manufacturing in four different ranges. (i) up to Rs 50,000, (ii) Rs 50,001–100,000, (iii) Rs 100,001–7.5 lakh, and (iv) over Rs 7.5 lakhs. Canara Bank also presented the general guidelines governing their agricultural finance as crop loan.

The issues such as the impact of the new liberalized global economic policy on the import/export of by-products of the aromatic and medicinal plants, high cost of distillation units especially where the production is low, lack of modern pre- and post-harvest techniques as existing conventional practices consumes considerable man-hours with low input, R&D project funding, and scientist-entrepreneur coordination formed the basis for much heated debate among the participants.

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SCIENTIFIC CORRESPONDENCE

Declining trend in MSc and PhD manpower: Modelling and forecasting

During 1938–47, the number of students graduating with Master's degree in sciences from Indian Universities was about 6560 of which 259 (4%) went on to take PhD degrees[1]. This number increased to 12% (23,934 PhDs out of 206,343 MScs) during 1980–89 (ref. 2).

In this paper we study this growth trend and look for a mathematical model which would capture the process of growth and make projections for future. We note that the observed trend is the result of not only the facilities (such as available seats) but of wider socio-economic factors such as supply and demand. It is this dynamics of growth that we wish to capture in model formulation.

Here we present in brief a model and forecasts for the total numbers of MScs and PhDs. For subject-wise analysis, details of various other models and a comprehensive review of literature, we refer to our report[3].

When a new course of study is introduced those who graduate influence the newcomers; one person talks to another and influences him/her about its utility, two influence four, four influence eight, eight influence sixteen and so on. That is the number of people who are convinced about the utility of the course grows. This mechanism of growth is similar to the colony of biological cells in a medium, which grows through cell division and is described by the logistic equation

$$dN/dt = qN\,[1-(N/M)], \qquad (1)$$

where M in biological growth denotes the carrying capacity of the environment and in the context of MScs and PhDs, represents the total possible number of people who ultimately acquire the degrees. N is the number of degree-holders at time t and q is a constant growth parameter. The growth follows a S-curve and is such that it is almost exponential in the beginning, slowly tapering off and ultimately vanishing when the total number N reaches M.

The above mechanism also holds for the growth of a new product, technology, or idea, where the person who adopts an idea influences another, two influence four and so on. This can be interpreted as a growth which takes place in any socio-economic environment through the interaction between those who have adopted the product N and those who are potential adopters, $(M-N)$. In fact, equation (1) which was formulated by Verhulst as early as 1835 for biological growth is known as the Mansfield model[4] of technology diffusion and is extensively used in modelling new product diffusion[5–8]. The mechanism of growth of an academic discipline is similar to that of a new technology, product or idea, as the MScs and PhDs can be thought of as products of the education sector.

In equation (1) N, the cumulative number of those who have acquired the degree, is not the same as the total stock at that time, since our influencing agents include even those who have retired. N must exclude those who leave because of death. However, since in India major expansion in academic manpower has come around early sixties, the number of those who leave because of death can be assumed to be small.

The meaning of M, in the context of cumulative manpower needs explanation. Since, in general, seats for MScs and to some extent PhDs, remain fixed, technically there should not be a finite M, i.e. an upper limit to the cumulative manpower. Why then do we introduce M? This is because, in a long-term perspective, once the existing degrees and qualifications become non-productive and unattractive, the facilities would remain unutilized. If this happens there will be a decline in the out-turn and such a data would visualize a finite M. Thus existence of M implies a possible saturation in growth. Such a trend is indeed noticed in the actual data (Figures 1, 2).

Within the framework of this model, the growth trends in Figures 1 and 2 are seen as consisting of three S-curves. Since two of them start at higher value of MScs and PhDs we introduce a parameter p which has the effect of shifting the y (out-turn) axis. Our model equation thus becomes

$$dN/dt = qN\,[1-(N/M)] + p. \qquad (2)$$

The model parameters q, M and p for three s-curves are determined by fitting the past data[2] to equation (2) using SYSTAT package[9]. The values of the parameters and their fit statistics are

Table 1. Estimated values of model parameters and their statistics

Item	Time span	P	Q	M (×100)	R^2
	1951–66	12.7 (2.9)	0.1550 (0.010)	2190.8 (445 0)	0.9945
M Sc	1967–77	– 98.0 (13 4)	0 2678 (0 017)	4203.9 (85.2)	0.9989
	1978–89	– 63.6 (17.5)	0 1114 (0.006)	13895.0 (404.9)	0 9992
	1951–62	74 6 (72 5)	0.1309 (0.043)	260.7 (58.6)	0.9937
Ph D	1963–76	41.7 S.H	0.1510 S H.	434.2 S.H	0.9973
	1977–89	277.9 S.H	0 1090 S.H	976.2 S.H	0.9976

Values in bracket indicate associated standard error S.H. (singular Hessian).

