Available online at www.sciencedirect.com

SCIENCE DIRECT®

Technological Forecasting & Social Change 72 (2005) 287–299

Technological Forecasting and Social Change

Indian remote sensing program: A national system of innovation? ☆

N. Dayasindhu[a,*], S. Chandrashekar[b]

[a]Software Engineering Technology Labs, Infosys Technologies Ltd., Electronics City, Bangalore 560100, India
[b]Corporate Strategy and Policy Area at the Indian Institute of Management Bangalore, Bannerghatta Road, Bangalore 560076, India

Received 1 February 2004; received in revised form 4 June 2004; accepted 26 August 2004

Abstract

When India launched the satellite IRS 1C in 1995 with a resolution of 6 m, it had the distinction of having the highest spatial resolution among all operational civilian remote sensing satellites in the world at that time. This world-class technological capability in remote sensing was a result of favourable organisational and institutional factors that nurtured innovation. There was a domestic need for remote sensing information for managing natural resources like land, water and forests. Since India is still largely agriculture and natural resources dominated economy, a generic technology that could be used in many sectors related to natural resources has the potential to accelerate the economic development process. This paper looks at the link between an organisational innovation that creates a world-class capability that meets a domestic need and ability of this innovation to change the larger national system. It tries to identify institutional factors that seem to inhibit innovation and suggests approaches that can create a suitable national climate for the rapid diffusion of innovation.

Keywords: National system of innovation; India; Remote sensing

> "There are some who question the relevance of space activities in a developing nation. To us, there is no ambiguity of purpose. We do not have the fantasy of competing with the economically

☆ This paper expresses the opinion of the authors and not necessarily those of the organizations to which they are affiliated.
* Corresponding author.
E-mail addresses: nd@iimb.ernet.in (N. Dayasindhu), schandra@iimb.ernet.in (S. Chandrashekar).

0040-1625/$ - see front matter © 2004 Elsevier Inc. All rights reserved.
doi:10.1016/j.techfore.2004.08.012

advanced nations in the exploration of the moon or the planets or manned space flight. But we are convinced that if we are to play a meaningful role nationally, and in the community of nations, we must be second to none in the application of advanced technologies to the real problems of man and society." *Dr. Vikram Sarabhai, Father of Indian space program*

1. Introduction

The first Indian remote sensing satellite, Bhaskara 1, was launched in 1979 with a resolution of 1 km. When the satellite IRS 1C with a resolution of 6 m was launched in 1995, it had the distinction of having the highest spatial resolution among all operational civilian remote sensing satellites in the world at that time. The global technological leadership was a result of the unique Indian remote sensing program. For the first time in the world, a country that was outside the developed OECD countries or the Soviet Union/Russia achieved a position of global leadership in one domain of space technology. The organisation that pioneered this technology, the Indian Space Research Organisation (ISRO), has created the nucleus of a remote sensing industry covering both the resource side applications with the information technology skills required to manipulate, organize and analyse remote sensing data. Support services covering the entire gamut of the value chain from the payload for remote sensing satellites to its use in various applications have emerged. The salient features of the Indian remote sensing program that made possible an indigenous development of a world-class capability is discussed. The paper then focuses on one application in one user domain-land use mapping. The reasons why capability in land use mapping in spite of making a domestic need has not been used in large scale is analysed. The link between a new capability in an emerging area and the concept of a larger system of innovation is explored. Some initiatives that may accelerate the process of national innovation are suggested based on this experience.

2. The Indian remote sensing program

Remote sensing is the science of deriving information about an object from measurements made at a distance from the object. In satellite remote sensing, information on an object is obtained by measuring the light/radiation reflected and emitted by this object at different wavelengths from the ultraviolet to the microwave. Specially designed sensors placed on satellites collect this radiation. The radiation data captured by the sensors is transmitted to earth stations where they are stored and analysed using computers to get information on weather, land use, ocean resource profile, etc. Most often, the data are converted into images that can be used to quantify natural resources, monitor changes in resources and provide quantitative estimates about resources. India's tryst with a remote sensing program started in 1972 when ISRO created the Space Applications Centre (SAC) that housed a Remote Sensing Meteorology Division (RSMD). In 1975, the National Remote Sensing Agency (NRSA) was established for operationalising remote sensing activities.

