Diffusion of Public Sector Innovation:
The Case of Remote Sensing Technology in India

Dissertation submitted in partial fulfillment of the requirements for the Degree of Master of Philosophy in Applied Economics of the Jawaharlal Nehru University, New Delhi.

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I hereby affirm that the work for this dissertation, 'Diffusion of Public Sector Innovation: The Case of Remote Sensing Technology in India' being submitted as a part of the requirements of the M. Phil Programme in Applied Economics of the Jawaharlal Nehru University, was carried out entirely by myself. I also affirm that it was not part of any other programme of study and has not been submitted to any other University for the award of any degree.

16th June 2007

Satheesh K G

Certified that this study is the bona fide work of Satheesh K G, carried out under our supervision at the Centre for Development Studies.

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Dedicated to

My Father, Mother and Brother.

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ABSTRACT OF THE DISSERTATION

Diffusion of Public Sector Innovation: The Case of Remote Sensing Technology in India

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In India, almost two third of the gross national expenditure on Research and Development (R&D) is in the Government sector. Government R&D expenditure is primarily concentrated in defence, space, atomic energy and in agriculture. An often-repeated complaint is that most of the technologies developed by government research institutes in these areas with the possible exception of agriculture are not diffused, especially at the civilian space. Very often, this lack of diffusion of public sector technologies are attributed to the excessive security concerns that these agencies may suffer from. In this context, the present study is an examination of the nature and extent to which one public sector generated technology, namely remote sensing, has actually diffused in the economy and also in one of its potential market for it, namely urban planning. The study also examines the factors that are influencing the diffusion process of the technology. Findings of the study reveal that the level of diffusion of remote sensing technology (RST) in India is about 34 percent of the potential level of diffusion. Similarly, in one application of the technology, urban planning, the level of diffusion is 45 percent of the potential diffusion. However, the speed of diffusion of the technology both at aggregate level and in one of its application is slow. The study also found that the diffusion of the technology is influenced by factors that are related to the benefits from adoption, the information on the technology, and the regulatory environment. Factors that are related to the benefit from adoption and the information on the technology have improved or developed over time, thereby encouraging the diffusion process. On the other hand, the study finds that the regulatory environment characterized by map policy and remote sensing data policy, together with the lack of potential adopters' capability for efficient utilization of the technology hamper the speed of diffusion of RST in our economy. Thus, our study shows that the diffusion of a public sector generated technology is impeded by the existence of public regulatory policy.

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Abbreviations

AEC	Atomic Energy Commission
CCD	Charge Coupled Device
CCRS	Canada Centre for Remote Sensing
CD	Compact Disc
CESS	Centre for Earth Science Studies
CSIR	Council of Scientific and Industrial Research
CSIR	Council of Scientific and Industrial Research
DAE	Department of Atomic Energy
DoD	Department of Defence
DoS	Department of Space
DRDO	Defence Research and Development Organisation
DSM	Defence Series Map
EOS	Earth Observation System
GDP	Gross Domestic Product
GIS	Geographic Information System
GIS-BPO	Geographic Information System -Business Process Outsourcing
GPS	Global Positioning System
GPT	General Purpose Technology
GRS	Ground Receiving Station
HRC	High Resolution Image Clearance Committee
ICAR	Indian Council of Agricultural Research
ICT	Information and Communication Technology
IIRS	Indian Institute of Remote Sensing
IISU	ISRO Internal Systems Unit
IIT	Indian Institute of Technology
IMSD	Integrated Mission for Sustainable Development
INCOSPAR	Indian National Committee for Space Research
INSAT	Indian National Satellite
IRS	Indian Remote Sensing
ISAC	ISRO Satellite Center
ISRO	Indian Space Research Organisation
ISTRAC	ISRO Telemetry Tracking and Command Network

KSREC	Kerala State Remote Sensing and Environment Centre
LISS	Linear Imaging Self-scanner Sensor
LPSC	Liquid Propulsion Systems Centre
MHR	Machine Hour Requirement
NDC	NRSC Data Centre
NGO	Non-Governmental Organization
NMRF	National Mesosphere-Stratosphere-Troposphere Radar Facility
NNRIS	National Natural Resource Information System
NNRMS	National Natural Resource Maintenance System
NNRMS	National Natural Resource Management System
NRSC	National Remote Sensing Centre
OSM	Open Series Map
PAN	Panchromatic Camera
PRL	Physical Research Laboratory
PRL	Physical Research Laboratory
R&D	Research and Development
RGTIL	Reliance Gas Transportation Infrastructure Ltd
RRSSC	Regional Remote Sensing Service Center
RSDP	Remote Sensing Data Policy
RST	Remote Sensing Technology
SAC	Space Application Centre
SHAR	Sriharikota Range, formerly Satish Dhawan Space Centre of ISRO
SoI	Survey of India
SRSSC	State Remote Sensing Service Center
TCS	Tata Consultancy Services
TIFR	Tata Institute of Fundamental Research
VRC	Village Resource Center
VSSC	Vikram Sarabhai Space Centre
WiFS	Wide Field Sensor

Chapter One
Introduction

1.1. Context and Background of the Study

In India, around two third of the total national Research and Development (R&D henceforth) expenditure is performed in Government sector[1] (Department of Science and Technology, 2006). According to the latest R&D statistics published by ministry of Science and Technology, Govt. of India, 75.6 percent of the total national R&D resources is devoted to Government sector (comprising of both central and state governments) and 20.3 and 4.1 percent of the resources is disbursed in private sector and higher education respectively. Defence, space, atomic energy and agriculture are the four sectors where more than 50 percent of the Government R&D is concentrated. Five major government research agencies, Defence Research and Development Organisation (DRDO), Department of Space (DoS), Indian Council of Agricultural Research (ICAR), Department of Atomic Energy (DAE), and Council of Scientific and Industrial Research (CSIR) account for nearly 86 percent of the central government R&D expenditure (Department of Science and Technology, 2006). A frequent criticism is that the technologies that are developed by these government research agencies other than ICAR are not diffused in the economy, particularly at the civilian space. The low diffusion of technologies developed by government agencies is often attributed to the high security considerations that these research agencies may suffer from. In this context, the purpose of the present study is to understand what extent has a public sector technology diffused and to identify the determinants of the diffusion process, which we have observed in the case.

[1] The highly skewed distribution of national R&D resources between public and private sectors has been attributed to the Nehruvian science policy (Nayar, 1985).

This study on the diffusion of public sector innovation in India, examines the case of Remote Sensing Technology (RST henceforth). The remote sensing industry in India is largely based on government designed, owned and operated Indian Remote Sensing (IRS henceforth) satellite systems and to some extent foreign satellites especially Landsat and SPOT[2]. At present IRS satellite constellation has seven satellites in orbit, designed for different applications, and India is one among the few countries who have developed technical capability in this technology (detailed discussion on the development and features of RST is provided in chapter two). Very few economic studies examine India's competence building in complex dual use technologies like space technology. Economic literature suggests that competence building in Indian space programme[3] is attributed by different factors such as; a) strong scientific leadership and political backing, b) the role of Indian Space Research Organisation (ISRO henceforth) in building infrastructure and skills, c) strong indigenous effort through the building of inter-institutional linkages, d) foreign technological inputs (Baskaran, 2001 and 2005). Taking the case of RST, favorable internal organizational factors and external institutional factors combined with the choice of an emerging technology of Charge Coupled Devices (CCD) based sensors helped ISRO to move from being a laggard to the world leader in RST (Chandrasekar and Dayasindhu, 2005).

1.2. Statement of the Research Problem

The process of technological change envelops three stages: invention, innovation, and diffusion. It has been pointed out that the diffusion is the pivotal element in the process of technological change, as without being spread, the new innovation or technology would have little social or economic impact. The economic significance of the technology diffusion is that it is the process of diffusion that determines the improvements in productivity and

[2] Landsat and SPOT are satellite systems of US and France respectively.
[3] Indian space programme is comprised of IRS and INSAT (for communication).

product quality and thereby enhances the competitiveness of economic agents. In case of a public sector technology, its foremost goal of socio-economic development is realized only when the concerned technology has diffused successfully in the economy. Moreover, the diffusion of a public sector technology is supposed to generate a good amount of positive externalities or spillovers in the economy. While the spread of the technology is important, it is never an easy or rather a smooth process. Technologies can diffuse in multiple ways and with significant variations, varying across time, over space and between different industries or sectors. As mentioned in the earlier section, in India, the technologies developed by the public sector research agencies in different sectors (other than agriculture) have not successfully diffused over time. This phenomenon signifies the complexity of the potential forces and environment that work simultaneously to determine the dynamics of diffusion. The major explanations for the unsuccessful diffusion of technologies developed by the public sector laboratories are[4] that; those innovations were not in accordance with the demand or need of the economy, and thereby the benefit from adoption of these technologies were low. Secondly, there was lack of interaction between the public sector research agencies and the industry/market, failing to spread the technologies from 'lab to land'. Finally, the high security considerations that the public sector research agencies suffer from.

