

CONCEPTUAL AND METHODOLOGICAL PROBLEMS PERTAINING TO SCIENCE INDICATORS*

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INTRODUCTION

The formulation of science and technology (S&T) policy and the development of S&T plans and programs require reliable, up-to-date and comprehensive data on a country's scientific and technological potential. Data could be broadly divided into two aspects - the input and the output data. Recognising the need for S&T data, any country should be able to compile systematically the data on S&T activities. The question then is to identify all the relevant data on different aspects to be collected either from the field (primary source) through statistical surveys or from secondary sources or from both. It is then important to decide the format of presentation. Such data should be amenable for comparison with the country's socio-economic data, its past and future trends in S&T, and with the other countries' S&T scene.

Science indicators are quantitative indicators of the many facets/characteristics of organised science and technology accompanied by trend analyses and interpretations. They are not intended to replace the judgment of policy makers who are faced with specific scientific and technical issues. Rather, they are presented to provide a broad information base to assist and stimulate planning, debate and negotiations which surround the issues faced by policy makers and planners. Taken individually, sets of data generally are not sufficiently definitive in describing certain aspects of science and technology, but when considered together as multiple indicators of a phenomenon, these data and analyses present a more comprehensive picture and encourage broader perspectives. And as indicators, they are indirect reflections of performance, behaviour, or status.

A comprehensive appraisal of the science and technology system must encompass many areas--the inputs to the system in terms of funds, personnel, and institutions, the varying approaches taken in pursuit of different research goals, the sophisticated equipment and

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instrumentation by which observations are made and scientific results are put to use, the various forms of documenting and disseminating research results, the impact of R&D investment on the nation's general economic and social well being, and the outputs of S&T in terms of publications, patents, new products/processes. A complete assessment of such characteristics requires examining the system both from internal and external vantage points.

Such an effort involves many approaches, diverse data sources, and a wide range of analytical and statistical methods. Thus, the creation of sophisticated methodologies for such an appraisal in itself raises major research questions. The complexity of infrastructure for science, engineering and technology makes the challenge of understanding its dynamic even more demanding. The diverse sectors of R&D performance, the multiple sources of its support, its relation to scientific and technological developments across the world, the multiplicity of purposes served and other such issues, illustrate the need and the importance of a multidimensional approach to the understanding of the science and technology enterprise.

It is desirable to present science indicators in such a manner that intercountry comparison is possible. But one should realise the inherent problems in such comparisons. Different countries are at different stages of development, with different priorities and political systems, and have varying infrastructure facilities for S&T. Therefore, to create science indicators for international comparison in such a diverse situation is not very easy and it calls for a number of basic definitions and assumptions about S&T enterprise in each country. Presently, only a very few countries are engaged in developing S&T indicators.

Because the substantive aspects of science and technology are not (or cannot be) easily captured by quantitative indicators, qualitative description of advances in sciences and engineering will also have to be given.

Having given a broad definition and use of science indicators, it is quite in order to discuss briefly the types of indicators which could possibly be used for analysing the different aspects of S&T enterprise and the conceptual and methodological problems in constructing and using such indicators.

FINANCIAL INDICATORS FOR S & T

There is no known optimal level of R&D investment. One would not expect each country to invest the same absolute amount in S&T activities. It is, therefore, necessary that indicators which show the level of funding for R&D incorporate the size of the nation's economy and population. One such indicator is the investment in S&T as a percentage of the gross national product (GNP). This is effected to some extent by inflation. Experts feel that inflation may impact industrial R&D investment more heavily than the general

economy. Perfect S&T deflators are still not available. In spite of the deficiency, this indicator is helpful for international comparisons since it attempts to compensate for fluctuating rates of exchange and inflation. In order to take care of inflation, S&T investment (or expenditure) at constant prices can be worked out but this poses problems due to lack of perfect deflators. One has to choose between two types of indicators--S&T expenditure at current or constant prices for different years. These indicators may project different pictures of rate of growth for S&T investment in a country. For a country with a huge population, such as India, S&T investment per capita both at current and constant prices will give a very dismal picture when compared to any other country, (except perhaps China), either developing or developed. One has to decide while working out this indicator whether to consider the entire population or only the literate population. Only 40 percent of the population in India is literate.