India's first remote sensing satellite, Bhaskara 1, was launched in 1979. It had a two-band TV camera system with a resolution of 1 km (visible and near infra red) as well as three-channel passive microwave radiometers. At present, the Indian Remote Sensing Satellite (IRS) constellation has three satellites in orbit out of which one is specially configured for oceanographic applications. The IRS 1C and 1D satellites with a resolution of 6 m (panchromatic[1]) were the satellites offering the highest spectral resolution in the world when they were launched in 1995/1997. This scenario has changed with the launch of IKONOS 2, in 1999. IKONOS has a panchromatic resolution of 1 m [1]. IKONOS is a satellite system from Space Imaging, a US company. Space Imaging took over Earth Observation Satellite Company (EOSAT) that had operated the Landsat satellite system when it was privatised by National Oceanographic and Atmospheric Administration (NOAA), USA. From 1995, stations around the world including those in USA are receiving the IRS data. It is interesting to note that data from the IRS constellation is a part of the Carterra data marketed by Space Imaging, the company that owns and operates the IKONOS. All data reception ground stations receive data from IRS satellites and use Indian data processing software to convert received data into useful information. The rationale for starting a satellite remote sensing program was to provide timely and accurate information of natural resources for its optimum management to assist the country's economic development. Dasgupta and Chandrashekar have provided an account of the innovation and institutional framework that have contributed to India acquiring a world-class capability in remote sensing [2].

Favourable internal organisational factors and external institutional factors combined with a choice of an emerging technology of Charge Coupled Devices (CCDs)-based sensors helped ISRO move from being a laggard to the world leader in remote sensing. ISRO believed that remote sensing technology could be used in many innovative ways to overcome the bottlenecks associated with in existing processes and procedures in user domains that they identified. For example, ISRO found that a more accurate estimate of agriculture production and hence gross domestic product could be obtained by using remote sensing technology. This estimate was found to be more reliable than those made using the land records available with the Government. ISRO and its sister concerns like NRSA, SAC, etc., were driven by a common vision and shared values. Dr. Sarabhai defined the vision of the Indian remote sensing program for national development. A core team of engineers and scientists in various areas transformed this vision into reality. Dr. Sarabhai and his successor Prof. Dhawan were instrumental in nurturing the shared beliefs among the scientists and a collegial atmosphere that helped build world-class technological capabilities. The scientists were united by a common vision of developing a state of the art indigenous technology. Linkages between different organisations (SAC, NRSA, etc.) and divisions (like sensor group, applications group, etc.) in the space program were encouraged. The main drivers of the innovation in the choice of CCD were the role of informal relationships based on professional respect and organisational flexibility and a successful management of liaison with Government.

ISRO has also pioneered working with the users of remote sensing data, such as the Ministries of Agriculture, Water Resources, Forests, and Environment as well as with a large number of other state and national organisations involved in the management and regulation of various resources. They cover a broad range of applications that include irrigation management systems, assessment of sugarcane crop, monitoring water logging and ground water location, forest cover and forest type identification as well as applications in geology and mining. These applications normally are done through joint projects and through major mission mode endeavours.

The creation of a technological capability and the potential for innovative uses for this technology has seen the emergence of a nucleus of a remote sensing industry in India. ISRO, NRSA and its sister organisations develop the technological capability in remote sensing and develop innovative uses of this technology. The users are usually Government organisations like the Ministry of Agriculture, Ministry of

[1] Ultraviolet and visible wavelengths.

