $b = 0.60$, a pair of values that will yield the "recommended" output of 7.5×10^3 doctorates in these fields in 1970.

Figure 3 (right) relates to doctorates in a single field, mathematics. All the arrows originate at the 1961 operating point for mathematics, $r_o = 0.09$, $b_o = 0.66$. The two curves correspond directly to the two curves shown in Figure 3 (middle), and they were obtained in the same way. The "projected" number is 0.74×10^3, and the number "recommended" by the President's Science Advisory Committee is 1.14×10^3 doctorates in mathematics in 1970. As before, arrows A, B_1, and C represent alternative policies designed to achieve the "projected" number, and arrow B_2 repre-

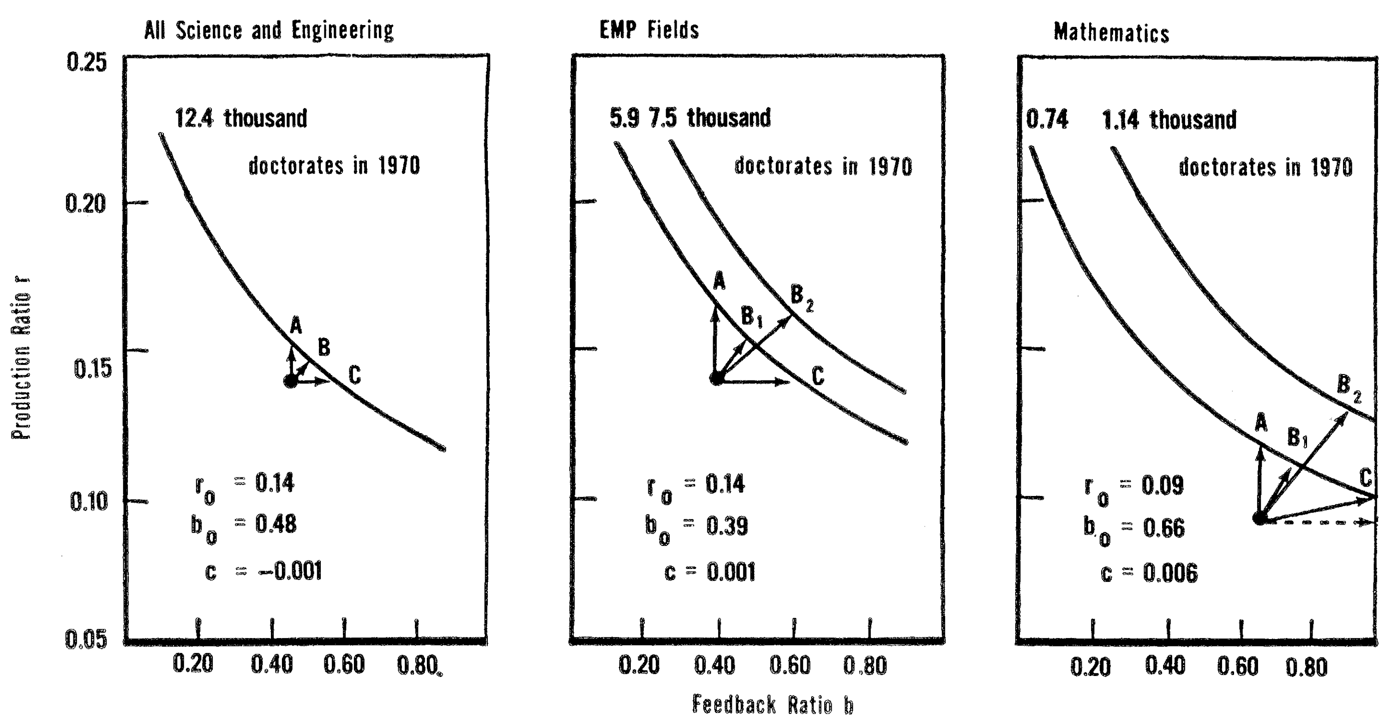

Fig. 3. Graphical representation of alternatives in policy concerning the production of doctorates. Each curve represents the operating characteristic of the system required to yield, in 1970, the number of doctorates designated on that curve. The arrows, which represent the policy alternatives, originate at a point marking the 1961 initial condition r_o, b_o. The attrition rate is $a = 0.02$ for all cases.

sents a possible policy designed to achieve the "recommended" number.

