Indicators of Science, Technology and Innovation

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1. Introduction

Science, Technology and Innovation have contributed for the human development. The quality of life we are enjoying compared to our previous generations has been the output of the efforts put in by scientists in unraveling the secrets behind atoms, materials and their intrinsic values, converted into technology through different processes of engineering. The innovative mind has gone into all aspects of life, be it earth sciences, biological spheres, physical, chemical, etc. Aided with information and communication technology, the human efforts have seen unfathomable areas and brought about applications for human development.

Abstract

Albeit the limited resources, India has been trying to increase the budgetary allocations to the Ministries/Departments dealing with Science & Technology, which are engaged in basic/fundamental research and applied research. The Ministries/Departments have been extended special privileges/ perks/incentives with the expectation that young and experienced scientists and engineers would address the basic problems faced by vast majority population and science and technology will be an important growth engine for the progress of the country.

Consuming the budget allocated, recruiting more number of scientific and technical staff, setting up new laboratories, starting new projects/schemes, publication of articles in international peer reviewed journals, etc. are the parameters by which the efficacy of the organizations is now measured. Do these measure the real worth and output of these organizations? Are they adequate? What is the practice followed in other developed countries? This paper attempts to find out the indicators of Science, Technology and Innovation in different countries and identify the indicators which can be used for evaluating the selected Scientific Organizations in Government sector. This will help in Strategic Management Process from public policy perspective.

Key Words: Science, Technology & Innovation (STI), Indicators, Performance Measurement Tools, Public Policy, R & D Intensity, Research Outcomes

Recognizing the potential of science, technology and innovation, several organizations have been established in government sector, either purely as Government Organizations or as autonomous institutions. Other Laboratories/Institutions have been set up by private or public private participation for pursuing science or together with academic component. In addition many non-governmental bodies, associations of scientists, etc. are also involved in Science, Technology and Innovation in different countries. The efforts of these organizations have yielded development of several technologies and products of daily use. Innovation and technology are used to further the improvements for wealth generation and better quality of life. Heavy investment is made in creating infrastructure, manpower and other resources for this purpose. While the innovations leading to development of technologies is the testimony for the status of life today in many developed countries, the degrees of deployment vary on the level of investment, availability of facilities in lab scale and industry level as also availability of skilled manpower in other countries.

2. Public Policy towards Science, Technology And Innovation

Policy instrument guides furthering the activities in science and technology. Policy is concerned with the purpose and intent of research. It mobilizes all key stakeholders and resources. Research Policies cover the aspects of funding, the methodology of conducting basic research and application thereof and further dissemination of the outcomes. Science & Technology policy is concerned about use of knowledge of Science & Technology in furtherance of public policy and formulation of regulation. Governments help in pooling S & T capabilities and frame laws and other instruments for

executing activities in areas of public interest like environment, health, etc. Governments also formulate Innovation Policies, to make best use of science & technology to produce new products with better quality at competitive prices. They also help in developing new processes of production and innovative organizational approaches. (Doern, 2009)

Efforts of science, technology and innovation should benefit the society, which is the objective of these efforts. Society can derive maximum benefit, if it focuses its attention on the following aspects of the research systems:

1. Talented and interconnected workforce,
2. Adequate and dependable resources and
3. World class basic research in all major areas of science.

The above aspects lead to research discoveries, sharing of knowledge generated among scientists and organizations. It also gives insight into how infrastructure and other resources including funds, management, research environment, organizations/institutions, peer review, etc. Knowledge generated by people is transformed into research products by application, creating value for society. Technological problems arise during the course of development of innovation. This requires research to find solution to the problems. Accordingly maintaining expertise among researchers is very vital. Sustained flow of funds required for ensuring flow of continual and competitive discoveries. Requisite infrastructure, tools, top level Institutions/Universities, national laboratories are necessary for the research process. Basic research is the foundation on which the transformative discoveries are made and knowledge is developed in different fields. Application and development of new technologies/innovations require fundamental knowledge, which can be acquired only from the basic research. As basic research requires new methods of research, data collection, measurement, analysis, experimentation, it helps in augmenting and improving scientific infrastructure. (National Research Council :Richard F. Celeste, 2014)