Irrigation, Ministry of Environment, etc. ISRO and NRSA have transferred technology to organisations in the private industry to develop information systems to analyse the remote sensing data. Many of these organisations now offer services to a large number of users. These services not only cover land, water, forest and environment but also include new emerging areas like urban mapping and planning, telecom and oil pipeline infrastructure projects. Though the Indian Government's Department of Space (the apex organisation that encompasses ISRO, NRSA, SAC, etc.) earned only Indian Rupees (INR) 0.35 billion directly from remote sensing in 1998–1999, remote sensing technology if used in a few important user domains in agriculture would have resulted in benefits of about INR 100 billion *for the year* 1998–1999. Improved land use mapping alone could increase the contribution of agriculture to Indian GDP by about INR 120 billion *for the year* 1998–1999 [3]. It is interesting to note that the entire cost of the Indian remote sensing program *for 24 years* from 1975 to 1999 is INR 24.34 billion, when adjusted to 1998 value of the INR and the estimated benefits seem to far outweigh costs [3]. The International Finance Corporation estimates that 67% of India's workforce is engaged in agriculture and 29% of India's GDP is from agriculture in 1999. The fact that agriculture employs a majority of the Indian work force motivated ISRO to develop innovative uses for remote sensing in agriculture. The benefits of innovative uses of remote sensing technology in some important user domains like estimating agricultural production of cotton and sugarcane (two important cash crops of India), managing irrigation systems, developing rainfed (non-irrigated) regions, land use mapping, mapping and managing forest regions have been studied in detail [3].

3. Diffusion of remote sensing technology

ISRO and its sister organisations have provided Indian users with world-class, cost effective and innovative uses of remote sensing technology. In spite of this effort, the benefits that have accrued from this capability so far is still only a small fraction of the potential. It appears that the link between the creation of a significant world-class capability for meeting a major domestic need and its diffusion to multiple users is not easy or simple.

Research on diffusion of technological innovation has generally focused on the conditions which increase or decrease the likelihood that a new idea or technology will be adopted by potential users. Diffusion is the process by which an innovation is communicated through certain channels over a period of time among the members of a social system and the four main elements influencing diffusion are the nature of innovation, communication channels, time and the social system [4]. A technology like remote sensing consists of a "hardware" part that includes the remote sensing satellites, the receiving stations, etc., and a "software" part that includes the information derived from the remote sensing data. The diffusion of the "software" part of the technology is generally more difficult than the "hardware" part. The communication of an innovation is when the diffusion is among players with a similar socio-economic background and beliefs. For example, it is easier for the scientists in NRSA to convince the idea of using remote sensing data to engineers in a private construction organization building cross-country pipelines because of their similar educational backgrounds that gives them a shared language. An important determinant of time taken for diffusion is how well the adopter is persuaded to form a favourable attitude towards the innovation. In this case, NRSA needs to develop the right communication strategies to influence the user community to develop a disposition to using remote sensing information. Social norms can sometimes be a barrier to change and diffusion of innovation may require change agents and a network of interconnected organizations. NRSA will need to be a part of and get the user community along with change agents (preferably from the user community to form a network. Press et al. [5] explain how the users adopt a new information technology like the Internet and the factors influencing adoption are very similar to the four elements discussed.

The complex interplay between the organisations and institutions in the technology development and user domains and the social, political and economic forces will shape the adoption and diffusion of technology. Change in one part of this system without accompanying change in other parts may affect the rate of diffusion of innovation. Can a new capability like remote sensing force a radical change or should change take place through a slower process of interaction and incremental adjustment? Will the larger policy initiatives in terms of institutional and market reforms automatically create conditions for speedy diffusion of innovations? Can the Government initiate steps that can facilitate innovation and its diffusion? These are some of the issues that will be addressed in the following sections of this paper.

4. Methodology

The contemporary nature of the research on Indian remote sensing and the researcher's lack of control over the events make case study an appropriate research methodology [6]. The review of research literature and a preliminary secondary data based study of the Indian remote sensing program provided the knowledge that though a world-class technological capability exists it had not been translated into a national system of innovation. The application of Remote Sensing in the user domain of land use mapping was chosen for a detailed study since it was evident that there was a national need that existed in this domain for remote sensing applications. Primary data is from in-depth semistructured interviews with senior professionals associated with the Indian remote sensing program and the user community. It was decided not to reveal names of the interviewees since we wanted to capture the "real information" for the case study and not just the "official information". Secondary data is from published reports and surveys. The dominant mode of analysis of the case study used in this research is explanation building [7]. The emphasis is to explain how Indian Remote Sensing has created a world-class technological capability that has not yet been transformed into a national system of innovation and the implications for policy making.