1) *Policy A*. The feedback ratio is held constant at 0.66; then r must increase to an average value of 0.12.

2) *Policy B_1*. Both r and b vary, increasing up to $r = 0.11$ and $b = 0.76$.

3) *Policy C*. In this case even the "projected" number cannot be reached if the production ratio is held constant at an average value of 0.09 during the decade. If *all* doctorates were fed back every year—that is, if $b = 1.00$ throughout the decade—then the average value for the production ratio would have to be $r = 0.10$ in order to yield the "projected" 0.74×10^3 doctorates. In the case of the "recommended" goal of 1.14×10^3, policy C is even farther from being a practical possibility.

4) *Policy B_2*. Both r and b vary simultaneously, up to the values $r = 0.13$, $b = 0.92$.

Figure 4 introduces some alternatives in the transfer rate c, for producing the "recommended" 1.14×10^3 doctorates of mathematics in 1970. The dashed curve represents the initial value $c = 0.006$ and coincides with the upper curve in Fig. 3 (right). The three solid curves represent the alternative values $c = 0$, $c = -0.03$, and $c = -0.06$. The negative values correspond to a net transfer of doctorates into the E-box, as against the net outward transfer observed in 1961. The arrows, which are shorter than arrow B_2 in Fig. 3 (right), show ways in which the "recommended" goal can be reached without the drastic increases in b and r that would be required if the transfer rate were to stay at its 1961 value. The middle arrow in Fig. 4 depicts, for example, the following possible combination of adjustments: change r from 0.09 to 0.12; b from 0.66 to 0.74; and c from 0.006 to -0.03.

All the curves shown in Figs. 3 and 4 lie "above" the operating points; the arrows point toward increased values of the product br and therefore toward increased values of growth rate. If the system were to continue operating exactly as it did in 1961, none of the doctorate-production figures indicated for 1970 would be reached. The only way to reach them, short of introducing factors not represented by the model, is to achieve some sufficient and acceptable combination of changes in the several operating variables. The arrows drawn show some of the possible combinations. Any number of other arrows from point to curve may be drawn.

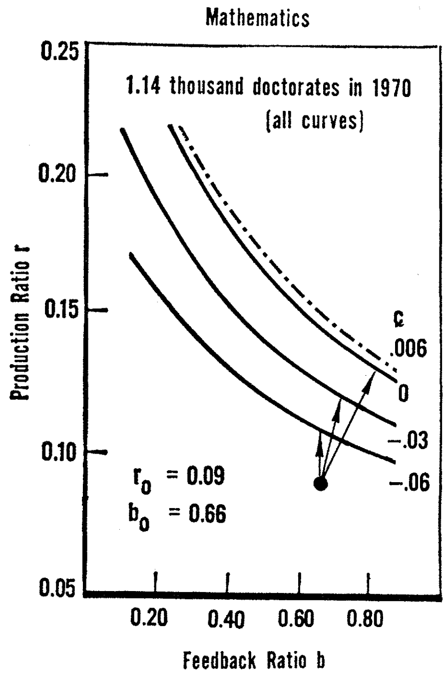

Fig. 4. Graphical representation of alternatives in policy concerning production of doctorates, for different values of the transfer rate c. (See also legend to Fig. 3.)

Within the limitations of the model and the measurements, the arrows represent facts, not values. Only when a particular arrow is chosen, whether explicitly or implicitly, do value judgments enter the policy process. In our examples, such value judgments may be divided into two categories. One category, associated with b and c, relates to the allocation of doctoral scientists and engineers between educational work and other work, to the relative needs for their services, to competitive demands, and to incentives that attract them into one employment or the other. The second category, associated with r, relates to the efficiency and effectiveness of the educational endeavor, to the numbers of students taught by a given number of teachers, and to the amount of student-teacher interaction as it may affect the quality of education for the doctorate.

The relative lengths and directions of the arrows suggest to the policymaker the extent to which such matters of value, in one category or the other, may require special consideration. He can see in Fig. 3 (left), for example, that a relatively small amount of adjustment will suffice to achieve the "projected" output of science and engineering doctorates in the aggregate, whereas major changes will be needed to achieve it in the field of mathematics, as he can see in Fig. 3 (right). In the latter case, in fact, he can see clearly that no amount of adjustment in the feedback ratio alone can lead to the indicated outputs, and that the "recommended" output cited can be achieved only through substantial adjustments in several parts of the doctorate-producing system.