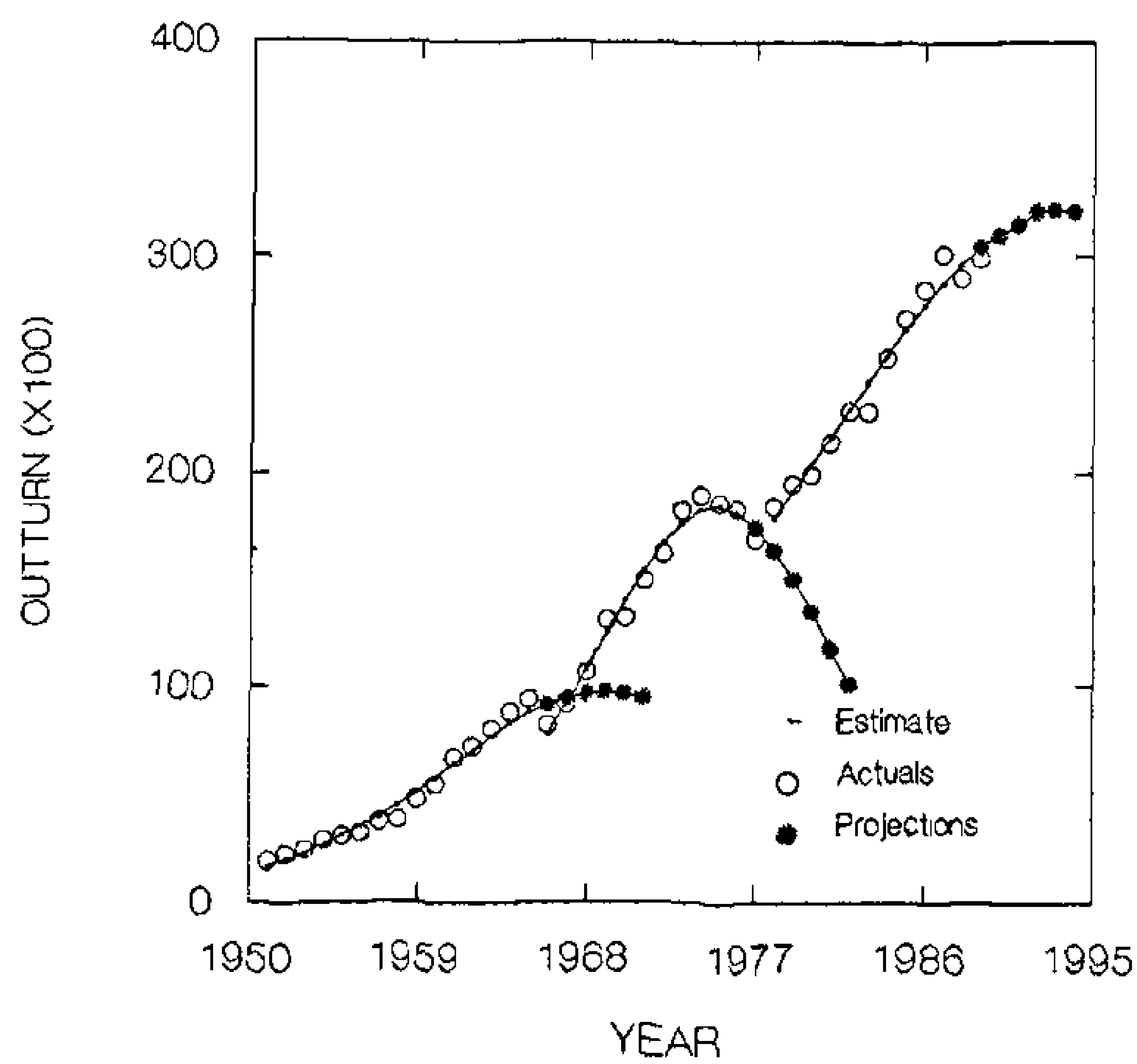

Figure 1. Fit and model projection for M Sc in natural sciences.

given in Table 1. The goodness of fit is indicated by the R^2-values. These parameter values enable us to make projections for future.