Countries are different in their priorities, policies, practices and political systems. This obviously affects the funding patterns for S&T. Further, priorities and patterns of funding are different in the private and public sectors within any given country. Such differences affect the allocations to civilian R&D and, in turn, the contribution of R&D to economic growth. It is evident from the experience of many countries that privately financed R&D contributes more to productivity growth than does publicly financed R&D. This is natural since industrial R&D is generally aimed at projects which are more likely to materialise into commercial use and, thus, to contribute to the national economy. Government investment in R&D is often aimed at areas which are unlikely to receive support from the private sector (like the high risk, high value, high cost or high status projects in defence, space, environment, nuclear research, etc.) and where government itself is the major consumer of results.

The priorities of a country (or even an industry) might change from time to time. For instance, during the oil crisis, most countries diverted their funds to energy-related projects. Industrial R&D funding patterns in different countries may also vary according to the different stages of industrial development, consumer requirements, standards of living and raw materials and natural resources. Government funding of S&T can also affect the R&D intensity of industries and concentration of R&D by industries. Constructing S&T indicators to fully reflect the national differences and characteristics is, therefore, not easy.

Indicators to analyse the investment of R&D by different objectives can be constructed only if the apportioning of investment among different objectives is made in clear terms. These indicators should, over time, take into account a nation's changes in priorities which are dictated by external and internal situations.

Such indicators should be used cautiously for analytical purposes. The types of indicators used to gauge the intensity of industrial S&T funding are explicit. Among these, one could include the following: the ratio between total industrial investment for S&T and domestic industrial production, the ratio between R&D investment and sales turnover, the ratio of

industry's investment to the total R&D investment of a country, the ratio between investment in R&D and exports of technology-intensive products and the investment in R&D related to import of technology.

There are inherent problems in not only constructing but using these indicators for decision-making. For instance, certain industries require higher investment in R&D due to higher levels of product sophistication and precision. Sales turnover of new companies is generally lower. Categorisation of products according to their technology intensity is difficult. Investment in R&D is not necessarily negatively related to import of technology, etc. Judgments based on R&D investments in these situations need to be made with caution.

Indicators of S&T investment in the broad spectrum of activities ranging from basic research to development of new technologies are useful. However, there are conceptual and practical problems in segregating large numbers of projects into basic, applied, and developmental research. Similar conceptual and operational problems exist in constructing investment indicators by field of science. Indicators of the government and industry funding cooperative research and consultancy projects in universities and other institutions are useful. But sometimes it is difficult to identify S&T investment by source and performer and the problem of double counting arises. Moreover, the decentralized nature of academic institutions makes it difficult to keep account of sponsored projects. Even their own funds for S&T activities are not properly accounted for. This makes it extremely difficult to construct S&T indicators for the academic sector.

Indicators based on time series data of S&T expenditure by industries is useful to analyze shifts in industrial R&D and innovation. In the Indian context, R&D investment patterns in small scale industries, large manufacturing firms, and multinational companies can be identified. Again, there are operational problems to assemble data and build indicators of S&T investment by small scale industries. Apportioning investment between capital and recurring expenditure on S&T in all the sectors (and between plan and non-plan expenditure in government) is problematic. There is no separate classification, code or definition for equipments and instruments purchased for S&T activities. They are simply counted as capital expenditure.

It is also useful to be aware of public attitudes toward national investment in science and technology. Public attitudes towards spending on controversial areas like nuclear power, space programs, recombinant DNA, etc. can be useful social indicators for S&T planning.

MANPOWER INDICATORS FOR S&T

One important class of science indicators is based on the availability and deployment of qualified S&T personnel. These scientists and engineers can be counted and classified

according to their level of education, rank and salary, deployment in S&T and other productive activities in different sectors, degree of utilization, mobility and migration patterns, participation in technical meetings and conferences and other measures. Similar to the S&T funding pattern, the availability and deployment of scientific and technical personnel will have to be related to the country's size and population.

Some researchers have tried to establish a direct relationship between a country's total stock of S&T personnel and its population, and between S&T personnel employed in R&D and industrial production or gross national product. These relationships are hard to establish. It is generally felt that the contribution of S&T personnel towards national economy is quite indirect. It is also difficult to use the number of R&D personnel per unit of population to draw conclusions about the optimal size of the S&T stock and optimal mix of scientists, engineers and technicians in a society.