5. Remote sensing technology for land use mapping

An India wide remote sensing survey was carried out by NRSA in 1988–1989 to provide an overview of various land use categories. Discrepancies were observed when the NRSA data obtained from remote sensing was compared with the data obtained from land records available with the Bureau of Economics and Statistics (BES), a part of the Ministry of Agriculture. Since these discrepancies were observed at a district (administrative divisions in an Indian state) level, NRSA and the BES of the State Government of Andhra Pradesh decided to undertake a ground study to unravel this discrepancy and reconcile the NRSA and BES data. The details of this study are available in "A Summary Report on Reconciliation of Land Use/Land Cover Statistics Generated by Remote Sensing and Ground Based Techniques", published by NRSA in 1993 [8]. Three districts in the Indian state of Andhra Pradesh, Krishna, Kurnool and Nalgonda were selected for the reconciliation exercise. This ground study indicated that the NRSA

Table 1
Comparison of BES and NRSA estimates for Net Area Sown (adapted from Rajan et al. [3])

District	BES estimate of Net Area Sown (%)	NRSA estimate of Net Area Sown (%)	Ground study estimate of Net Area Sown (%)	Difference between BES and ground study estimate (%)	Difference between NRSA and ground study estimate (%)
Krishna	55.8	75.05	68.70	−12.90	6.98
Kurnoool	47.1	64.80	63.46	−16.36	1.34
Nalgonda	43.25	70.07	61.26	−18.01	8.81
All Three	47.62	68.47	63.75	−16.13	4.72

estimates were closer to the actual values for Net Area Sown (NAS), the area of land that is under cultivation. The BES estimates were consistently under reporting Net Area Sown. It was also found that in the BES data land under cultivation was shown as fallow land and vice versa. It is interesting to compare the accuracy of Net Area Sown data obtained from NRSA and BES. These results have been documented in “Report on Area statistics of Land Use/Land Cover Generated Using Remote Sensing Techniques—India”, put out by NRSA in 1995 [9]. Table 1 shows the comparison between the BES, NRSA and ground study estimates. The numbers in the table represent the percentage of area of land in the district that is Net Area Sown. The ground study estimate is the base for calculating the difference.

It is clear that the NRSA estimates for Net Area Sown are closer to the real values obtained by the ground survey than the BES estimates and hence remote sensing technology provides a superior method of collecting data on Net Area Sown. The next step is to understand the implications of the difference in these estimates in value terms. The total area in the three districts and the Value of Agriculture Production (VAP) per area in each of the three districts are given in Table 2 [10]. Value Of Agriculture Production per unit area is the average for the period 1986–1987 and 1988–1989 that corresponds to the period of Net Area Sown data estimates. From these values and the percentage of land that is Net Area Sown from Table 1, the Value Of Agriculture Production is calculated under the BES, NRSA and ground study estimates of Net Area Sown. The Value Of Agriculture Production for the districts is shown in Table 3.

The NRSA estimates seem a better representation of reality than the BES estimates. Extrapolating this analysis to all districts in all states, the NRSA estimates would result in an increase in estimate of the Value Of Agriculture Production by INR 42 billion for India for the year 1988–1989 or INR 120 billion for 1998–1999 [3]. This improved estimate of the measure of the Value Of Agriculture Production has an impact on import and export policies for agricultural commodities, inventory holding decisions of the Government and private sector and futures trading in agricultural commodities. One could argue that the BES estimates in other districts and other states may be better and closer to that obtained from a ground study. Experts in this domain are of the opinion that the results of the sample from these three districts of

Table 2
Area of district and value of agriculture production per unit area (adapted from Rajan et al. [3])

District	Area (ha)	Value of agriculture production (INR/ha)
Krishna	872 700	5500
Kurnool	1 765 800	2740
Nalgonda	142 400	3283

Table 3
Value of agriculture production for districts under BES, NRSA and ground study estimates (adapted from Rajan et al. [3])