In order to have effective outcomes, R & D policy instruments have to be designed with clear cut definitions, scientific classification and conceptual frameworks. It should involve R & D research community to get better insight. We need to have effective policy mix instead of single policy of R & D as it requires interaction with various other instruments. The policy mix should include economic policy, industrial policy, and policies connected with environment, health and regional development. R & D policy instruments should aim to shift from linear to systematic thinking and innovation, from federal level to multi-level governance, establishing collaborations and networks instead of research at the level of individual researchers, teams, labs or firms, supported by policy mixes. (Martin, 2015)

3. Performance Measurement In Different Countries

We may review measures used in different countries to assess the development and deployment of science, technology and innovation and their relevance for evaluating the performance of different Organizations involved in Science, Technology and Innovation:

3.1 Performance Measurement In The Organization For Economic Cooperation And Development (oecd) Countries

An intergovernmental economic organization, with 35 member countries formed the OECD in 1961. It is to stimulate economic progress and world trade. The OECD countries are regarded as developed countries, in view of their high GDP.

R & D intensity of a country measured by the expenditure on R & D over the GDP (R&D/GDP) is the most popular indicator developed for formulating S & T Policies, in terms of quantifiable targets. Other measures developed or evolved were intangible investment, patents, bibliometrics, etc. The innovation was also measured in terms of direct surveys, globalization and surveys of firm performance. A new Blue Sky S & T Indicators Project was commissioned by OECD in 1990s, to formulate new generation indicators to serve the policy needs, in a better way. Measuring the innovative performance and associated outputs is the purpose of this Project. ((OECD), 2005).

According to Andrew Wyckoff, Science, Technology & Innovation Director, OECD, for better policies in Science, Technology and Innovation, it is necessary to have sound measurement tools. We can get insights into emerging areas of policy interest, provocation to debate and move the measurement agenda forward, by experimentation with metrics based on new tools and data, using existing data in new ways. (OECD, 2016)

OECD releases Research & Development Statistics (RDS) database every years, on the standards of the Frascati Manual, covering funding and spending on R & D, number of personnel involved in R & D, their qualifications and gender, budgets of government for R & D and the historical data, covering the OECD Members countries and other major economies. The database provides data on ICT readiness and skills for the digital economy under Digital Readiness, ICT usage in business and households, emerging and converging technologies covering bio and nano-technologies, experimental methods (using data mining), human resources in S & T, innovation statistics, Knowledge Based Capital (KBC) for investments in training, share of employment by routine intensity of jobs, global interdependencies in terms of output, value addition, employment and investment. Current price matrices of inter-industry flows of goods and services covering both domestically produced and imported are presented in the latest set of harmonized national input-output and Inter-Country Input-Output tables. The Micro-data Lab covers data infrastructure collects and links large-scale administrative and commercial micro-level databases. These data mainly rates to intellectual property assets, scientific publications and information of companies from private providers. (OECD, 2016)

3.2. **Performance Measurement in Canada**

Canada uses the following indicators, for measuring science and technology activities at country level:

1. Expenditure on R & D
2. Scientific activities of the federal government
3. Personnel working in S & T
4. Canadian Research Output, in terms of citations
5. Patented Inventions,
6. International Payments and Receipt for Technology,
7. Trade in selected commodities.

