Measures of impact of science and technology in India: agriculture and rural development

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The M.S. Swaminathan Research Foundation undertook a study on the 'Measures of Impact of Science and Technology: Agriculture and Rural Development' with the principal objective of analysing significant technologies that have been developed in the public research system pertaining to the major sectors of the rural economy of India over the post-independence period. Crop husbandry, animal husbandry, fisheries, forestry, irrigation, health, drinking water and energy have been the areas of concern. This article is an attempt to provide a summary of the major findings of this publication.

Keywords: Agriculture, rural development, science and technology, Technology Achievement Index.

IN the context of economic reforms under way in India since 1991, it would be of interest to explore the role played by the Indian state in the development of significant technologies pertaining to the major sectors of rural economy during the post-independence period. Such a study becomes especially relevant in the context of assessments made by the Human Development Report of 2001 of the United Nations Development Programme (UNDP) concerning the technological achievement of various countries, including India.

The UNDP Report

The UNDP Report set forth a methodology to calculate what it called a Technology Achievement Index (TAI) on a global scale, intended to serve as an indicator of the progress made by different member states of the United Nations in the area of technology achievement. The indicators used for developing TAI were based on the following components:

1. Technology creation
   - Patents granted to residents
   - Receipts of royalties and licence fees
2. Diffusion of recent innovations
   - Internet hosts
   - High and medium technology exports
3. Diffusion of old innovations
   - Telephones
   - Electricity consumption
4. Human skills
   - Mean years of schooling
   - Gross tertiary science enrolment ratio.

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Using the above measures of technology achievement, India was ranked 63rd among the 72 countries considered. The indicators chosen to reflect technological achievement were largely related to profit-driven research, while the dominant sector of research in India has been in the public domain, carried out in institutions and universities supported through public funds. The significant role played by public-domain research in achieving progress across various sectors of the rural economy of India during the post-independence period has not been taken into account by the UNDP while assessing the country's performance.

The MSSRF study

Shortly after the publication of the UNDP Report, and possibly in part in the light of the report, the Office of the Principal Scientific Adviser to the Government of India supported a series of studies under the umbrella title 'Measures of Progress of Science and Technology in India', to examine the progress made in various sectors in India during the post-independence period. The study whose findings are discussed in this article, was a part of this series. This study was carried out at the M.S. Swaminathan Research Foundation (MSSRF), Chennai (The MSSRF study was carried out by a team of researchers comprising Drs R. Rukmani, Indumathi M. Nambi, S. John Joseph, M. Prabhu, K. N. Sevakumar, K. Susheela, Mr V. Senthilkumar, Mr Karuna Krishnaswamy and Ms N. Thenmathi). The principal objective of the study has been to analyse significant technologies developed since independence in the public research system in the areas of crop husbandry, animal husbandry, fisheries, forestry, irrigation, health, drinking water and energy as well as to examine the impact triggered by these technologies.

The definition of 'technology' that has been adopted in this study – the steps taken in the application of scientific knowledge in achieving some goal – has enabled the cov-

erage of a broad field encompassing several sectors of the Indian rural economy. Each one of the sectors considered has benefitted from a large number of technological interventions. However, the emphasis in the study has been on a few significant technological interventions that have helped in bringing about rapid transformation in a sector rather than analysing all the technological interventions. Such significant technologies, referred to as catalytic technologies, have been identified and various dimensions of technological achievement have been discussed. In crop husbandry, animal husbandry and fisheries, the attempt has been to analyse technologies that have brought about significant changes in output. The analysis on health, drinking water and energy, on the other hand, pertains to technologies or interventions that have brought down the incidence of various diseases, and improved access to drinking water and electricity.

Let us now turn to a brief discussion of key technological interventions in each major sector and their impacts.