For M Scs there are three different phases of growth: 1950–67, 1968–80 and 1981–89. It can be seen from Figure 1 that there was a point of inflexion around 1967 and if boost in opportunity had not come around that time the numbers of those taking M Sc degree would have declined (see Figure 1 starred numbers). Similarly points of inflexion came in 1980 and 1989. The emergence of new growth curves after the points of inflexion is linked to the expansion of facilities for M Sc and Ph D in the late sixties and seventies.

Figure 2 displays analysis for total Ph Ds. There are again three phases of growth: 1950–64, 1965–74 and 1975–1989. The points of inflexion are clearly seen only for the second region around 1974 and for the third region around 1989.

A significant result of this analysis is that around 1989 we see a point of inflexion both for total number of M Scs and Ph Ds and their numbers have started declining in nineties. This trend is likely to continue unless new opportunities and facilities are created. This result is at variance with all the earlier manpower studies[10, 11] that predict increase in M Scs up to the year 2000.

Our analysis based on mathematical models unmistakably predicts a declining trend for annual turnover of science manpower both for M Sc and Ph D during the nineties. This result besides being at variance with available projections[10, 11] sends a clear warning signal to the planners.

Why is there a declining trend when in most of our institutions seats for M Sc are fixed and in general there are excess number of people seeking admissions? One possible reason could be the underutilization of facilities. Even if in the beginning all science seats are filled, some people do not utilize the facility to graduate in the subject but rather migrate to more lucrative courses such as MBA, engineering, medical and other professional courses. The catchment area for these courses is so narrow that the same set of students qualify for various courses. Is there a possible way of reversing this trend? We argue that increasing the number of seats and expansion of facilities at the existing institutions that award M Sc and Ph D degrees is unlikely to reverse the trend. This is because at many places even the available facilities are under-utilized.

The possible solution lies in spreading the facilities more widely across the country. If one assumed that the accessibility to M Sc and Ph D facilities for those coming out of schools and colleges is not a problem, then the average transfer rates from lower to higher education will continue to follow the past trend. This would imply that with the expansion of school education, those going in for higher education should proportionately increase. Estimates based on such average transfer rate arguments are contrary to the observed declining trend. We therefore look for alternate explanations.

Although the educational facilities at school and to some extent at undergraduate level have spread over the years, students coming out of these courses will have to move to distant places where facilities for post-graduate education are concentrated. Neglect of this mismatch in the spread of educational facilities at school level, under-