Since India is more or less agriculture and natural resource dependent economy, the spread of a technology like remote sensing has much economic significance. The technology has the potential to accelerate the economic development process (Rao, 1991). The growing population, rapid industrialization and urbanization has caused tremendous pressure on natural resources. RST addresses these challenges to development, and provide efficient information that is vital in scientific planning. Government of India

[4] This information is obtained from the discussions held with the people in the area.

initiates many National Programmes using RST such as: National Drinking Water Technology Mission, Integrated Mission for Sustainable Development, National Natural Resource Information System, National Natural Resource Maintenance System, FASAL, etc. Accordingly, a study on the diffusion of RST is significant as the importance of utilization of potential of the technology is high in a natural resources abundant country like India.

Essentially, RST is a spatial information provider[5]. As economies grow more complex the generation and use of relevant, timely and accurate information becomes increasingly important. For example, basic data on production, acreage and yields of various crops influence many economic activities. If forecasts on crop production are inaccurate it can lead to rent seeking rather than value adding behavior[6]. Accurate information of crop acreages and production is therefore important for government, farmers, traders and industries involved with the agriculture sector. Timely import and export decisions and future market also depend on accurate forecasts of production. Conventionally, collection of basic agriculture statistics at village level is largely based on the records maintained by revenue officials. The many other responsibilities thrust on officials at village level make the collection of statistics a burden and is therefore often neglected. As a result the quality and accuracy of the data has suffered (Vaidyanathan, 2001). So, timely accurate forecasts and estimates of basic statistics on various crops that are necessary for the functioning of basic market mechanisms are absent in many cases. In this context, adoption of RST for basic agriculture data is relevant as it meet the basic needs of market; generation of relevant, timely and accurate information. Similarly, RST has innovative applications in the areas of

[5] RST can be used as a complimentary, substitute and unique technique for collecting information (discussed further in chapter two). Generally, RST is considered as a substitute for ground level survey for collecting spatial information.
[6] The sudden spurt in prices of onions in the middle of 1998, which created a major problem for government, is the crisis that happened because of absence of timely accurate information on the production of this crop (Outlook: 'The onion bungle', Oct 1998, p.22).

hydrology, fishing, forestry, mining, infrastructure mapping, urban planning etc. However, the level of utilisation of the technology is also important. As discussed earlier, ISRO and its sister agencies have created significant capability in RST and the question how far this capability has been utilized or in other words the level of diffusion of this technology, remains significant.

One of the significant applications of RST, in which we are interested to examine the extent of diffusion, is urban planning. Day to day problems of urban development, i.e. traffic and transportation, greenery, solid waste disposal, pollution, location of new layout for urban growth, road alignment etc., have been given a new look (under Geographical Information System [GIS][7] environment), with possibilities arising out from high resolution images of IRS satellites (Radhakrishnan et al, 1996). In India, 27.86 percent of population (285 million people) lives in urban areas, consisting of 4,378 urban agglomerations/towns of varying size (Census of India, 2001). According to the World Urbanisation Prospects, the urban population of India in 2025 will rise to 42.5 per cent (566 million people). The impact of urbanisation includes the problems of housing, sanitation, supply of power and water, disposal of wastes and environmental problems. Hence, there arise the need for integrated urban planning, which calls for information on the spatial distribution and information on extent of land and other natural resources in and around the urban centers, and their dynamics. RST addresses these needs of spatial information associated with urban planning and management[8]. But remote sensing data does not appear to be used by large number of local bodies. Economic literature suggests that the benefits that have been acquired by the economy from the technological capability in RST are still only a small fraction of the potential (Bagla, 1996, Chandrasekhar and Dayasindhu, 2005,

[7] GIS is a computer-assisted system for the capture, storage, retrieval, analysis and display of spatial data.
[8] For a detailed discussion of scope and areas of application of RST in urban planning and management, see Saxena (2001).

Sankar and Rao, 2007). More clearly, even though ISRO and its sister organizations have provided Indian users with world class cost effective and innovative uses of RST, its diffusion remains low. Chandrasekar and Dayasindhu (2005) examines institutional factors such as issues related to land reforms responsible for slow adoption rate of remote sensing in land use mapping. Sankar and Rao (2007) observes that a large use of remote sensing derived information has been denied due to the lack of institutional mechanism. But none of the studies attempted to measure the diffusion of RST and factors determining the diffusion of the technology.

1.3. Objectives of the Study

In the light of above discussion, this dissertation aims to study the dynamics of diffusion process of RST by enquiring the level and speed of diffusion and the key factors that determine the spread of the technology in the economy. The specific research objectives can be outlined as:

a) To measure the extent of diffusion of RST in India.

b) To measure the extent of diffusion of RST in one of its application-Urban planning.

c) To identify the factors influencing the diffusion process of RST.

1.4. Research Methodology and Data Sources

In order to measure the extent of diffusion of RST in India, the study will be using the secondary data provided by National Remote Sensing Centre (NRSC). We employ average annual growth rate of real revenue of NRSC as a proxy to measure the speed of diffusion of RST. With the speed of diffusion at different time periods and by assuming an initial level of diffusion, the level of diffusion for different time periods would be measured (a detailed discussion on the methodology employed for measuring diffusion is provided in sections 4.2 and 4.3). Similarly, in case of urban planning, diffusion of RST is measured by adopting inter adopter (inter firm) method of measuring diffusion. The source of data on adopters of RST in urban planning is the unpublished data from NRSC and answers to questions in parliament.

For identifying the factors influencing the diffusion process of RST, we employ qualitative field survey as the research method, and adopt semi-structured interview technique to collect primary data. In this study, a purposive sampling procedure is adopted to select the sample from the population of technology provider and different sections of adopters (a detailed discussion on the research methodology adopted for selecting the sample, data collection and data analysis is provided in section 5.2).

1.5. Outline of the Dissertation

This dissertation is composed of six chapters, which can be organised into three complementary parts. In the introductory part (chapters one and two) we present the research outline of the dissertation, and examine theoretical and empirical literature on diffusion. The second part (chapter three) presents an overview of Indian remote sensing industry, wherein the trends in the industry are analysed using secondary data from NRSC. Part three consists of two chapters (chapters four and five) that form the core of this dissertation. These chapters deal with the measurement of diffusion of RST in the economy and in one of its application, and also identifying the factors influencing the diffusion process of RST.

Chapter one presents the contextual background of the present study, the research problem and outlines the study objectives. This chapter also concise the methodology adopted and the data sources. Chapter two provides a review of the existing literature. Although bulk of the discussion centers around the mainstream economic literature on diffusion, an attempt is made to bring sociological perspective into the review. Also, chapter two layouts a theoretical framework for the dissertation, which is drawn from the theoretical and empirical literature discussed in the previous sections. Chapter three provides an overview of the evolution of Indian remote sensing industry. In this chapter we attempt to historically trace the developments of Indian remote sensing programme from its origin to the present state. Using secondary data from NRSC, we also analysed the sales and revenue of NRSC and sectoral composition of the same. Chapter four is an attempt to measure the extent of diffusion of RST in India and in one of its application- urban planning. The chapter discusses methodological issues involved in the measurement of technology diffusion and details the methodology adopted in the present study. In this chapter, we measure the speed and level of diffusion of RST in India. Diffusion of RST in urban planning is also measured in this chapter. Chapter five investigates the factors that are influencing the diffusion process of RST. The second section of the chapter details the methodological approach (field survey) adopted for the investigation, followed by a detailed discussion on the findings from the field survey. The chapter also provides an explanation for the diffusion curve that we observed in chapter four. Chapter six summarises the main research findings of the study. The chapter also discusses the limitations of the study, and traces the future directions of research.

Chapter Two

An Overview of Theoretical and Empirical Literature on Diffusion

2.1. Introduction

The present chapter is an attempt to survey the research existing in the area of diffusion of innovation. This endeavor is to serve two purposes: First, to summarise what we already know about the diffusion of high tech general purpose technology like Remote Sensing; second to make a search for a theoretical framework with in which to analyse the diffusion of innovation, in the present case.