District	Value of agriculture production estimate from BES (INR in billion)	Value of agriculture production estimate from NRSA (INR in billion)	Value of agriculture production estimate from ground study (INR in billion)	Difference between BES and ground study estimate (INR in billion)	Difference between NRSA and ground study estimate (INR in billion)
Krishna	2.68	3.60	3.30	−0.62	0.30
Kurnool	2.28	3.14	3.07	−0.79	0.07
Nalgonda	2.02	3.31	2.86	−0.84	0.45
All Three	6.98	10.05	9.23	−2.25	0.82

one state is likely to hold across India since the reasons for the discrepancy are a result of institutional factors that are prevalent in all Indian states. Though the benefits of using remote sensing data are evident from this case, the users have been reluctant to use this data. This is in spite of ISRO communicating the benefits of remote sensing to users and policy makers in a number of ways including projects. A National Natural Resources Management System was set up under the aegis of the Indian Planning Commission in 1983 to encourage use of remote sensing data. Only a few Indian states (like Andhra Pradesh) have been using remote sensing for land use mapping. The technological capability and the attempted innovation in applying remote sensing for land use management have seen a slow adoption rate as a result of unfavourable institutional factors. We believe that national technology missions and joint projects between Government, science and technology organisations, academia and industry and allowing free trade and removing institutional restrictions to trade especially in agricultural commodities and related industries will help India realize the full potential of remote sensing technology.

6. Influencing diffusion of remote sensing technology

6.1. Issues of land reform

The salient features of land reforms in India have been to abolish the intermediary tenures, imposing ceiling on land holdings and distribution of surplus land among those who did not own land [11]. The ceiling on land holdings plays an important role in incorrect estimates by BES that are based on land records. Laws pertaining to the fixation of ceilings contain a number of exemption clauses and loopholes. These have led to collusion between some employees of the Government (who were trusted with the implementation of the law) and landowners. For example, it has been difficult for small-time farmers to register the land they obtained as a result of the land ceiling law with the Governments. Some Government officials in collusion with bigger landowners record these as fallow land. Incorrect, fictitious and incomplete land records have helped landowners in evading ceiling laws. There are instances where large tracts of fallow land in Government records are actually being cultivated. There are also instances of landowners continuing to cultivate land that should have been above the ceiling and is in the possession of the entire village community and accounted as non-agricultural land in Government records. The allotment of surplus lands by the Government also witnessed favouritism and creation of doctored records. The Governments never considered maintaining an accurate land record system a priority. Experts are of the opinion that in some states the land records are typically two decades out of date and frequently unusable [11]. Under these institutional conditions, it is only natural that the BES estimates of Net Area Sown is less than the ground study estimates. It is only from 1998 that a few of the states like Andhra Pradesh have started verifying and computerizing land record data. Most of these efforts so far have been pilot projects confined to one district or a few districts in the state. If some of these constraints are removed and transfer of land is freely allowed then some of the reasons for this under reporting may disappear. Also, information on agricultural surplus does not have any value if free trade between different Indian states cannot take place and if spot and futures trading are not permitted.

In this institutional context, it is difficult for remote sensing technology to become widely used even when the economic benefits are clear. Some of the users who are employees of the State Government will not like their collusion with the landowners to be exposed. Experts from the user community interviewed are of the opinion that exposing collusion in certain cases will create embarrassment for some State Government employees and some politicians. The use of remote sensing data may take away the power of some Government employees that is derived from making a survey and writing land records. Needless to add, there will be little opportunity to accept bribes for making fictitious records. Though the Ministry of Agriculture is for using remote sensing technology and contributes to the development and diffusion of the innovative uses of remote sensing technology, the existing institutional framework for policy making does not provide an ideal environment for the diffusion of innovative uses of remote sensing technology. As seen in the land use mapping domain, some Government officials would not like to obtain a more realistic estimate of land use mapping since this would lead to questions on not only BES estimates but also on the validity of Government land records. These institutional factors clearly inhibit the diffusion of innovation in land use mapping even when India possesses a world-class remote sensing technological capability. Though this is just one case of a remote sensing user domain that clearly shows the influence of institutional barriers that can slow a diffusion of innovation, it is representative of many other user domains. In some user domains like forest cover, ground water and wasteland mapping, there has been some impetus for a nation wide diffusion of remote sensing technology. A few significant institutional factors influencing diffusion of innovative use of remote sensing technology in other user domains are discussed in the next section.