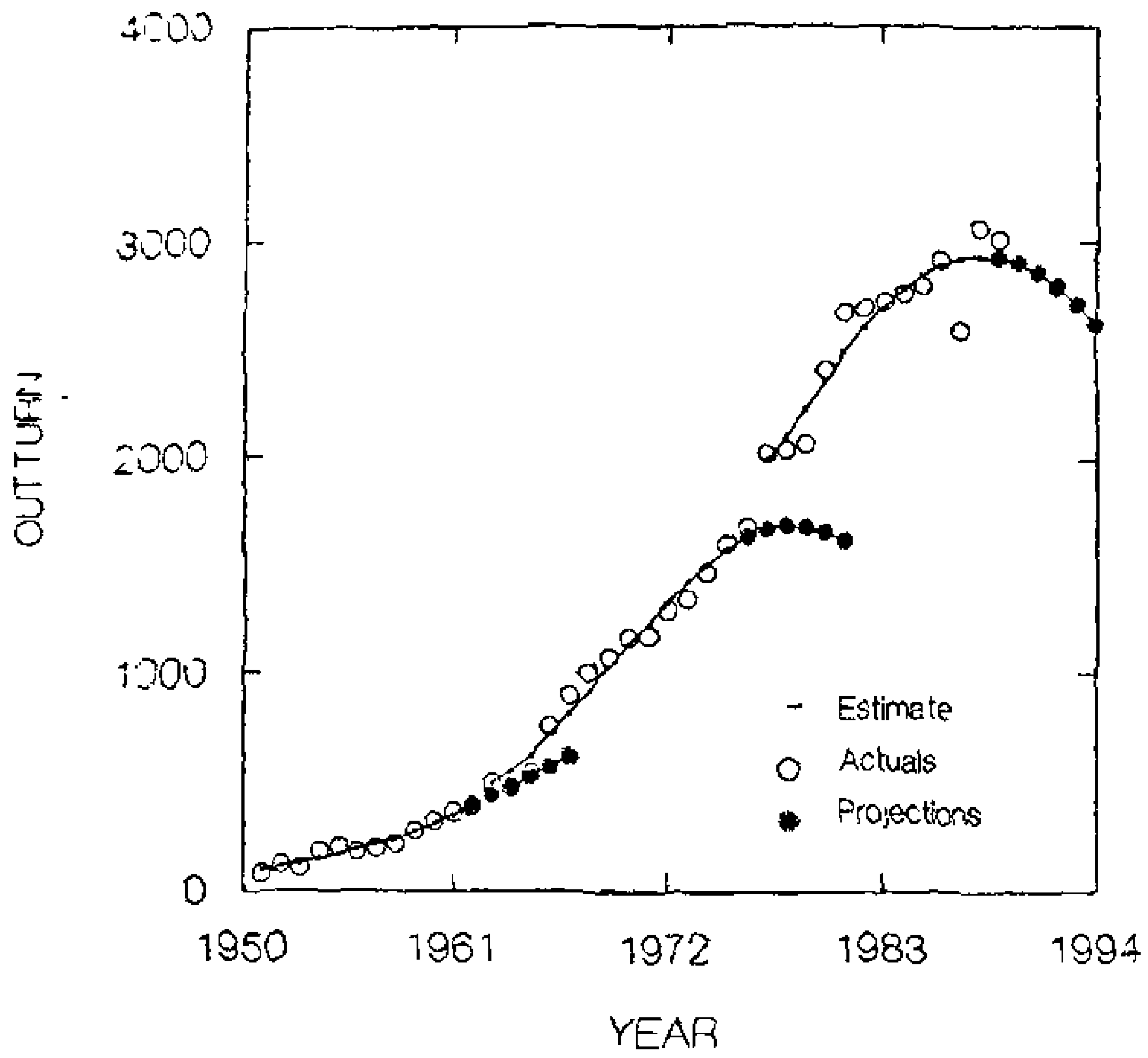

Figure 2. Fit and model projection for Ph D in natural sciences.

graduate level and post-graduate levels[12] give increasing projections based on average transfer ratios[10, 11] contrary to the observed data. Therefore instead of increasing the seats in existing institutions in proportion to the increased output from school and college system a strategy of creating new facilities for higher education at smaller and widespread places or awarding more scholarships to facilitate movement of these students to centres of post-graduate education is more likely to succeed because this will enlarge the base from which to draw students. This may initially dilute the quality which however is expected to improve over time.

Decline in the out-turn of Ph Ds implies a somewhat different form of under-utilization of existing facilities. The set of students who qualify for research fellowships are also the one who compete for various administrative jobs and leave without fully availing the facility/fellowship given to them. Also catchment area for Ph D remains small due to limits on the number of fellowships. In addition, non-availability of secured career commensurate with the number of years of work leads to leakages out of the Ph D stream. One possible mechanism to prevent leakage and for increasing science Ph Ds is to increase the number of fellowships by lowering the amount in the first year to widen the catchment area and making it more attractive to those who continue research.

In this context it is worth mentioning a general concern in USA about the shortage of Ph D scientists in nineties[13, 14] and of levels of federal R&D funding particularly to young investigators. In a recent paper Baker[15] has analysed in detail Ph D labour market within the context of demand and supply of Ph D scientists in USA and indicated that low levels of federal research funding, particularly to young investigators, is not sending the right message to young bright minds, viz. that the state values their efforts. This is also true in the Indian context. The importance that the state attaches to R&D has a direct bearing on the growth trend of Ph Ds. A positive and encouraging attitude of the Government towards R&D is necessary if the declining trend in the out-turn of M Scs and Ph Ds in sciences is to be reversed.

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