To begin with, there are conceptual problems in deciding who should be included in the S&T population and whether these decisions should be based on academic qualifications, type of functions or both. Different definitions adopted for S&T personnel by different countries make international comparisons difficult. Methodologically, the problem of creating large data bases on the available, economically active and employment-seeking S&T personnel will have to be surmounted.

It will be useful at this stage to enumerate the kind of indicators that can inform S&T planning. Wherever possible, the conceptual and methodological problems pertaining to such indicators will be highlighted.

The employment pattern of S&T personnel reflects their utilization in R&D and other science and technology related activities. It also reflects the employment opportunities for S&T personnel. Employment characteristics and opportunities for women scientists and engineers can also be worked out. Women scientists and engineers are generally poorly represented in S&T activities. Employment data on involvement in, and contribution to, scientific and technical professions of scientists and engineers could indicate opportunities to increase their development and role in the S&T activities. Employment of scientists and engineers as compared to employment of all personnel categories indicates the emphasis society is placing on scientific and technical activities. It might also be possible to determine what percentage of S&T personnel are actually engaged in scientific and technical work compared to those working on auxiliary and administrative services.

Data on the work of scientists and engineers as measured by the number, proportion and distribution of those engaged in R&D, teaching and other activities are direct indicators of the character of the science and technology enterprise. Changes in these sectoral employment patterns would indicate changes in the character of the S&T enterprise.

Difficult as it may be, indicators to tell us the quality of the S&T workforce can be constructed. For instance, the proportion of S&T personnel holding doctorates could be an indicator of workforce quality. The quality of doctorates obtained from different universities or institutions can indeed be debated. This apart, there exists no organised mechanism to collect the data on doctoral degree holders and their employment.

Statistics on employment of scientists and engineers alone do not indicate whether the current supply is sufficient or insufficient to meet the needs of the economy. Standard labour market indicators of supply and demand and the utilization rate in scientific professions help to assess both the market for scientists and engineers and the extent to which they are utilising their training.

No single statistic can provide a firm basis for measuring the shortage and surplus of scientists and engineers. The S&T labour force includes scientists and engineers who are employed either in or out of scientific and technical fields as well as those who are unemployed and seeking employment. A standard measure of labour market conditions is the unemployment rate. While a low unemployment rate might indicate that scientists and engineers are not having difficulty in finding jobs, it says nothing about their success in finding jobs in their areas of expertise. An indicator like the scientist and engineer utilization ratio has been developed to show the degree to which the science and engineering labour force finds science and engineering jobs. Further inferences can be drawn from these indicators; for instance, the relative demand for personnel in different fields of science and technology and for people with different levels of qualification can be inferred.

Salary trends are another way of assessing the labour market. If scientists and engineers are in short supply, their salary will increase relative to the general salary structure. If salaries of scientists and engineers increase at the rates equal to or lower than the general salary increase in the labour market the inference is that supply is equal to (or greater than) current demand. Such salary indicators can be constructed separately for different disciplines and for different levels of academic qualifications. In India salary levels are quite variant and private, and government sector structures do not follow the same pattern. Even in the government sector, salary scales are not standardized. A high technology recruitment index (HTR) is also an indicator of market conditions for S&E. This index measures the amount of advertisement space devoted to recruiting scientists and engineers.

The employment status of recent S&E graduates in various fields is another indicator of labour market conditions since any change in demand is normally reflected first in hiring decisions. Labour market conditions can cause students to alter decisions concerning college careers. The adequacy of recent S&E degree production in terms of employment and demand can be indexed by the ratio of employment classified by field of employment to the labour force classified by field of degree. This index would suggest a relative supply and demand balance: for example in engineering and chemistry, and most other science

subjects, there is excess supply in India at present while in computer sciences demand continues to exceed supply. The data also suggest that imbalances are somewhat similar at the masters and doctorate levels but the strong demand for computer specialization is evident for all degree recipients. Such indicators are not constructed by many countries though they are essential for educational and employment planning. Both the quality and size of the pool of new scientists and engineers (as reflected by indicators) will cause concern to S&T policy makers about such trends as the declining rate of enrolment in science subjects, falling standards in science education and high or low demand for certain types of specialists.