The significance of diffusion process has triggered a vast corpus of literature. The phenomenon of diffusion has been analysed from several perspectives such as Economics and Management, Sociology, Geography, and Marketing. While the economics and management studies looked into the behaviour and decision-making process of economic agents (Stoneman, 2002), sociologists described the process as purely social phenomenon (Rogers, 1995) and geographers depicted it as a spatial process (Brown, 1981). The marketing literature on diffusion primarily focused on how to encourage consumers to purchase a new product or technology and to forecast success in market (Bass, 1969). For economists, the diffusion process is the result of interaction of both demand and supply factors. Recognising this fact, section 2.2 depicts how the concept of diffusion is defined and measured. Section 2.3 explains demand and supply side economic theories on technology diffusion. The next section (section 2.4) deals with the sociological perspectives on diffusion of innovation. Section 2.5 reviews the empirical literature that discusses the factors influencing the diffusion process. The next section (section 2.6) deals with the theoretical framework of the study. Section 2.7 concludes the chapter.

2.2. Defining the Concept of Diffusion and its Measurement

Technology diffusion can be defined as a mechanism that spreads 'successful' varieties of product or process through an economic structure and displaces wholly or partly the existing 'inferior varieties' (Sarkar, 1998). While the process of invention and innovation are the necessary preconditions for the development of a new technology, it is the process of diffusion that determines the extent to which the new technology or innovation is being put to use. Thus the process of diffusion determines the level of technological dynamism in a firm, industry or in an economy.

According to Stoneman and Karshenas (1995), diffusion can be defined in terms of movements of the stock of potential adopters from a point where there are only a few early adopters to a point where all potential adopters have adopted the technology. Accordingly, suppose S_t is the current stock of a new technology owned by a group of population and S^* is the potential level of use of that technology, diffusion problem entails how S_t approaches S^* over time. The term therefore can be interpreted in two different senses: the level of diffusion, which is a stock concept and the speed of diffusion, which is a flow concept.

In the literature, there is a distinction between adoption and diffusion. Adoption refers the incorporation of new products and processes into the individual firms or organisations and thus, focuses on the decision of individual units. Diffusion, on the other hand, is an aggregate phenomenon centered on how innovations in new technologies are transmitted across an economy and through time. In the literature, distinctions are also made between intra firm (intra adopter) diffusion and inter firm (inter adopter) diffusion. Intra adopter diffusion refers to the level of use of the technology by an adopter over time. Inter adopter diffusion concerns not the level of use of the technology by adopters but the number of adopters using the technology at a particular period of time. Accordingly, intra adopter diffusion for i^{th} adopter can be defined as the ratio S_{it}/S_t^*, where S_{it} represents the current stock of a new technology owned by a group of population, and S_t^* represents the potential level of use of that technology. On the other hand inter adopter diffusion can be indicated by N_t/N^*, where N_t and N^* are the number of adopters at the time't' and the potential stock of adopters respectively. The diffusion process can also be analysed at the national level, by aggregating different adopters.

Consider an adopter i (firm, house hold or what ever it may be) ($i=1....n_{ij}$) in industry (sector) j at time t, producing output Y_{ijt}, of which X_{ijt} is produced on the new technology. The diffusion ratio (Z_{ijt}) is measured as:

$Z_{ijt} = X_{ijt}/Y_{ijt}$

Similarly in case of inter adopter diffusion, the diffusion ratio is measured as $M_{jt} = m_{jt}/n_{jt}$, where m_{jt} is the number of users of the new technology in the industry (sector) j, and n_{jt} is the number of potential adopters in industry 'j' at time 't'.

A well-known empirical regularity on diffusion of innovation is that when the number of users of a new technology or product is plotted versus time, the resulting curve is typically an 'S' shaped or ogive distribution[9] (Brown and Cox, 1971). The implication is that adoption proceeds slowly at first, accelerates as it speeds through out the potential adopting population, and then slows down as the relevant population becomes saturated (Hall, 2005).

[9] The earliest statement of 'S' curve was from Ryan and Gross (1943), and Hagerstrand (1952) who is credited in introducing the concept in geography.

2.3. Technology Diffusion: Perspectives from Economics

The following discussion concentrates on analysis of diffusion as a demand side phenomenon. Accordingly, the information of the technology and the changes there in, the benefit of technology adoption and the changes there in, and cost of acquiring the new technology and the changes there in will all impact on adopters' decision to whether and/or when to adopt a new technology.

2.3.1. Epidemic Models[10]

Although Schumpeter can be described as the precursor of the study of diffusion in economics, most of the modern work on diffusion owes its origin to the epidemic approach pioneered by Griliches (1957) and Manfield (1961). The epidemic approach regards diffusion results from the spread of information on the technology. The spread of information takes place through personal contacts, like the spread of an epidemic.

The essence of the epidemic model is that, they assume there exists a population of potential adopters of a given new technology that is usually taken as invariant over time. At the initial point of diffusion process there will be a given number of users of the new technology. Users and non-users mix socially and make contact over time. On making contact with a user of the technology a non-user gets information on the technology and adopt that technology. Over time, the number of users increases and with constant mixing of population, there is a greater chance of a non-user meeting a user and becomes a user. The growth in number of users over time, resulting from an increasing probability of contact and decreasing number of non-users, will generally map out an 'S' shaped curve.

[10] The epidemic models are also known as disequilibrium models. In these models the process of information transmission guides the diffusion path, which is a self-perpetuating adjustment process to a fixed-end point. Here, the process of adjustment is driven by uncertainty reduction due to information spreading as a result of extensive usage.

Epidemic models have been criticized for rendering rather stringent assumptions and weak theoretical foundations (see Stoneman, 2002). The central point of criticism is that while the model cogently depicts the aggregate behavior it does not provide a 'behavioral' explanation of the adoption process. The subject matter of other criticism is that the models assume a constant population of the potential adopters, which is homogeneous, and inter personnel contact is the only source of information.

2.3.2. Adoption Perspective

Unlike the epidemic models, the adoption perspective considers sources of information other than interpersonal contact. The basic tenet of adoption perspective is that the adoption of an innovation is primarily the outcome of a learning or communication process (Rogers and Shoemaker, 1971). Accordingly, the fundamental step in examining the process of diffusion is the identification of factors related to the effective flow of information and of the characteristics of information flows, information reception, and resistance to adoption. An important aspect of resistance indicates adopter's general propensity to adopt an innovation, or his innovativeness.

The lack of 'micro foundations' in the above discussed 'aggregate behaviour' models led to a more explicit treatment of behavioral phenomena underlying the diffusion process in the later models. The basic features in these models are (i) adoption occurs only when the actual cost of adoption is identical to the perceived benefit of adoption, and (ii) diffusion depends up on the heterogeneity of adopters' characteristics and the difference in the timing of adoption is due to this factor only. These models are widely denoted as 'equilibrium models' due to the assumption that at any point in time the adoption extents only to the point up to which it is profitable to adopt the technology, thereby ensuring equilibrium at each point on the diffusion path[11]. The equilibrium models have been classified as Rank, Stock and Order effect models or alternatively probit (rank) and game theoretic (stock and order) models (Karshenas and Stoneman, 1993). In probit models, potential adopters are ranked by their gross benefits, and those with greater benefits adopts first. In these models potential adopters of a technology have different inherent characteristics and consequently obtain different gross returns from its use. These different characteristics generate difference in adoption among potential adopters. In the game theoretic models, strategic interactions among potential adopters, rather than heterogeneity in individual adopters' characteristics play a critical role in determining the pattern of diffusion.