6.2. Other institutional factors

Remote sensing technology is a source of information for the user. Information has value only when the institutional factors are favourable. For example, there is no use for an accurate estimate of the cotton crop in India using satellite remote sensing since the Government controls the pricing and movement of cotton across India. The Government also controls what quantity of cotton can be exported or imported and when it can be done. In such institutional framework, information on accurate estimates of the cotton crop is of little value to the users (Ministry of Agriculture, Ministry of Textiles, farmers, cotton traders and sinning mills). Only when the institutional framework allows for cotton spot and futures trading that users will appreciate the value of accurate estimates of cotton crop.

The Ministry of Forests on the other hand uses remote sensing to estimate the national, state and district forest covers after joint efforts with ISRO has proved the efficacy of using remote sensing technology. The strong pressure from the environment lobby and an active judicial process has contributed to make this diffusion possible. For some users, external pressure has necessitated the use of remote sensing technology. The World Bank insists that remote sensing needs to be used to establish a baseline for an irrigation project. This has made the Central Water Commission of India in the Ministry of Irrigation put to use remote sensing to monitor areas under irrigation projects in terms of area actually irrigated, the crops grown and difference between "head" and "tail" end of the project. The Ministry of Environment has taken a cue from the World Bank and insists on remote sensing based assessments for infrastructure projects. In fact, remote sensing for environment impact assessments has become a major activity for private remote sensing information systems providers who build information systems that use remote sensing data provided by NRSA. Research and development, training and piloting of new remote sensing technologies have been the focus of NRSA and its policy for technology diffusion has been to assist private firms to develop and market information systems that use remote sensing data from NRSA. The record of diffusion of remote sensing technology has been mixed and a lot more needs to be done to accelerate this process.

7. Recommendations

Various measures have been suggested to accelerate the process of diffusion and use of remote sensing technology. Some of these are linked to the chain of value adding activities of remote sensing and the institutions that shape them. The remote sensing information is the "software" part of the innovation that is more difficult to diffuse and requires interventions from NRSA to establish effective communication channels [4]. ISRO and NRSA need to make sure that they strengthen existing training programs in the use of remote sensing technology. The private sector can be increasingly involved in the effort to commercialise the capability both in the organisation and management of the data as well as in applications. Dasgupta and Chandrashekar trace the privatization of the Landsat program in the USA [2]. In 1979, the Landsat program in the USA was transferred from National Aeronautics and Space Administration to a user organization, National Oceanic and Atmospheric Administration. In 1981, it was decided to transfer the Landsat program to a private operator who would be subsidized by the Government. The Earth Observation Satellite Company (EOSAT) was formed in 1985 to take over the Landsat program. After almost a decade that frequently saw difficulties in funding for satellites and in EOSAT's pricing remote sensing data, the Government established the Landsat Program management to develop a data policy that will work on the basis of "cost of fulfilling user request". NRSA can learn from this experience and a pay per use scheme could be introduced where the remote sensing data is sold according to the area required by the customer and not by what is captured by the satellite. Turnaround time for remote sensing data procurement could be reduced by NRSA by insisting that data would be supplied through the Internet (say by e-mail). NRSA could serve users better by allowing them to surf for data and order them over the Internet. Some large users may want to access real time data. This facility is not provided at present but can be a potential value-added service of NRSA in the future. Another institutional factor that influences diffusion of remote sensing are Government of India restrictions on digitising maps and blocking off those areas that are considered sensitive to national security. These restrictions seem meaningless today when commercial remote sensing satellite systems can provide 1 m resolution images.

Social systems resulting from a network of organizations can have a positive influence in the diffusion of technology innovations [4]. Apart from these factors that are to some extent under the control of ISRO and NRSA there other institutional factors that seems to inhibit diffusion of innovation. Historically, Indian R&D (that is concentrated in Government organisations) has been isolated from the users (both Government and private industry). Only a few innovations in R&D have benefited a large percentage of the Indian population. Notable among them are the Green Revolution (that helped India Achieve self sufficiency in food grain production in the 1970s). Efforts need to be taken by the Indian Government to create a network of organisations in R&D, user domains and private industry so that diffusion of innovative uses of indigenously developed technology is easy and quick [12]. Needless to add, the institutional frameworks for meeting these needs have to be altered to allow for the diffusion of innovative uses of a technology. The question remains as to how an understanding of the institutional factors can be useful to diffuse remote sensing technology. The concept of National Systems of Innovation will help us understand the implications of these factors of policy formulation and implementation.