Crop husbandry

The MSSRF report discusses developments in the crop husbandry sector, where the varietal improvement programme has been identified as the catalytic technology. The ICAR system, with its elaborate network of research activities, has developed and released more than 3300 high yielding varieties and hybrids pertaining to various crops[1]. A detailed analysis of the nature and extent of development of the varietal improvement programme has been undertaken with regard to some selected crops: rice and wheat among major cereals, maize and sorghum among nutritious millets, soybean and sunflower among oil seeds, potato among vegetables and sugarcane and cotton among non-food crops.

The most important aspect of the varietal improvement programme in India is that the germplasm received from international research institutions has been used to develop varieties suitable for Indian conditions. Various plant breeding techniques have been used to develop varieties and hybrids of crops with desirable characteristics. While improving crop yields is an important aspect of varietal improvement, other dimensions of the programme include improving quality, developing resistance to biotic and abiotic stresses, altering the duration of maturity, and developing photo-insensitivity. Release of varieties and hybrids of various crops combined with a policy that actively promoted the use of these improved varieties resulted in a significant increase in area under these varieties. A significant achievement in adopting high-yielding varieties has been the quantum jump in yield of almost all crops. Table 1 indicates that yields across all crops have registered a rapid increase over five decades. The improvement in yield has led to a corresponding increase in agricultural output in the country.

If one considers the entire period of five decades since 1950–51, land productivity or the value of output per hectare has improved significantly in Indian agriculture. Land productivity captures the improvement in crop yield as well as in crop quality. Given that these aspects are influenced by technological interventions, this factor may be used as a summary measure that reflects technological achievement in the crop husbandry sector. Considering all crops, value of output per hectare in constant terms has increased two and half times over the period 1951–52 to 1999–2000.

Irrigation

The study has provided an overview of irrigation development since the 1950s and examined the role of technology in irrigation development. Expansion of irrigation in the country is in part related to a conscious policy decision of the government to invest in irrigation works and in part to development of technologies.

Several technologies, major and minor, have played a crucial role in the development of irrigation in the country with regard to harnessing, distributing and managing water resources as well as in conserving and quantifying available water. The design and construction of dams in India have undergone several modifications based on new scientific inputs and experience over the years. Technology has enabled construction of large dams even in areas susceptible to seismic activity, which is a major breakthrough, particularly with regard to the flood-prone north-eastern states. As regards sub-surface irrigation, high-speed drilling technology has replaced traditional, shallow dug wells by modern, deep borewells in hard-rock areas.

Table 1. Yield of foodgrains and major non-food crops in India, 1951–52 to 2001–02 (kg/ha)

Average centred around the year	Rice	Wheat	Maize	Sorghum	Total food grains	Total oilseeds	Sugarcane	Cotton lint
1951–52	764	697	663	420	546	445	31,539	87
1961–62	988	807	959	501	699	494	42,961	117
1971–72	1112	1268	1093	459	848	519	48,902	128
1981–82	1281	1683	1155	681	1030	578	57,497	160
1991–92	1774	2301	1524	820	1406	762	65,142	232
2001–02	1980	2715	1821	768	1641	811	66,825	190

Source: MSSRF[2].

The spread of tubewell technology has brought large tracts of the plains under irrigation. Pumping technology has undergone major strides from low-cost zero energy pedal pumps in shallow aquifers to high-power pumps to reach deep aquifers in the hard-rock areas. The use of several computer-simulation models, remote sensing and GIS tools along with advanced imaging techniques has replaced the traditional methods of water resource quantification and management. In areas of water conservation, the list of technologies is quite long, ranging from improvements in water conveyance to water application and on-farm conservation methods. Lining of canals using several scientific methods has resulted in significant reduction in water loss in many canal systems in the country. Rainwater harvesting, groundwater recharge and micro-irrigation technology have tremendous potential for water conservation, in addition to other benefits.