(Statistics Canada, 1984)

3.3 **Performance Measurement in The United States of America**

In USA, the scientific research has followed the pattern of free enterprise. The scientific research is done in a decentralized and pluralistic manner. The research is carried out with the spirit of competition, merit and for the purpose of entrepreneurial development. In this complex system, it will be difficult to have a control or monitoring mechanisms for research and transformative outcomes. However, emphasis is given on talent, resources and fundamental research, which have contributed for discoveries and innovations emerging from the scientific enterprise. For funding research, USA follows the system of peer review. The peer review system envisages evaluating the investigators' qualification, individual programmes and their effectiveness/innovativeness in the research programme. It is aimed at funding the projects and not necessarily performance assessment. The United States appears to have no institutional mechanism for systematically assessing the research establishments holistically, for the federally funded research. (National Research Council :Richard F. Celeste, 2014)

National Centre for Science and Engineering Statistics (NCSES) of National Science Foundation under the guidance of National Science Board of USA prepares Science and Engineering Indicators. The indicators are broadly classified as under:

1. Elementary and Secondary Mathematics and Science Education.
2. Higher Education in Science and Engineering
3. Science and Engineering Labour Force
4. Research and Development: National Trends and International Comparisons
5. Academic Research and Development

6. Industry, Technology and the Global Marketplace

7. Science & Technology : Public Attitudes and Understanding

8. State Indicators

Output of research activity is measured in terms of refereed journal articles. Although the research capabilities of other countries have tremendously increased over time, in terms of publication of articles on Science and Engineering, the United States continues to be the world leader. Another indicator of the quality and impact of research output is the citations to refereed articles of journals. The United States is the world leader in this aspect also, which sets the high standard in production of influential research results. Articles from the United States are cited the most in all spheres of science. Another innovation related indicated which reflects the outcome of the research efforts is patents. The United States leads in this aspect also, outstripping other countries.

State Level Indicators used by the States of USA are categorized under the following heads:

1. Elementary and Secondary Educators, covering achievements of students at elementary and secondary levels, expenditures of public schools, and persons with high school credentials,

2. Higher Education Indicators, covering credentials awarded and sought in Science & Engineering, Persons with higher education credentials, and higher education supported by the State and student resources,

3. Workforce indicators, covering higher education credentials of the workforce, labour force involved in Science & Engineering,

4. Financial R & D Inputs Indicators, measuring level of R & D Activity and public-sector support for R & D activities,

5. R & D Outputs Indicators, covering human capital outputs and research based outputs,

6. Science & Technology in the Economy Indicators, to assess high-technology business activity and early-state, high-risk capital investment.

(National Science Board, 2014)

3.4 Performance Measurement in India

India is now (2016-17) US $ 1.86 trillion economy. Per capita income of India during the current fiscal is US $ 1,538.5 (approximately equal to Rs. 1,00,000). It is also third largest technical manpower in the world. It has 162 universities which award 4000 PhDs and 35,000 Post Graduate degrees. Its position for producing graduates in science and engineering is 8th in the world. It has a huge consumer base, which is in need of cheap, durable and technologically advanced products. As a result many multinational companies are setting up R & D Centres in India. Spending of India on R & D is estimated to reach US $ 77.46 billion by this year end. It is an increase of around US $ 7 billion in 2016. Based on the figures of annual R & D spending India became sixth largest country in the world in 2015. It had spent 3.53% of global R & D expenditure, which is expected to rise to 3.75% in 2017. In terms of R & D expenditure to GDP, it is 0.9% in 2014, which is expected to increase to 2.4% by 2034. While India had 28,940 patent filings during 2006-2007, it has risen to 46904 during 2015-2016, which is an increase of 52.93%. (Indian Brand Equity Foundation, 2017)

Recognizing the fact that Science & Technology driven innovation and knowledge are the key drivers for the growth, Government of India declared 2010-2020 as the Decade of Innovation. Science & Technology Policy 2013 has been formulated in this direction. Towards this goal, the Department of Science and Technology has created National Science and Technology Management Information System (NSTMIS) which has taken up the programme of Science, Technology, Innovation and Creation of Knowledge (STICK). Developing indicators to comprehend the intricacies of innovation and knowledge creation activities and their relation with the economic growth and benchmarking the performance of the national innovation system is the mandate of STICK. STICK has developed a model for measuring capabilities of innovation and knowledge creation, in terms of process innovation, organizational innovation and marketing innovation, to develop innovation indicators. Based on the study conducted, it was found that innovative firms have taken initiatives and carried out certain changes. They have adopted innovations in production, process, quality and standard, changes in input use, using new or alternative material, introduction of new machines, etc. (Indian National Innovation Survey, 2014)