8. National systems of innovation

A national system of innovation is a set of organisations that individually and more important jointly contribute to the development and diffusion of new technologies and provides a framework for policy making to influence the innovation process [13,14]. The interconnection among organisations is a critical factor that creates stores and transfers technical knowledge that defines new technologies. The nationality aspect is rooted in the shared vision, culture and policies; in short, the institutional frameworks that condition the innovation environment. The national system of innovation involve different organisations; Government, Government laboratories, universities, private companies, etc., working in collaboration. Although, there is a formal division of labour among the different organisations constituting the national system of innovation, informal networks are the important routes for transferring the more tacit technical knowledge.

The national system of innovation is a continuously evolving system that attempts to adapt to the socio-economic realities rather than attempt Pareto efficient optimisation. As shown in Table 3, the Value Of Agriculture Production estimate using the statistical methods using historical data has been understated by about 24%. It usually reflects a predominance of co-ordination by non-market means due to the economic peculiarities of information. When the national system of innovation is organized well, it is a powerful engine for progress as is evident in the case of Japan [15].

The central concern of the national system of innovation is the innovation process that operates under a set of institutions within which technological capabilities are accumulated. The evolutionary approach of economic change is useful to understand the dynamics of the national system of innovation. Evolution means a cumulative and path dependent change where the focus is on adapting rather than optimising. From the national system of innovation viewpoint, change is interpreted as the emergence of novel form of technology configurations under certain set of institutions and the development of these configurations through a sequence of innovations [13].

The national systems of innovation are not easily transferable but are country specific and rooted in skills and capabilities and knowledge that are accumulated over a period of time [16]. Though the national systems of innovation are not totally transferable, the process of creating these systems can at least provide a road map for other countries in a similar context on how to attempt developing national systems of innovation. It is interesting to study the Indian remote sensing program that took India from a laggard in 1979 to a global leader having a civilian remote sensing satellite system with highest resolution in 1995. Apart from developing a world-class technological capability, this program also envisaged innovative uses of remote sensing technology unique and relevant to India. The remote sensing program provided Indian scientists to successfully plan and implement large technology projects that developed skills in leading edge technologies in sensors and optics. The remote sensing data has been useful in water resource planning benefiting Indian agriculture (that contributes to 29% of GDP) and assess environmental impact of large infrastructure projects. The potential users of the remote sensing technology were (and in most cases still are) operating under a different set of institutional and policy frameworks from those who helped to build the technological capability. This has inhibited the diffusion of the innovative uses of remote sensing technology even when the benefits were clearly evident to the users. The Indian remote sensing program has still not translated itself from an ISRO innovation into a national system that can have a major impact on Indian economy. Policy implications related to the diffusion of remote sensing technology are discussed next.

9. Implications for policy

Remote sensing is an information technology. However, unlike telecommunications or computers it provides information on natural resources. Government users require such information for managing natural resources in India. This information has also has value only if it can be used for practical decision making. In a society that is significantly constrained by the institutional framework, the value of information is bound to be low. Science and technology organisations like ISRO have created world-class capabilities that have not been strongly linked with Government user domains. When industry is to be brought into the innovation chain, the links are even more tenuous. Though the economic reform to transform India from a planned economy to a market economy has ostensibly started in 1991, the process has been slow and retarded by a variety of institutional factors. Though macro level reform in the Indian economic agenda has made some headway, reform at a micro level has not taken place. The abuse of networks between Government, industry, science and technology organisations and regulators has come in the way of innovation. This is reinforced by this study on the diffusion of remote sensing technology in India. Even if one argues that the changing the national systems of innovation is evolutionary, there are certain policy interventions that can accelerate the diffusion of innovation in using new and appropriate technology. These include:

- Understanding the dynamics of competition at a micro industry level and using appropriate institutional and regulatory reform. This has not happened in the Indian context.
- Allowing free trade and removing institutional restrictions to trade especially in agricultural commodities and related industries. Futures and spot trading in agricultural commodities seem important.
- A micro level approach to technology-based innovations in some sectors of the Indian economy that are considered important. These could be in the form of national technology missions and joint projects between Government, science and technology organisations, academia and industry.
- Encouraging and fostering the emergence of networks that link science and technology organisations, Government regulators and users and private industry not only for building technological capability but also to encourage diffusion of such innovations.