Since independence, net irrigated area in the country has more than doubled, while the gross irrigated area has more than trebled. However, traditional irrigation systems such as tank irrigation have declined from 16% to about 4% of the net irrigated area over the five decades since 1951–52 in the country as a whole. Tanks are vital sources of irrigation in the hard-rock areas with uneven distribution of rainfall and poor recharge characteristics. Revival of these traditional irrigation structures and use of technology to enhance their performance in a sustainable manner are important challenges ahead.

Animal husbandry

The study discusses the various technological interventions in the post-independence period in the livestock sector of the country, that have led to significant improvements in the production, productivity and per capita availability of livestock products. To improve milk production in the country, which was quite low in 1960, multi-pronged approaches in breeding, health cover, feeding and marketing were initiated by the Government through various development programmes. Cross-breeding and upgradation were done to improve the productivity of indigenous cows and local buffaloes respectively. Artificial insemination with improved germplasm using frozen semen has been the most strategic intervention in increasing milk production. Vaccines against various diseases were developed and cattle in every part of the country were vaccinated. Various feeding technologies were developed to exploit the full potential of cattle, along with the creation of marketing facilities for rural milk. These combined measures resulted in improvement in milk production to 91 mt in 2004, with India standing first in the world in milk production. The growth of productivity in the dairy sector was significant, as indicated by the twofold increase in the value of output per milch animal.

Introduction of high-yielding varieties of eggers – Rhode Island Red, White LegHorn, Babcock, etc. – during the 1970s and broilers – Cobb, Ross, etc. – in the 1980s, has been a benchmark in the development of the poultry sector in India. Along with this, the development of newer vaccines and diagnostic kits, least cost formulation of feeds, and adoption of newer management techniques in rearing have contributed to improving productivity and production. Average productivity of a layer was 4.9 kg per annum during 1961–63. This increased rapidly over the years and in the triennium 2002–04, it was 11.51 kg/annum.

Fisheries

The discussion on fisheries deals with aquaculture as well as capture fisheries. Over the years, the fish production system has been subjected to several technological interventions pertaining to production, processing, product formulation, packaging and storage. Intensification of fish culture with biotechnological tools, diagnosis and control of diseases that affect fish, improvement in fish nutrition from feed formulation to encapsulation, and assessment of water quality are some of the technological interventions pertaining to aquaculture that have been developed over the years in India. As far as capture fisheries are concerned, major technological intervention has been with regard to development of different kinds of fishing craft and gear.

The Central Institute of Freshwater Aquaculture (CIFA) has standardized three technologies: (i) induced breeding of carp through administration of pituitary gland extract, (ii) carp nursery rearing and pond management practices, and (iii) composite carp culture, where the different layers of the pond ecosystem are effectively utilized. Carp production has contributed a major share to inland fish production, increasing from 34% in 1986 to 65% in 2000. To promote carp production with adequate seed availability, hatchery production of seeds by induced breeding was also developed. Marine fish production has increased through successive stages, with a change from natural to synthetic fibres in gear fabrication, introduction of mechanized craft, introduction of trawl nets and mainly motorization of fishing craft during the five decades after independence. These developments have paved the way for what is hailed as the 'blue revolution' or 'aquaplosion' in India. The 'blue revolution' has resulted in an increase in per capita availability of fish in the country, from 3.82 kg/annum in 1986 to 5.55 kg/annum in 2000.

Forestry

Improvement in the area under forests in India is largely due to interventions in the aspects of conservation and management of the fast-dwindling natural forests, protection of endangered flora and fauna, wildlife management and development of high-yielding plantations. The impact

of science and technology on the forestry sector is evident in each of the constituents of the sector and is discussed in detail in the report. The impact of satellite technology in forest management has resulted in the appreciation of the status of forests, the nature and extent of deforestation, and the current conditions of forests. The Forest Survey of India's biennial assessment of forest cover has helped in understanding the complexity and challenges facing the country.