2.3.3. Rank Effect

As opposed to the 'information spreading' models, wherein there is information asymmetry in the population of potential adopters, the probit or rank effect models (equilibrium models) assume that there is perfect information in the economy on the existence and nature of new technologies (Davies, 1979). In these models adopter's decision to adopt a new technology depends upon the benefits from adoption relative to the cost of adoption. At any point of time, the limit to the number of users of a new technology is such that it is not beneficial to the marginal non-user to adopt at that time period. However, as time moves the benefit from adoption or cost of adoption changes and thus, the new technology get spread. Detailed discussion of the model is as follows:

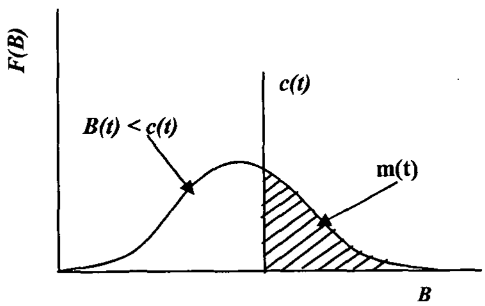
Consider that potential adopters know of the existence of the technology. Let the population of potential adopters be of the size N, and there is heterogeneity among the adopters, so that different numbers of population get different

[11] They are also touted as neoclassical models due to the obvious similarities with some of the basic tenets of the neoclassical theories (Sarkar, 1998).

benefit from adoption. This heterogeneity is shown in figure 2.1 as a frequency distribution of gross benefit of adoption, *B*, plotted against population proportion.

An individual considering adoption of the technology will compare gross benefit against the cost of adoption. Let the cost of adoption in time *t* be *c(t)*, which is assumed to be same for all members of the population. The adoption rule is that the technology is adopted if $B(t) \geq c(t)$. In terms of figure 2.1, the proportion of the population for whom $B(t) \geq c(t)$ in time *t* is equal to the area under the frequency distribution to the right of *c(t)*, labeled as *m(t)*, and the level of use of the technology in time *t* will be $M(t)=m(t).N$. To generate a diffusion path one needs to generate changes in *M(t)* over time. Such changes can come about in two ways: (1) changes in cost of adoption over time; (2) changes in benefit from adoption over time. For the model to produce the increasing levels of diffusion it is necessary that the cost of adoption falls and/or the benefits from adoption increase over time.

Figure 2.1: Probit Model



This approach has been called as Probit (Davies, 1979) or rank (Karshenas and Stoneman, 1993) because its empirical application makes use of probit models, and it ranks the firms by their significant characteristics.

2.3.4. General Purpose Technologies and Complementary Inputs

General Purpose Technology (GPT henceforth) is a term that is being applied to technologies that are characterised first by their pervasiveness, in that they are used as inputs by a wide range of sectors in the economy and secondly, as they diffuse they foster complementary investments and technological change in user sectors bringing about sustained productivity gains (Stoneman, 2002).

Helpman and Trajtenberg (1994) discuss the diffusion of such GPTs. The basic principle underlying the diffusion of a GPT is that in an early stage a new GPT requires the development of complementary inputs that would allow the GPT to be used and offer greater productivity than the previous technology. At some stage, the stock of complementary inputs is large enough to enable the GPT to be more productive than the old technology. Then only the benefits start to flow influencing the diffusion process. In short, an initial investment stage always precedes the generation of benefits from a new GPT. However, once the new GPT is in use further development of the GPT takes place that reinforces its productivity effect. Information and Communication Technologies (ICTs) can be the best example of GPT. ICT need the development of complimentary inputs and infrastructure such as education, skills, telephone and electricity connectivity etc., in order to reap the benefit from the GPT (Pohjola, 2002)[12].

The importance of joint inputs cannot be restricted to the case of GPTs. It can also be crucial in the use of other stand-alone technologies. The benefit or utility flow, that will be generated by the technology will at least partly be restricted to the quantity and quality of the joint inputs available or used. Also the greater is the cost of joint input the greater will be the cost of generating the service flow. The net benefit from the technology will thus depend on the

[12] Pohjola (2002) observes that countries (other than US) that have invested in ICT could not reap the benefit out of their investment because of lack of investment in complimentary infrastructure such as education and skills.

availability and price of the complementary inputs. Accordingly, Acemoglu (1993) argues that the availability of skilled labour may act as a drag up on the use of new technology. However there can be a mechanism by which labour learns as a new technology is used (learning by using), and as usage extends a greater number of workers will become trained. Thus a pool of trained labour will be available for other adopters.

Analysis restricted to the demand side only tells a part of the diffusion story. In the following discussion, issues related to the supply of new technology have been addressed. When one adds supply side to the diffusion process, the improvements in technology (incremental innovation), the production cost, and the marketing strategies of the suppliers are the important determining factors of diffusion process. However, cost of production and improvements in technology are largely the result of R&D spending. The incentive to do R&D is expected profitability (expected social benefit/expected utility in case of Government R&D). This profit or social benefit is resulted during the diffusion process. Thus the diffusion process generates the incentives to R&D, and R&D brings forth improvement in technology, and lowers cost that drives diffusion (Stoneman, 1985).

2.3.5. Improvement in Innovation

As technology matures, not only the cost falls but the quality of the technology also improves. The rate of improvement of the technology will have impact on the diffusion path (Stoneman 2002). The economic history perspective (Rosenberg, 1976) considers most innovations are relatively crude and inefficient when they were first introduced in the economy. Likewise, they were badly adapted to many of the ultimate uses to which they would be eventually put; therefore new technologies might offer only very small advantages or perhaps none at all, over previously existing technologies. Diffusion under these circumstances will be slow, because the clear superiority of the new technology over the old has not yet been established.

Thus the perspective holds that the pace at which subsequent improvements on the new technologies are made will be a major determinant of the rate of diffusion[13].

2.3.6. Market and Infrastructure Perspective

Market and infrastructure perspective focus on the supply side of diffusion by giving attention to the process by which innovation and conditions for innovation are made available for the potential adopters. Brown (1981) who developed this perspective is of the view that a great deal of variance in diffusion of innovation can be explained by looking at institutional rather than individual behaviour. Thus the role played by the diffusion agencies, which propagate the innovation, draw importance in explaining the diffusion process.

Market and Infrastructure perspective conceptualizes diffusion as a process involving three activities (Brown, 1981). For majority of innovation, those propagated by government or private entrepreneurs, the initial activity is the establishment of diffusion agencies through which innovation will be disseminated. As a second activity, a strategy[14] is developed and implemented by the agencies to induce adoption. Only third is the adoption of innovation. The establishment of innovation diffusion agencies and operating strategies of each agency are the aspects of marketing the innovation. This marketing involves both the creation and utilization of infrastructure. Thus, the characteristics of relevant infrastructures (such as service, delivery, information etc.) have important influence up on the rate and spatial pattern of diffusion.

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[13] However, Rosenberg does not suggest that a continuous rate of improvement in a technology implies some constant continuous rate of its diffusion.

[14] Strategies of diffusion agency may include development of infrastructure and organizational capabilities, pricing and promotional communications.

2.4. Perspectives from Sociology

The sociological perspective is exemplified by Rogers (1995). He provided a set of analytical categories that classifies the attributes that influence the potential adopters of an innovation. Even though he viewed diffusion from a sociological perspective, economic factors and role of development agencies were taken into consideration. The attributes include: the relative advantage of innovation, its compatibility with the potential adopters current way of doing things, the complexity of the innovation, trialability and observability (trialability and observability specify the ease with which the innovation can be tested and evaluated by a potential adopter)[15]. In addition to the above attributes that influence the adoption decision, Rogers added a variety of external or social conditions that may slow or accelerate the diffusion process:

i) The communication used to acquire information about an innovation.

ii) The nature of social structure in which the potential adopters are embedded, its norms and degree of interconnectedness.

iii) The extent of change agents' promotion efforts.

Rosenberg (1982) strongly challenged Rogers implicit assumption that neither the new technology nor the technology it replaces changes during the diffusion process and that new is better than the old. Rosenberg argued that not only the new technology was improved due to user experience and feedback from adopters, but also that the replaced technology experience a "last gap" improvement due to competitive pressure, and this could slow the diffusion of the new.

2.5. Empirical Studies

The empirical literature on technology diffusion closely follows the theoretical developments in the area. The earlier studies relied mostly on the epidemic learning models (e.g. Mansfield, 1961). But later on empirical research was

[15] Both trialability and observability are the characteristics that indicate the level of uncertainty faced by a potential adopter.

more in the line of equilibrium models (e.g. Davies, 1979). However, various empirical studies identify the expected benefit from adoption, cost of adopting new technology, and regulatory environment as the significant factors that influence the diffusion process (see Stoneman, 2002).