Such interventions will open the Indian economy and create the necessary conditions for the speedier diffusion of innovations.

10. Conclusion

The Indian remote sensing program has created a world-class capability but has not yet been able to translate this capability into a national system of innovation because the institutional framework among the users (mostly in the Government) does not provide any incentive for the diffusion of the innovation in using remote sensing data. The institutional framework is so strong that even hard data on economic benefits do not seem to have an impact in bringing about a change. This paper shows that even if a country develops a world-class technological capability, it still may not be able to develop a national system of innovation. The technological capability can be developed under supportive institutional factors that ensure the congruence in motivation of all stakeholders creating the technological capability. The diffusion of the innovation can be hampered by a different set of institutional factors that inhibit users from adopting the innovation. A national system of innovation can develop only when institutional factors for both technological capability building and user adoption is conducive to the diffusion of innovation.

Acknowledgement

We thank Prof. Oscar Hauptman, Prof. Winston Koh, Prof. Arcot Desai Narasimhalu, Prof. Tan Wee Liang, and Prof. Ted Feichin Tschang of Singapore Management University for their support. We also thank the reviewers for their comments. N. Dayasindhu thanks Singapore Management University for the METiA Participant Fellowship.

References

[1] W.E. Stoney, Land sensing satellites in the year 2000, International Geoscience and Remote Sensing Symposium (IGARSS), Singapore, 1997.
[2] A.R. Dasgupta, S. Chandrashekar, Indigenous innovation and IT enabled exports: a case study of the development of data processing software for Indian remote sensing satellites, University of Pennsylvania Institute for the Advanced Study of India, 2000.
[3] Y.S. Rajan, S. Chandrashekar, G. Raj, An evaluation of the benefits of the Indian remote sensing programme. Report submitted to the Department of Space, India, 1999.
[4] E.M. Rogers, Diffusion of Innovation, 4th ed., The Free Press, New York, 1995.
[5] L. Press, G. Burkhart, W. Foster, S. Goodman, P. Wolcott, J. Woodard, An Internet diffusion framework, Commun. ACM 41 (10) (1998) 21–26.
[6] R.K. Yin, Case Study Research, Design and Methods, 2nd ed., Sage Publications, Thousand Oaks, 1994.
[7] M.B. Miles, A.M. Huberman, Qualitative Data Analysis: An Extended Source Book, 2nd ed., Sage Publications, Thousand Oaks, 1994.
[8] National Remote Sensing Agency, A Summary Report on Reconciliation of Land Use/Land Cover Statistics Generated by Remote Sensing and Ground Based Techniques, NRSA, Hyderabad, India, 1993.
[9] National Remote Sensing Agency, Report on Area Statistics of Land Use/Land Cover Generated Using Remote Sensing Techniques—India, NRSA, Hyderabad, India, 1995.
[10] CMIE, Profile of Districts, Centre for Monitoring Indian Economy, 1993, Mumbai, India.
[11] H. Laxminarayan, S.S. Tyagi, Changes in Agrarian Structure in India, Agricole, New Delhi, 1982.
[12] S. Chandrashekar, K.P. Basavarajappa, Technological innovation and economic development: choices and challenges for India, Econ. Polit. Wkly 25 (2001 (August)) 3238–3245.

[13] B.A. Lundvall, in: G. Dosi, C. Freeman, R.R. Nelson, G. Silverberg, L. Soete (Eds.), Innovation as an Interactive Process: From User–Producer Interaction to the National System of Innovation in Technical Change and Economic Theory, Pinter, London, 1988.
[14] J.S. Metcalfe, Technology systems and technology policy in an evolutionary framework, Camb. J. Econ. 19 (1) (1995) 25–46.
[15] C. Freeman, Technology Policy and Economic Performance: Lessons from Japan, Pinter, London, 1987.
[16] D. Archibugie, J. Michie, Technology and innovation: an introduction, Camb. J. Econ. 19 (1) (1995) 1–4.