In conservation forestry, data and information generated by the Rapid Biodiversity Assessment has helped in formulating strategies both for *in situ* and *ex situ* conservation. In restoration forestry, significant work in rehabilitation of mangroves is being done all along the Coromandel coast. In the restoration of forests to their original status, the Joint Forest Management is playing a perceptible role all over the country by enlisting the active participation of people motivated by village forest committees. In production forestry, the large-scale plantation programme as well as clonal forestry and agro forestry have an outstanding record of application, diffusion and achievement both in the public and private sectors. The Wildlife Institute of India has developed relevant grass-root-level technology in wildlife management, significant among them being methods to conduct census, radio-collaring, use of GPS in conjunction with GIS, and conservation genetics of tigers and turtles. In forest protection, establishment of the Wildlife Forensic Cell and its role in identification of species by use of DNA technology, thereby securing conviction for forest offences, have been major breakthroughs.

Consequent to various measures taken by the state, the area under forests has registered an increase from about 40 mha in 1950–51 to 69 mha in 1999–2000.

Health

The MSSRF report analyses the technical as well as managerial aspects of the various health programmes that have been initiated in our country since independence. The discussion relates to major communicable diseases, non-communicable diseases, vaccine-preventable diseases and nutritional deficiencies. Diseases that are discussed in the report include malaria, leprosy, tuberculosis, cholera and diarrhoeal disorders, HIV/AIDS, poliomyelitis, diphtheria, pertussis, tetanus, measles, tuberculosis and preventable blindness. The impact of the health programmes is measured using parameters like prevalence, incidence, morbidity and mortality rates of diseases. The analysis clearly brings out a definite decline in the incidence of diseases over time.

Given that life expectancy at birth is influenced to a large extent by a decline in mortality rate in general and infant mortality rate in particular, decline in the incidence of diseases and improvement in sanitary conditions, the improvement in life expectancy of an average villager in India is taken as a summary measure of achievements in the overall health status of the population. Life expectancy at birth of the average rural Indian in 1970–75 was 48 years and it rose to 61.2 years by 1998–2002.

Drinking water

Provision of safe drinking water that is free from biological contamination (guinea-worm, cholera, typhoid, etc.) and chemical contamination (excess fluoride, brackishness, iron, arsenic, nitrate, etc.) to all rural habitations continues to remain a challenge in India. In 1986, the National Drinking Water Mission, which was later renamed as the Rajiv Gandhi National Drinking Water Mission (RGNDWM), was launched. This accelerated the pace of several programmes by providing a renewed form of mission approach for implementation. There has been a rapid growth in the coverage of rural drinking water supply from 56.3% of households in 1985 to 98% of households by 1999. The introduction of borewell drilling technology and the advent of new and more durable hand-pumps improved the coverage in previously inaccessible areas.

While the percentage of rural population provided with infrastructure for drinking water has grown from 18% in 1974 to close to a 100% in 2005, the actual usage of this infrastructure for access to drinking water is much less at 84%. This lacuna is due to several reasons, including groundwater depletion and water quality constraints. The Government is currently focusing its investments into filling this gap. A significant amount of pump breakdown problems have been taken care of with the introduction of Mark III pumps, and a strong back-up by village-level operation and maintenance schemes for hand-pumps. Measures such as rainwater harvesting and groundwater recharge are being introduced as an integral part of all rural water-supply schemes. Irrespective of the difference between drinking-water coverage and usage, the growth that has taken place in this sector is remarkable.

Energy

Improvement in power generation in post-independent India has been a consequence of planned investment, successful technology absorption from abroad, indigenous capacity building and modification of technology to suit local conditions. This growth in power generation has been led by growth in coal-based thermal power, including additional power stations, higher installed capacity of thermal power plants and higher power generation through gains in efficiency. Improvements and technological innovations in hydroelectric turbines, generators and governing equipment have produced a new generation of hydro equipment that offers higher efficiency, lower cost and improved reliability. Most of India's achievement in nuclear energy is the result of indigenous technology development.