4. **Analysis of The Performance Measurements**

OECD's measures, such as spending on R & D, number of personnel involved in R & D, their qualifications and gender, budgets of government for R & D, data on ICT readiness and skills for the digital economy under Digital Readiness, ICT usage in business and households, emerging and converging technologies, experimental methods (using data mining), human resources in S & T, innovation statistics, Knowledge Based Capital (KBC) for investments in training, share of employment by routine intensity of jobs, global interdependencies in terms of output, value addition, employment and investment will to some help in drawing cross-country comparisons. However, the spending on R & D over GDP may only indicate the importance a country accords on science and technology but it will not measure the effective utilization of the funds. Other data on ICT readiness or usage reflect the advancements achieved in science and technology, by application of these technologies. However, they will not be able to help measure the effectiveness of an organization pursuing science, technology and innovation. For the reasons mentioned for OECD, the measures used by Canada are also useful for the status of science and technology in Canada at national level, but not organizational level. The system followed in USA is too complex to have control or monitoring mechanisms for assessing the performance of any Scientific Organization. However, some of the parameters used at federal and State level may be worthy of application.

5. **Performance Indicators Proposed For Future Studies**

While different countries adopt different approaches to measure the performance of research in terms of outputs and technology transfer, the question remains as to whether we have measures or indicators to assess the performance and benchmarks to check whether the resources deployed in terms of finance, manpower, infrastructure are meeting the objective for which they have been created. Frankly it appears that no constructive effort has gone into developing indicators to assess the performance of these organizations. Government feels its duty is to allocate funds, sanction manpower and is happy with the incremental progress made by these organizations. While some mission oriented organizations like the Department of Atomic Energy, Department of Space, DRDO, etc. have made considerable progress in terms of output, it is not known whether an analysis has gone into at national level to check their productivity and whether these organizations have carried out their functions in accordance with their mandate. We have plethora of organizations under government, semi-government organizations, academic institutions, NGOs etc. The effort will be to take some of the best measures from across the world, examine their relevance for application to the scientific organizations in India and analyse the results. This analysis may lead to interventions in terms of management and policy.

From the indicators or measures being used by OECD, European Union, Canada and USA, we may pick up certain measures which can be used to assess the effectiveness and productivity of the organizations involved in science, technology and innovation. These measures could be grouped under categories as under:

I. **Research Environment**

a) Human resources in S & T and investments in training

b) Talented and interconnected workforce - maintaining expertise among researchers

c) Adequate and dependable resources

d) Methods for ensuring sustainable flow of funds for the research

e) Availability of infrastructure, tools, laboratories

f) Usage of ICT and other converging technologies, like bio and nano-technologies

g) Basic research in all major areas of science

h) Peer review system for evaluating the individual programmes and their effectiveness/ innovativeness in the research programme.

II. **<u>Outcomes of efforts on Science, Technology & Innovation:</u>**

a) Technology transfer - by applied research

b) Patented Inventions,

c) Receipts for Technology,

d) Benefits to the Society in addressing enhancing the quality of life

e) Contribution of STI to the GDP

III. **Other Outcomes**

a) Publications in refereed journals

b) Bibliographies

c) Spin-off technologies

6. Conclusions

It is necessary evaluate the performance of our Scientific Institutions, pursuing science, technology and innovation in a more methodical way. The research environment could be measured in terms of availability of meritorious and multi-talented workforce, adequate and dependable resources, sustainable flow of funds for the research, availability of infrastructure, tools and laboratories, usage of ICT and other converging technologies and investment in human resources including training. Collaborative research conducted in multi-disciplinary fields in different laboratories within the country and in other countries could be the other parameter to assess the research environment and its direction. The outcomes of science, technology and innovation could be measured in terms of technology transfer, patented inventions and receipts for technology, in addition to publications in the refereed journals.

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