From the earlier work of Griliches (1957) and Mansfield (1968) to the work of Davies (1979), it has been emphasized and confirmed that the greater the benefit of technology adoption, the faster will technology be adopted and the greater will be the final level of use. Griliches' (1957) study of the diffusion of hybrid corn[16], emphasizes the economic factors such as expected benefit from adoption and scale in determining the varying rates of diffusion across the Midwestern United States. According to Griliches, to certain extent diffusion depend on the activities of the suppliers of the technology in adapting it to the local conditions. Following Griliches, several empirical studies focused on the activities of suppliers on improving the benefit from adoption (see Rosenberg, 1976). Mark and Walton (1972) study on diffusion of steam boats identifies that the introduction of steam boat (1815 to 1820) led to a significant fall in real freight costs, but the absolute as well as the relative decline in real freight rates was greatest during the period of improvement (1820 to 1860), which led to a successful diffusion. Similarly, Bruland (2002) focus on the activities of the technology suppliers and finds that the nineteenth century development in Norwegian textile industry was greatly facilitated by the workers training activities undertaken by the British machinery suppliers, thereby increasing the supply of skilled workers in Norway.

Cost of adopting a new technology includes not only the price of acquisition, but also more importantly the cost of complementary investment and learning required to operate the technology. For example, Brynjolfsson (2000) argues that the full cost of adopting new computer information systems (based on

[16] The first empirical study on technology diffusion by an economist.

networked personal computers) is about ten times the cost of the hardware. Greenan and Guellec (1998), finds that the adoption of ICT requires organizational change as well, and this raises the cost of adoption, which slows the diffusion process. Caselli and Coleman (2001) compare the rate of computer investment across OECD countries between 1970 and 1990 and highlight the importance of both worker skill level and complementary capital investments in determining the rate of purchase of new computing systems. The implication of the work is that the use of new computing technology requires both the training of workers and the installation of other related equipments. This type of complementary investment usually takes time, and so it slows down the rate at which the benefits of the new technology are perceived by the potential adopters. In order to reduce the cost of adoption and induce adoption, the technology providers often try to subsidise the adoption of new technologies. For example the suppliers provide free training and other assistance to potential users and charge reduced introductory rates for a period (see Shapiro and Varian, 1999).

The general regulatory environment will have an influence on the rate of adoption. The regulation tends to slow the rate of adoption in some cases due to the relative sluggishness of regulatory change. But in some cases, mandating a new technology or a particular technology standard by the government increases the speed of diffusion. An example for the case of regulation responsible for low rate of adoption is the use of plastic pipeline for plumbing, which is low in cost but has been slow to diffuse due to regulatory building codes (Hall, 2005). On the other hand, Mowery and Rosenberg (1982) find that airline regulation by the Civil Aeronautics Board in the US was responsible for promoting the adoption of new innovation in airframes and jet engines. Similarly, Battisti and Stoneman (2002) identify government regulation (rules on the fitting of catalytic converters to cars[17]) and other

[17] Cars with catalytic converters only can use unleaded petrol.

government intervention, i.e. fiscal incentives, encouraged the use of unleaded fuel in UK market[18]. Hannan and McDowell (1984) find that unit banking and branching restrictions increased the probability of adoption of automatic teller machines. Rose and Joskow (1990) show that government owned electricity utilities are slower in adopting new technologies than privately owned ones.

2.6. Theoretical Framework

Diffusion process is influenced by a multitude of forces. From the review of literature, it is apparent that the explanation on diffusion process is rich with competing and complementary theories that are broadly interrelated. Despite the vast literature on the subject, the study of diffusion throws new challenges to the researchers to find a holistic explanation of the determining factors of diffusion. In order to identify the determinants of diffusion process, a theoretical framework is developed with the objective of encompassing a set of tentative influencing factors of diffusion of a high tech general-purpose technology like RST. The set of determinants of diffusion are broadly related to the following facts or observations:

- Whether/when the adoption of the particular technology is advantageous to the potential users.
- The provision and costs of specific information and complementary inputs essential for the effective use of the technology.
- The general regulatory environment on which the technology is placed.

Benefits Received from the New Technology:

The most important determinant of benefits derived from adopting a new technology is the amount of improvement, which the new technology offers over any previous technology (Hall, 2005). Accordingly, when a new technology is introduced in the economy, the amount of improvement or

[18] Unleaded petrol first appeared in UK market in June 1986. By May 1995 (i.e. with in nine years), unleaded petrol held a 60-per cent market share.

advantage it provides over the old one is frequently rather small. As diffusion proceed, the technology improves and adapt to different environments. These incremental innovations increase the benefit of adoption, and make it more attractive to a wider set of adopters (Rosenberg 1972). As pointed out in the earlier sections the reasons for the improvement can be increased R&D expenditure, learning, and feed back from adopters. Remote sensing is a GPT that is used as inputs by a wide range of sectors. Generally, a new GPT requires large amount of complementary factors and infrastructure for effective employment of the technology. Shortage in supply of complementary inputs and infrastructure diminish the productivity of the technology, thereby decreasing the benefit of adoption. Consequently, the provision of complementary inputs and infrastructure determines whether or when it is beneficial to adopt, and influence the diffusion process

Cost of Adopting the New Technology:

The second main class of factors influencing the decision to adopt new technology is those related to its costs. This includes not only the price of acquisition, but also more importantly the cost of the complementary investments and learning required to make use of the technology. Such investment may include training of workers and expenditures on necessary complementary inputs. In short, the need for complementary investments has two effects: First, it raises the cost of adoption, and secondly, as this type of investment usually takes time, it slows down the rate at which the benefits of the new technology are seen by the adopters and economy.

Information:

The choice of new technology requires information that it exists and some knowledge about its suitability to its potential adopters' situation. Therefore vital determinants of diffusion are information on the availability of the new technology, and information on how to employ the new technology efficiently.

The choice of adoption might also depend on the information available about the experience with the technology in the decision maker's environment. This kind of information is mainly acquired from the interactions between adopters. Thus, the third set of factors that influence the diffusion process is those related to the information on the technology, i.e. information on the availability, effective employment and experience with the technology.

Regulatory Environment:

General regulatory environment will have an influence on the diffusion of a technology. Usually, governments are concerned about security and safety aspect associated with different new technologies. In the perspective of technology diffusion, the security concerns induce the governments to adopt restrictive or regulative policies. Such regulatory policies would have an impact on the speed and level of diffusion. On the other hand, on perceiving the net social benefit (positive externality) of technology diffusion, the government can mandate certain technologies or technological standards to encourage diffusion. In short, in addition to the factors that are directly related to the demand and supply side of technology diffusion, the regulatory environment on which the technology is placed would have an influence on technology diffusion.

2.7. Summary

In this chapter we reviewed the theoretical literature in economics and sociology on diffusion and empirical studies. The economic literature is perceived from both demand as well as supply side. Accordingly, information on technology, adopters' characteristics, costs and benefits of adoption, growth of complementary technologies and inputs, improvement in the technology, the role of diffusion institutions and their strategies etc., were the subject matter of the economic explanation of the diffusion process. The sociological perspective addressed the external conditions that influence the diffusion process. Accordingly, these studies were the explanations of two important characteristics of diffusion process propounded by Rosenberg (1972): (i) the overall slowness of diffusion process, and (ii) wide variations in the acceptance of different innovations. On the basis of the discussion of theoretical and empirical literature, the study put forward a theoretical frame to analyze the factors that are influencing the diffusion process of RST. Accordingly, we put forward that the factors that influence the diffusion process of RST are broadly related to the facts: Whether and when the adoption of the specific technology is advantageous to the potential users, the provision and costs of specific information and complementary inputs required for the effective use of the technology, and the general regulatory environment on which the technology is placed.

How the above theoretical discussions and framework is applicable to the case where the potential adopters are government agencies?[19] In our perceptions, the above-mentioned characteristics such as information, benefit of adoption, regulatory environment etc., are equally important to the adoption decision of government agencies also, and we could not consider that government agencies are irrational.

[19] The author is indebted to Prof. Chiranjib Sen, IIM-Bangalore for this discussion.

Chapter Three

An Overview of Indian Remote Sensing Industry

3.1. Introduction

"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 competeting with the economically advanced nations in the exploration of moon or the planets. 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 problem of men and society"

-Dr Vikram Sarabhai, Father of Indian space programme.

The discussion on RST can be divided into three sections: first, what the technology is; second, how RST has been developed in India; and third, the application of the technology. Keeping these points in mind the present chapter is organized as follows: Section 3.2 discusses the RST in brief, followed by section 3.3, which deals with the discussion of Indian Remote Sensing programme. Section 3.4 analyses the Indian remote sensing industry. The final section (section 3.5) concludes the chapter.