The total power generated by all the plants – thermal, hydro and nuclear – has progressed significantly over the last fifty years. From 6.6 billion kWh in 1950–51, power generation increased at the rate of 9.2% per annum over the five decades and was 554.5 billion kWh by 2000–01. Of the overall power generated in 2000–01, 74% was from thermal plants, 13% from hydro plants and 3% from nuclear plants. Power reach to rural areas has been made possible by the rural electrification policies. However, despite tremendous advances in power production achieved primarily through the public sector and state action, demand for power still outstrips the supply.

Decentralized renewable energy is seen to be the direction forward in rural areas that are harder to reach through transmission and distribution lines from a central plant, as well as for sustainability and environmental friendliness. India is one of the world leaders in renewable energy programmes. India has one of the largest and most complex power-grid systems among developing countries, and has indigenously acquired competence in demand forecasting, power-plant design and creation, technical specifications, project management and engineering capabilities.

Summing up

While this study has attempted an explication of the proposition that the major sectors of the Indian rural economy have seen significant technological achievements primarily through effective state action, it is far from our contention that it has done justice to every dimension of the enquiry.

First, the study has analysed the impact of technological interventions in broad terms and there has been no attempt to isolate the pure effect of technology. This is partly due to the fact that the purpose of the study has only been to highlight the achievements triggered by state-supported technological initiatives and not to separate the effect of catalytic technologies from the overall results.

Second, while improvement in productivity has been used to assess technological achievement in production-related sectors, our study has not examined the reasons for the difference between potential and actual productivity or that between international levels of productivity and corresponding Indian levels.

Third, while the study has analysed the role of public-funded research in the development of various catalytic technologies, there has been no substantive investigation of various other policies that were put in place to successfully operationalize the catalytic technologies.

Fourth, technological achievement has been analysed in isolation from the social and environmental impact of technology. However, the examination of the social and environmental impact of technology would require a separate detailed line of investigation.

Limitations apart, we have documented the unambiguous progress in production with regard to crops, milk, eggs and fish, improvement in health status, and growth in access to electric power and drinking water for India's rural population over the post-independence period. These achievements are a result of the proactive role played by the state in promoting R&D that has contributed the technologies crucial for a breakthrough in production and promotion of people's access to basic facilities. However, the analysis clearly shows a tapering of growth in the 1990s compared to the 1980s, in the major sectors of the rural economy. The rate of growth of yield of almost all major crops as well as that of milk, eggs and fish has declined in the 1990s. This seems to be linked to the decline in the proactive role of the state in technology development and dissemination during the period of economic reforms initiated in 1991. This has serious implications for the food security of the people. An active role by the state is critical to resolve such key problems as food security through an appropriate package of technology and development policy interventions.

The National Agricultural Research System (NARS), developed and strengthened to address the various challenges that face agriculture from time to time, has clearly made positive contributions to the rapid increase in food production (foodgrains, milk, eggs and fish) in the decades since independence. Given this, it is imperative that the current concern over the declining rate of growth in agricultural production receives urgent attention from NARS. Moreover, agricultural research in the early part of the 21st century also faces challenges regarding the adoption of Intellectual Property Rights and assessment of biotechnology advances. This is yet another reason why the role of the state becomes crucial to safeguard the interests of millions of farmers. However, public domain research is not independent of the larger macro economic policies pursued by the state. The policies pursued by the Government of India since the early 1990s promote the withdrawal of the state, and rest on an extraordinary confidence in the ability of a deregulated, privatized and globalized economic regime to solve all major economic and technological problems. The foregoing analysis of the role of the state in post-independent India in promoting the development and application of new technologies to achieve rural development suggests that present policies need to be reconsidered. Without proactive intervention by the state, many of the achievements that have been elaborated in this study will get undone in the coming years.

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2. M.S. Swaminathan Research Foundation, Measures of impact of science and technology in India: agriculture and rural development, MSSRF, Chennai, 2007.

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