Indicators of industrial research activity are equally important. Employment of scientists and engineers in industrial R&D and production should be analyzed separately. That will help identify industry's needs for scientists and engineers. The importance of business and industry in providing employment opportunities varies from field to field. There is also variation in employment by academic levels. The proportion of all scientists and engineers with post-graduate degrees employed in industry can provide a real indicator of this sector's importance in the employment of highly qualified S&T personnel. Since the industrial sector is expected to be a major source of the national S&T effort, the work of scientists and engineers there should be considered a direct indicator of S&T priorities in this sector. It can also bring out the division of work (e.g. development and production versus R&D) between scientists and engineers.

Some indicators can point out the shift of resources from primary activities like agriculture and mining to tertiary activities such as services. These shifts may be related to the changes in consumer demand, government policy, pattern of foreign trade and technology. Such changes might affect demand for scientific and technical personnel that can lead to a redistribution of demand by field, degree level and type of work. It may also be true that a large part of private industries' demand for S&T personnel is still concentrated in the manufacturing sector. This may be due to changes in product mix which favour high technology industries as well as changes in staffing requirements of matured industries. High technology industries that manufacture computers, semiconductors, microprocessors, robots and other electronic equipment are expected to continue their rapid expansion in the years ahead. The availability of properly trained scientists, engineers and technicians will be critical for competitiveness and growth of these industries. The industrial sector may also face skill obsolescence due to technological change that would have to be studied through S&T manpower indicators.

All these data bases need to be continuously monitored with respect to changes in product mix, market priorities, technology levels and R&D programs. Conceptually, it is difficult to classify high technology, low technology and no technology industries. There are no clear cut categories in India and, consequently, employment data on S&T personnel have also not been classified according to these categories.

The importance of the university sector in S&T activities is obvious. Universities educate scientists, engineers and technologists who are employed by other sectors including universities themselves. The indicators on enrolment, output, disciplines, faculty strength, laboratory facilities, etc. are quite important for science planning. Such indicators are easiest to develop when universities maintain and update this information on a regular basis.

Exchanges of personnel between academic or research institutions and industries is a fruitful way of doing need-based R&D. Information on the sponsored, cooperative and consultancy projects between government, industry and the R&D institutions can be extremely useful in planning and promoting such cooperative efforts. An inventory of leading research journals representing joint industry and academic efforts would help identify the extent of cooperation.

Analyses of professional activities of academic scientists or engineers may help identify the nature of scientific activity in institutions of higher learning. The work of doctoral candidates is of particular interest because of their importance in the future growth of science. The distribution of academic R&D by field of specialization, could be an important indicator of emerging research trends, particularly in basic research. Distribution of faculty or scholar time over teaching, research, consultancy, administration and other related activities can provide a useful index of how academic scientists spend their time. Similarly, cost of education (capital and non-capital expenditure) per faculty, student, degree and discipline can help in planning science education.

OTHER INDICATORS

The science and technology enterprise of a country can also be measured in terms of institutional infrastructure available for S&T activities. Of course there are difficulties in grading institutions on their teaching and research potential and priorities. Institutional resources such as laboratories, scientific instruments and equipment, research personnel and libraries can, however, be usefully indexed and correlated.

APPLICATION/OUTPUT INDICATORS

It is difficult to quantify the results of R&D, let alone its value to the economy and society. Frequently used indicators of R&D output include production of scientific and technical literature and patents. Research findings are generally published in professional journals and thus add to the body of scientific knowledge which may stimulate further research or find a variety of practical applications. Publications counts do not indicate the importance of individual contributions. Technical inventions in the form of new products and processes are the principal outcomes of applied R&D. Patents, therefore, can be used as

output indicators of inventive activity. Patent data is available for many different countries at very disaggregated levels of detail and for extended periods of time. Patents represent a stage in the invention process prior to engineering design, production and market introduction. There are limitations in using patent data. For example, patents do not reflect total inventive activity because not all new ideas or inventions are patented or patentable, and all inventions do not necessarily have the same technical or economic value. Patent laws or practices vary from country to country. Patenting by inventors sometimes follows quite different patterns in different fields of technology.

It is difficult to measure the unique contribution of R&D to productivity and economic growth. Numerous conceptual and empirical problems are involved, such as insufficient understanding of the process through which research is transformed into technological inventions and their subsequent impact on the economy. Productivity measures such as GNP do not reflect the contribution of R&D to economic growth or its benefits to different sectors of the economy. They cannot capture the complex relations among various factors of productivity. All the same, economic growth and productivity can be used as measures of R&D output.