3.2. The Technology

Two well-accepted definitions of RST are given by, Canada Centre for Remote Sensing (CCRS), and India's National Remote Sensing Centre (NRSC) [20]. CCRS defines RST as the science of acquiring information about the earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing,

[20] National Remote Sensing Agency has changed to National Remote Sensing Centre from October 2008, as it became a part of ISRO. Earlier NRSA was an autonomous agency under Department of Space.

and applying that information. India's NRSC defined RST as the technique of deriving information about objects on the surface of the earth, with out physically coming into contact with them.

3.2.1. Remote Sensing Process

The first requirement for remote sensing is to have an energy source that radiates electro magnetic energy to the target of interest (object on the earth's surface). Usually the energy source is the sun. The energy makes its way to the target on the ground through atmosphere. Some amount of this incident energy on the object is reflected or emitted back to atmosphere. This reflected or emitted energy from the object on the ground is collected and recorded by the sensor (remote, not in contact with the object) in the satellite. The energy recorded by the sensor is then transmitted[21] (often in electronic form) to a receiving and processing station on the ground (Ground Receiving Station)[22], where the data is processed[23] into an image. The processed image is then interpreted to extract information about the target of interest. The processed data are written to some form of storage medium such as tape, magnetic disc, or compact disc (CD). The data are typically archived at receiving and processing station, and full libraries of data are managed (in India NRSC is the manager). In short, a remote sensing programme is consist of a sensor to collect the radiation from the earth's surface, a platform[24], and a ground station for receiving and processing the energy recorded by the sensor. The

[21] In case of aerial remote sensing, transmission and reception are not required because the flight (which is used as a platform for the sensor) comes back to the ground.

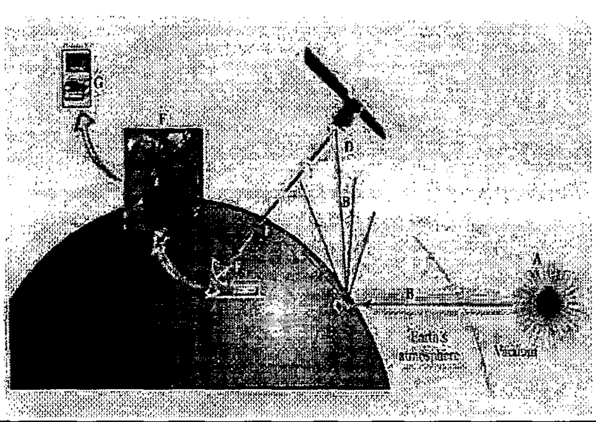
[22] In India, Ground Receiving Station (GRS) is at Shadnager, 55 km away from Hyderabad. Shadnagar covers India, Pakistan, Afghanistan, Bangladesh and Thailand, and some portions of Iran, Oman, Cambodia and Laos.

[23] The acquired data has a number of errors due to [i] imaging characteristics of sensors, [ii] stability and orbit characteristics of the platform, [iii] sense surface characteristics, [iv] motion of earth, [v] atmospheric effects. Preprocessing is carried out to correct these errors, so that the inherent quality of the original information of the scene is retained. The outputs of preprocessing are known as *data products* (Joseph, 2005).

[24] A platform can be a satellite, an aircraft or even a ground base stand that support the sensor.

diagrammatic representation of a satellite remote sensing technique is given in figure 3.1.

Figure 3.1: Remote Sensing Technique



- A - radiation from energy source, the Sun.
- B- interaction of energy with earth's atmosphere.
- C- interaction with the target & some energy is reflected back
- D- recording of energy by the sensor
- E- transmission, reception and processing
- F- interpretation & analysis
- G- application

Source and Courtesy: Bhatta, 2008

3.2.2. Advantages and Limitations of RST

RST has several unique advantages as well as some limitations also. The advantages include synoptic coverage, multi spectral and multi temporal capability, and provision of digital data (Sankar and Rao, 2007).

(i) Synoptic Coverage: Satellite sensors are capable of covering large areas in one scene. For example, one scene of WiFS sensor of IRS-1C and IRS-1D satellite covers an area of 800x800 kilometers, which is typically more than the area of an average state in the country. Different satellites with different types of sensor system cover different extent of areas. No conventional method has this advantage of synoptic coverage.

(ii) Multi Spectral Capability: 'Signature'[25] of the objects varies in different electro magnetic spectral bands. Spectral bands of the

[25] Signature of any object comprises a set of observable characteristics, which directly or indirectly lead to the identification of an object and/or its condition.

sensor have the capability to detect various objects making up the land use and land cover.

(iii) Multi Temporal Capability (Repetivity): Satellites, by virtue of their orbiting characteristics enable observations of the same area at regular intervals, varying from every day to once in twenty-four days. Thus the user can get the data of any area repeatedly at regular intervals of time, enabling monitoring of changes.

(iv) Digital Data: Satellite transmitted data are recorded digitally. The digital data can be subjected for corrections and enhancement in future using computer software. The data do not suffer the problem of bias. Also, large volume of digital data can be stored and retrieved in storage devices such as CDs or magnetic discs, which are compact and durable, compared to analogue (paper maps) data. Users can access digital data online with the internet facility.

(v) Economic in terms of cost and time[26].

Limitations:

(i) Satellites with optical remote sensors cannot capture data if clouds exist.

(ii) For obtaining meaningful information from satellite data, formal high-level training is required.

(iii) From the satellite sensors, only information on the ground can be obtained. For applications such as ground water or mineral exploration, the surface information obtained from remote sensing is interpreted (by thematic specialists) in conjunction with information from conventional geo-physical methods.

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[26] Radhakrishnan et al. (1991), provide an example for the economic advantage of the technology. In geological studies for mineral exploration, with the use of satellite data the ground surveys could be reduced to 5 percent of total area against 50 percent as in the case of conventional surveys. Thus the cost of mineral exploration using conventional methods cost Rs. 235 per sq.km, as against Rs. 37 per sq. km^3 with remote sensing survey.

3.3 Indian Remote Sensing Programme

3.3.1. The History

India has relied so much on science and technology for her modernization and economic development. Even before India attained independence, Pundit Jawaharlal Nehru believed that only through the growth of science and technology, the country could become wealthy and prosperous (Nayar, 1985). Based on this conviction, immediately before and after independence in 1947, India established a number of scientific research institutions. These include the Tata Institute of Fundamental Research (TIFR), Council of Scientific and Industrial Research (CSIR), Atomic Energy Commission (AEC), Physical Research Laboratory (PRL), etc. When Soviet Union surprised the world with the launch of 'Sputnik'[27], India recognised the immense socio-economic benefits of space technology and decided to organise a national space programme. In 1962, India established Indian National Committee for Space Research (INCOSPAR), and in the next year (1963) we were able to launch our first sounding rocket Nike-Apachie, donated by the United States. On 15th August of 1969, INCOSPAR was reconstituted and Indian Space Research Organisation (ISRO) was created under the Department of Atomic Energy (DAE) to conduct space research and applications. In the initial years, ISRO faced budget constraints for R&D and space programme expenditure. This forced ISRO to seek participation from private industries (Bhatta, 2008). In 1972, Indian Government set up the Space Commission and Department of Space (DoS) and entrusted these institutions with the responsibility of conducting country's space activities. ISRO, under DoS, is responsible for R&D and operationalisation of space system in the areas of satellite communication and earth observation[28].

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[27] Sputnik was the first satellite of the world, launched by USSR.

[28] At present India have established two operational space systems, viz: INSAT for communication and IRS for spatial information.

India's tryst with a remote sensing programme started in 1972 when ISRO created Space Application Centre (SAC) that housed a remote sensing meteorology division. In 1975, NRSA (at present, NRSC) was established as an autonomous agency under DoS. The chief activities of NRSC are capturing of satellite and aerial data, data dissemination, providing value added services, and training. After four years of the establishment of NRSC, India's first experimental remote sensing satellite Bhaskara-1[29] was launched in 1979 with the help of Soviet Union. It had a two-band TV camera system with resolution of one kilometer to collect data related to hydrology, geology and forestry. Following the successful launches of Bhaskara-1 and Bhaskara-2, India began developing indigenous[30] Indian Remote Sensing (IRS henceforth) programme to support the economy in the areas of agriculture, forestry, fishing, geology, water resources, watersheds etc. At present IRS satellite constellation has more than half a dozen of satellites in orbit, which is the world's largest constellation of remote sensing satellites in operation. The development, launch, and technological features of different IRS satellites are discussed in the next section.