Concluding Observations

This model has proved sufficiently useful in actual applications to warrant its further use in relevant policy deliberations. No elaborate calculations are required in applying it to any specific case. The graphical presentations, labeled in familiar terms, can become meaningful to nontechnical persons and can provide the policymaking community with a base of quantitative relationships among alternatives.

Because of the way in which its several variables are interrelated, the model can extend the usefulness of fragmentary data that may be inadequate for quantification of a single variable taken alone. However, the model also illuminates certain gaps in the available data, and it would become a more precise tool if those gaps were closed. Although we have put major effort into getting measured values of the variables, our results are deficient in many respects. Consequently we hope that manpower surveys in the future will be designed to yield more specific information on ratios and rates of change that measure more directly the time-dependent flows of persons into and out of the work performed by scientists and engineers (*19*).

Thus we conclude by noting that this and similar dynamic models of social systems can serve not only to aid in the development of policy but also to guide the collection of statistical information necessary to undergird policy with a solid factual base.

References and Notes

1. Throughout this article we apply the same value of a to both boxes, E and P. Perhaps a more refined analysis would show that the rate of attrition for persons engaged in education is not identical with the rate for persons doing other kinds of work; a difference might be associated, for example, with differences in the distribution of ages of persons serving different functions. Values of b and c are made self-consistent by restricting b to the first postdoctoral year and c to subsequent years.

2. In the study of particular policy problems, this limitation bears reexamination. If colleges and universities are in fact undergoing rapid changes in the distribution of activities in which their faculty and staff engage, then ignoring the differences among persons at different levels within the *E*-box could lead to serious errors in the resulting analysis.
3. "Doctorate Production in U.S. Universities 1920–1962," *Natl. Acad. Sci.–Natl. Res. Council Publ. No. 1142* (1963).
4. Because of interdisciplinary research activities, and even interdisciplinary teaching activities, we have classified the fields of science quite broadly. We use conventional fields of science because no satisfactory alternative exists. Throughout this article, fields of science are divided into successive levels of classification categories and are distributed as follows: *Science*: physical, life, and social sciences. *Physical sciences*: engineering, mathematics, chemistry, and all other physical sciences; this last category includes physics, astronomy, and earth sciences. *Life sciences*: biological sciences, agricultural sciences, health sciences, psychology, and social sciences; this last category includes sociology, anthropology, archeology, economics, geography, and political science; it does *not* include history.
5. The full-time-equivalent number is the hypothetical number of persons working full time who would contribute the same total effort as that contributed by the persons in the survey, some of whom work part time in education; it is obtained by summing all full-time and part-time efforts, measured in the proportion of time spent by each person.
6. Paul H. Kratz, now employed at the National Bureau of Standards, compiled the tables of survival rates.
7. Use of a median age of 30 years yields essentially the same results [see *3*, p. 44, and "Investing in Scientific Progress" (*8*)].
8. "Investing in Scientific Progress," *Natl. Sci. Found. Rep. NSF 61–27* (1961).
9. If 68 is taken as the retirement age, then attrition due to retirement alone is 0.4 percent.
10. "Scientists, Engineers, and Technicians in the 1960's," *Natl. Sci. Found. Rep. NSF 63–34* (1963).
11. M. Levine and W. L. Koltun, unpublished. We are grateful to Dr. Levine, study director of the National Register of Scientific and Technical Personnel, Office of Economic and Manpower Studies, National Science Foundation, for his assistance and for making the data available. See also "Report of the Select Committee on Government Research of the House of Representatives, Study Number VI, Impact of Federal Research and Development Progress" (Government Printing Office, Washington, D.C., 1964), p. 74.
12. "Reviews of Data on Research and Development," *Natl. Sci. Found. Publ. NSF 63–4, No. 37* (1963).
13. The expression "staff members with doctorates" at colleges and universities includes all persons holding a doctorate, not just traditional faculty members. One impact of research funds is the employment by colleges and universities of many doctoral scientists and engineers to do research and not to teach.
14. "Profiles of Manpower in Science and Technology," *Natl. Sci. Found. Rep. NSF 63–23* (1963).
15. L. R. Harmon, private communication; the series of studies "Teacher Supply and Demand in Universities, Colleges and Junior Colleges," published by the National Education Association, also provides relevant data. We used the National Academy of Sciences–National Research Council data because (i) the NAS–NRC survey concerns the individual doctoral-degree candidate, not the institution, as the NEA survey does; (ii) it is conducted on an annual, calendar-year basis, in contrast to the NEA survey, which is made on a biannual, academic-year basis; (iii) the NAS–NRC survey provides a time series compiled annually since 1957, whereas the NEA time series starts in 1959; (iv) in the NAS–NRC survey, data relevant to the feedback ratio are divided by type of activity in such a way as to yield full-time equivalents, and the data are given in greater detail than are the head-count data provided by the NEA survey; and (v) the NAS–NRC survey is related to the survey that provides the data on doctorate production of our study. In spite of these differences, however, the two sources of primary data yield values for feedback ratio that are in close agreement.
16. The specific survey question on which this determination is based was, "Is your post-doctoral activity *primarily* research, teaching, administration, professional services, fellowships, other (explain)." If an individual indicated more than one activity, we divided his effort equally among these activities. Thus: research = research + ½ (research + teaching) + ½ (research + administration); teaching = teaching + ½ (research + teaching) + ½ (teaching + administration); other = administration + professional services + ½ (research + administration) + ½ (teaching + administration) + other. Corresponding feedback ratios are, therefore, approximately on a full-time-equivalent basis.
17. The Office of Education has estimated that 18.1×10^3 doctor's degrees will be awarded in 1970 in all fields combined. We take 65 percent of this number, which is the average percentage of doctorates given in science and engineering during recent decades; actual annual numbers have departed from this average by only a few percentage points except during periods of war. This first estimate, then, is 11.8×10^3. The National Science Foundation has made a projection of 12.9×10^3 as a likely number. Discussion of these projections lies outside the scope of this article; we merely note that we have averaged the two projections cited and have used the result, 12.4×10^3, as a reasonable "projected" number for illustrating the feedback method.
18. "Meeting Manpower Needs in Science and Technology, Report Number One: Graduate Training in Engineering, Mathematics, and Physical Sciences," *Rep. President's Science Advisory Committee* (Government Printing Office, Washington, D.C., 1962).
19. Our study underscores related recommendations contained in the report "Toward Better Utilization of Scientific and Engineering Talent" (National Academy of Sciences, Washington, D.C., 1964) and enlarged upon by A. O. Gamble in an accompanying paper, which discusses the need for "data organized to show interrelationships among different factors such as . . . characteristics and output of systems for education . . . often expressed usefully as ratios or percentages."