Technological products and information can be transferred or transmitted in a variety of ways. Strictly speaking, a technology is transferred only after it has been effectively applied by the user. Because of the difficulties in determining the actual utilization of technology, measures of what may be more appropriately termed as "technology and information flows" are sometimes used as indicators of technology transfer. The unobstructed exchange of scientific and technical literature is one of the main channels of information transfer. Exchange of technology through personal contacts includes training of personnel and permanent or temporary migration of scientists and engineers. Attendance in technical meetings and conferences is another means of knowhow transfer. Foreign direct investments, licencing agreements and trade are the major channels for the transfer of industrial technology.

Royalties are payments for the use of copyrights or trademarks. Licencing fees are charges for the use of a patent or industrial process. Data on international transactions in royalties and fees are frequently used as indicators of technology transfers. Data on receipts and payments are often disaggregated between the transactions associated with direct investment and those which are between independent or unaffiliated organizations. Royalties and fees are only rough and partial measures of technology that crosses national borders. For example, trade in R&D-intensive products provides the opportunity to facilitate the use of new technology by "reverse engineering" or upgrading technical capabilities by integrating high technology products into domestic industrial processes. Some industrial technology transfer may not be paid for separately if they are part of larger transactions or operations.

Another method of transferring technology is by establishing overseas subsidiaries. Many corporations have become multinational to exploit a technology lead in other countries, or because foreign import restrictions make the establishment of overseas production facilities the only viable alternative for a foreign firm to introduce its products in the local markets. Although it is difficult to determine precisely how much technology is transferred through direct investment activities abroad, multinational firms do transfer large amounts of technology in a variety of ways. These firms train technicians and managers, communicate information to users, help client companies use their products more effectively and assist scientists and engineers in upgrading the acquired technologies.

International scientific cooperation contributes to the global diffusion of knowledge. It can also lead to lower research costs, improved results, improved relations between countries and greater human understanding. International meetings and collaborative research can often act as impetus to domestic scientific research by providing new perspectives.

These advantages aside, there are some possible drawbacks to international scientific cooperation, such as time delays due to increased organizational complexities and decreased abilities to make independent decisions about the directions and goals of research.

International scientific cooperation includes activities such as joint R&D projects, seminars and workshops, exchange of scientists, joint commissions for scientific and technical cooperation and participation in international scientific organizations. International cooperation in higher education in science should also be considered. Included in this are the education of foreign students, assistance in establishing or improving educational and research capabilities and developing curricula in areas of special interest to developing countries. The number of foreign visitors to research laboratories can also be taken as an indicator of international cooperation. A tangible output of international cooperation in research is jointly authored publications of scientific results. Joint authorship can be a product of regional or international scientific centres, bilateral agreements or graduate study abroad.

Much can be learned from scientific results obtained in other nations. It is important to recognise foreign scientific results and utilise them wherever appropriate. But to combine all these parameters into an indicator of effectiveness of international collaboration is conceptually and methodologically difficult.

It is useful to be aware of public attitudes toward science and technology. Opinion surveys are a unique way of revealing these attitudes. Confidence in science as expressed by the public is important. Consistent with its support for science, society may have high expectations for scientific advancements. One needs qualitative rather than quantitative indicators to measure society's preferences for, and expectations from, S&T activities.

CONCLUSIONS

An attempt has been made in this paper to highlight the various types of S&T indicators one could use to understand and plan science and technology in a country. The complexity of science and technology makes it challenging and difficult to construct indicators for the full S&T enterprise. The difficulties are compounded by complex terminologies and different definitions and standards for scientific activities and their performers in different countries. The contribution of S&T towards economic growth and social well-being is very often indirect. Even if one assumes that all the above indicators could be constructed with reasonable reliability and consistency, some of them may be more useful than others in explaining the current and future S&T scene. This warrants assigning an order of importance to the various types of indicators according to their usefulness in S&T policy and planning.

Construction of meaningful science indicators rests on a very strong and well designed information system and data base. Unfortunately, such information systems and data bases do not exist in most of the developing countries. Many among them have not even started the exercise of surveying their own S&T resources. But those engaged in one way or another with science policy, planning and analysis would agree that studies on science indicators will have to be initiated or strengthened in earnest with a view to building a suitable S&T base for self-reliance in technology and science.