In order to undertake marketing of space products and services, Government of India in 1992 approved formation of Antrix Corporation[31] as a commercial arm under DoS. Antrix has established collaboration with EOSAT Corporation (now Space Imaging) of USA, one of the global players in remote sensing industry. The collaboration resulted in sizeable impact of securing about 20 percent of share in global remote sensing data market. The leadership established by Indian Space Programme in earth observation applications, has also promoted a large number of value adding enterprises in private sector within the country. These enterprises integrate remote sensing data with

[29] The satellite is named after a seventh century (c. 600 - c. 680) Indian mathematician and astronomer.
[30] Bhaskaran (2005) provides a detailed discussion on the judicial mix of indigenous and foreign technology in the process of competence building in space technology.
[31] Antrix Corporation is structured as a private limited company.

emerging technologies such as GIS and GPS, and supply to domestic and international markets for spatial information.

Bhaskaran (2005) makes a historical examination of the evolution of Indian space programme. According to the study, Indian space programme in 1960s was mainly science oriented. In the 1970s it progressed to a technological experimentation and learning programme. In the following decade (1980-90), India could achieve technological capabilities in satellite and launching vehicle technologies. In 1990s, the focus of Indian space programme was successfully shifted to commercialisation.

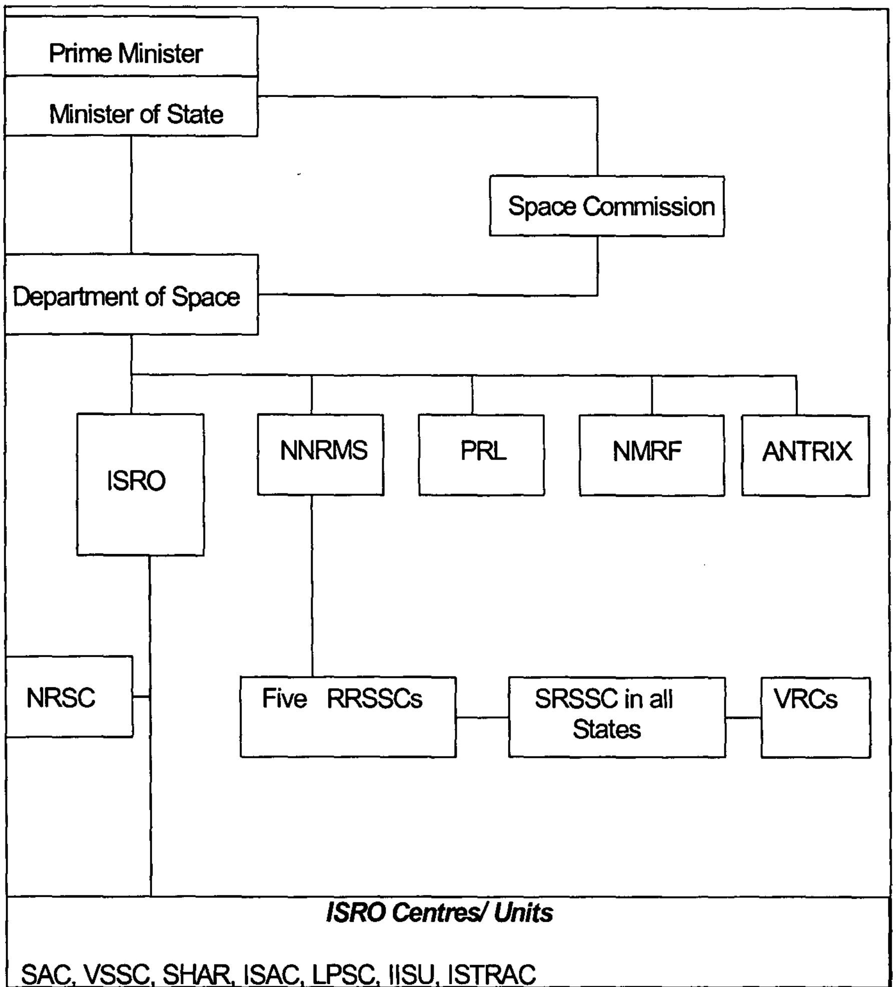
Figure 3.2 lists the institutions engaged in IRS programme and their mutual interrelations. The organization of IRS programme is designed to ensure autonomy and government support at the higher level and a strong interaction with the users or beneficiaries of the programme (Sankar and Rao, 2007). The space commission, which is the apex decision making body on national space programme, and DoS that execute space programme, functions directly under the Prime Minister of India. The programme is carried out through ISRO. The DoS also functions as the nodal agency for institutions such as National Natural Resource Management System (NNRMS), Physical Research Laboratory (PRL), National Mesosphere-Stratosphere-Troposphere Radar Facility (NMRF), and ANTRIX Corporation. NRSC, a part of ISRO, is engaged in capturing, processing and dissemination of the aerial and satellite data. National Natural Resource Management System (NNRMS) coordinates planning, development, operation, and application of the Earth Observation System (EOS). Under NNRMS, five Regional Remote Sensing Service Centers (RRSSC)[32] were instituted to facilitate analysis of remote sensing data to derive planning related inputs on natural resources of the country. The State Remote Sensing Service Centers (SRSSC), function at state level to assist state

[32] Five RRSSCs are located at Nagpur, Jodhpur, Kharagpur, Dehradun and Bangalore.

level users. ISRO/DOS also set up Village Resource Centers (VRC) in association with Non Government Organizations (NGOs), trusts, institutes, and government agencies at village level to take the benefit of space enabled remote sensing and communication capabilities to the rural population. The Physical Research Laboratory (PRL) under DoS conducts research in space science. ANTRIX Corporation, functioning as a commercial arm under DoS, is involved in marketing of remote sensing data and other space products and services at global level.

India has also established a strong infrastructure in the form of ISRO centers with designated roles for carrying out R&D and application missions. The Vikram Sarabhai Space Centre (VSSC, for rocket technology), Liquid Propulsion Systems Centre (LPSC, for liquid propulsions for satellites and launch vehicles), ISRO Internal Systems Unit (IISU, for internal sensors and systems required by satellites and launch vehicles), ISRO Telemetry Tracking and Command Network (ISTRAC, for mission support for low earth orbit satellites as well as for launch vehicle mission), and Space Application Centre (SAC) for designing remote sensing applications in different fields, are the different ISRO centers or units engaged in IRS programme.

Figure 3.2: Institutions Involved in IRS Programme



ISRO: Indian Space Research Organisation, NRSC: National Remote Sensing Centre, NNRMS: National Natural Resource Management System, PRL: Physical Research Laboratory, NMRF: National Mesosphere-Stratosphere-Troposphere Radar Facility, RRSSC: Regional Remote Sensing Service Centers, SRSSC: State Remote Sensing Service Centre, VRC: Village Resource Centre, SAC: Space Application Centre, VSSC: Vikram Sarabhai Space Centre, SHAR: Sriharikota range (Satish Dhawan Space Centre of ISRO), ISAC: ISRO Satellite Centre, LPSC: Liquid Propulsion Systems Centre, IISU: ISRO Internal Systems Unit, ISTRAC: ISRO Telemetry Tracking and Command Network.

Source: Bhatta, (2008).

3.3.2. The Indian RST

At present, India has seven operating satellites in its constellation. Each satellite has different technical characteristics in terms of spatial resolution, spectral resolution and temporal resolution[33]. From the launch of IRS-1A in 1988, the first operational remote sensing satellite, to Cartosat-2A launched in April 2008, India has launched fourteen satellites. It implies, on an average two satellites in three years. Table-3.1 details the launch of satellites and sensors from 1988 to till date with their corresponding technological characteristics. These earth observation satellites can be broadly classified in three categories (Navalgund et al., 2007): The first generation experimental satellites (Baskara-1 and 2), second generation operational satellite (IRS series), and present generation theme specific satellites[34].

The first two satellites among the operational remote sensing satellites, IRS-1A and 1B, had applications in natural resource management studies. The high-resolution satellites, IRS-1C and 1D, were useful in urban mapping, and in areas like infrastructure development where high-resolution data are needed. WiFS sensor[35] of IRS-1C and 1D were useful for frequent observations for monitoring crops. IRS-1C and 1D were the satellites offering the highest resolution in the world when they were launched (1995-1997). The present generation theme specific satellites are designed with application-specific sensors. For example, the sensors in Resourcesat are specially designed for agricultural applications and Cartosat for cartographic applications. However the process of competence building in RST required sustained heavy investments for 40 years as well as high level of human

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[33] Spatial, spectral and temporal resolutions are the three basic technical characteristics of a sensor. For a non-technical explanation of these three characteristics, see section 3.2.2 that discusses the advantages of RST.