20. The research described in this article was started when R. H. Bolt was associate director for planning and head of the Science Resources Planning Office, National Science Foundation; W. L. Koltun was a staff member of the Science Resources Planning Office; and O. H. Levine was a staff member of the Office of Economic and Statistical Studies, National Science Foundation. Bolt conducted part of the work while a Fellow of the Center for Advanced Study in the Behavioral Sciences, Stanford, California, during 1963 and 1964.

News and Comment

NSF Budget: Cuts by House Group Leave Little Leeway for Growth in Support of Research Projects

The National Science Foundation and its budgetary overseers in the House had a friendly set of hearings this year. The transcripts and report*, released last week by the Independent Offices Appropriations Subcommittee, revealed few quibbles or sharp exchanges at the customarily closed sessions, which were held in March. And in its report the committee took the unusual step of commenting that the top management of NSF is "doing a tremendous job." But the committee's financial verdict was to cut by about one-half the increased funds sought by NSF; and through its accompanying directives the committee made it plain that the scientists and the politicians hold some very different ideas about the role of NSF and the needs of American science.

The gap between the sums requested and the sums voted tells part of the story, but the problem runs considerably deeper than a mere difference of opinion over how much money the Foundation should have at its disposal in the next fiscal year. Briefly, the administration asked Congress to appropriate to NSF $530 million—an increase of $109.6 million over the Foundation's current budget. The size of the requested increase represented a victory for those within the executive who contended that the Foundation should be considered the keystone of federal support for basic research. It

* Independent Offices Appropriations for 1966, part 2, hearings, available without charge from Appropriations Committee, U.S. House of Representatives, Washington, D.C. 20515. (The report is available from Document Room, U.S. House of Representatives, Washington, D.C. 20515.)