[34] Theme specific satellites are those satellites designed for particular themes or applications like Oceansat for oceanographic studies, Resourcesat for agricultural applications etc.

[35] This sensor is most useful for vegetation studies. The sensor provide vegetation index at regional level, thus helping in assessment of crop condition and drought monitoring.

Table- 3.1: Technological Features of IRS Satellites

Satellites	Year	Sensor	Spectral Bands (µm)	Spatial Resolution (m)	Temporal Resolution (days)
IRS-1A & IRS-1B	1988 1989	LISS I LISS II	0.45-0.52 0.52-0.59 0.62-0.68 0.77-0.86 Same as LISS I	72.5 36.25	22 22
IRS-P2	1994	LISS II	Same as LISS I	36.25	24
IRS-1C & IRS-1D	1995 & 1997	LISS-III WiFS PAN	0.52-.59 0.62-0.68 0.77-0.86 1.55-1.7 0.62-0.68 0.77-0.86 0.5-0.75	23.5 70.5 188 5.8	24 24 24
IRS-P3	1996	MOS-A MOS-B MOS-C WiFS	0.755-0.768 0.408-1.010 1.6 0.62-0.68 0.77-0.86 1.55-1.7	157x1400 520x520 520x640 188	24 24 24 5
IRS-P4 (Oceansat-1)	1999	OCM MSMR	0.402-0.885 6.6,10.65, 18,21 GHz	360x236. 15,75,50 & 50 km resp.	2 2
IRS-P6 Resourcesat-1	2003	LISS_IV LISS-III AWiFS	0.52-0.59 0.62-0.68 0.77-0.86 0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.7 0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.7	 5.8 23.5 56	 24 24 24
IRS-P5 (Cartosat-1)	2005	PAN	0.5-0.85	2.5	5
Cartosat-2	2007	PAN	0.5-0.85	0.8	5
Cartosat-2A	2008	PAN		<1	5

Source: Compiled from annual reports of ISRO (Various years).

resources. Total investment in Indian Space Programme up to March 2006 was around US$ 7 billion (Kasturirangan, 2006). As Indian Space Programme consists of INSAT and IRS, the total investment up to 2001 on IRS programme on experimental and operational mission is Rs.1575.61 crore, and for data reception, processing and application the investment is Rs. 554.07crore (Sankar and Rao, 2007). Total space expenditure of India as a percentage of GDP now stands at .09 percent. Similarly, during the last 25 years the number of scientists and engineers in ISRO grew from 1250 to more than 11,000.

3.3.3. Applications of RST

RST is a general-purpose technology that provides spatial information having multiple uses in various fields. Space Application Center (and also NRSC and RRSSC) is responsible for R&D on applications of RST. While the technological breakthrough in satellite RST gained momentum, the application aspects took some time to catch up (Narayan, 1999). Sankar and Rao (2007), classifies the uses or applications of RST in different areas; such as applications where RST is an exclusive tool (for e.g. identifying potential fishing zone, assessing areas affected by natural calamities etc.), areas in which RST is a complementary or alternative tool (for e.g. Urban planning, infrastructure development, measuring environmental impact of industrial/development projects etc.), and areas in which RST is a tool in R&D (for e.g. in detection of crop decease).

The important application potentials of RST broadly fall under disciplines like agriculture, geology, water resources, forestry and land use mapping. Table 3.2 details some of the specific areas in which RST is applied[36].

[36] The list is not exhaustive.

BOX 3.1: Areas of Application of RST

- Natural resource identification and Management
- Land use/ land cover mapping
- Crop acreage and production estimation
- Recording ground water prospects[37]
- Geology
- Infrastructure development
- Environmental surveys
- Biodiversity
- Coastal zones
- Urban land use/ urban planning
- Encroachments [for legal applications][38]
- Oceanographic studies/ identifying potential fishing zones
- Detection of crop diseases
- Assessment of areas affected by natural calamities

Source: Narayan, 1999.

3.4. The Market for Remote Sensing Data: Sales and Revenue of NRSC

The remote sensing industry or market for remote sensing data products in India can be studied by examining four factors: The supplier, the consumers, the price of the commodity, and the nature of the commodity.

According to Government of India's Remote Sensing Data Policy (RSDP)[39], NRSC is vested with the authority to acquire and disseminate all satellite and aerial remote sensing data in India – both from Indian and foreign satellites.

[37] For example, PepsiCo India Ltd., and Hindustan Coca-Cola located their plants at Palakkad, Kerala, on the basis of information on ground water prospects from remote sensing survey.
[38] For example, Government of Kerala adopted remote sensing surveys to identify illegal encroachments in Munnar, Kerala.
[39] For more details, see http://www.nrsa.gov.in/policy.

Hence, NRSC is the only supplier[40] of remote sensing data in the country. NRSC sells data products at a price arrived at after taking into account the expenditure on various factors, i.e., capital cost (depreciation), manpower resources (technical manpower), maintenance and operational expenses. Per product cost is worked out on the basis of Machine Hour Requirement (MHR) approach, i.e., the product cost is a function of the time or resources utilized directly for its generation[41]. Based on the cost of generation, the pricing of data products is carried out. The objective is to recover all direct expenditure and manpower cost, and also capital expenditure. Based on an internal note from NRSC, Sankar and Rao (2007) review the salient features of price policy of 1998-99. The salient features of price policy as explained by Sankar and Rao (2007) are:

(i) Several activities common to all satellite missions and types of products were apportioned over the actual production (in terms of products likely to be generated) rather than on the capacity to ensure better assessment of revenue earning potential.

(ii) An access fee component of Rs.200 lakh each for IRS-1C and IRS-1D[42] was assumed for the purpose of per scene acquisition cost.

(iii) A 25 percent organizational overhead per product has also been taken into account in the costing procedure.

(iv) The depreciation of computer systems with in the first three years is 40 percent, 40 percent, and 20 percent of the cost. For the software, the rate of depreciation is 100 percent during the first year.

In short, it is apparent that the price of data products only tends to cover all the direct expenditure, manpower costs, and depreciation along with organizational overheads.

[40] NRSC enjoys a monopoly power resulted because of sole access to the technology.
[41] Due to economies of scale the cost has come down over the time. (But here, an economy of scale is not a reason for monopoly power).
[42] IRS-1C and IRS-1D were the only data generating satellites at that time.

The data products of RST are either public goods or private goods[43]. For example the remote sensing data products that are used for disaster management and mapping purposes are public goods, and data products used in the area of infrastructure development, mining and fishing zone advises are private goods. The sold data products from NRSC are generally differentiated and are rarely homogenous. There are multiple levels of consumers or users of the data, from an individual (for example, a farmer, having a large agricultural land holding) to government departments, business corporations like Rolta India Ltd., and Reliance Industries, NGOs, and research institutions like the Indian Institute of Technology (IITs).

3.4.1. Sales of Data products

The annual sales of data products (in terms of numbers) by NRSC and its growth rate from 1988-89 to 2007-08 are detailed in Figure 3.3. As NRSC is the monopolist supplier of remote sensing data in the country, the sales by NRSC indicate the level of usage of the same. In the year 1988-89, the annual sales were around eleven thousand data products, which rose to around twenty thousand in 2005-06. During this period, i.e. 1988-89 to 2005-06, the annual growth rates of sales were low, and it took seventeen years to nearly double the sales (see figure 3.3). However, the last two years (2006-07 and 2007-08) witnessed high growth rates of 34 and 39 percent respectively, and the sales accelerated to thirty six thousand data products in 2007-08.

The data products are not homogenous in nature; they can be differentiated on the basis of quantity and quality of information they provide. Generally, the data products from NRSC are classified on the basis of level of processing[44], output scale[45] and area of coverage[46]. In this context, the revenue received by

[43] Classification is on the basis of non-excludability and non-rivalry criteria.
[44] On the basis of level of processing the data products are classified into standardized products, value added products and derived products.
[45] The output scales vary from 1:1 M to 1:5000 M.

NRSC from sales of data products will be a better indicator of the level of use, as price of the data products reflect the quality and quantum of information the data contain.

3.4.2. Sales Revenue of NRSC

Figure 3.4 details the annual real sales revenue[47] of NRSC and its growth rate from 1988-89 to 2007-08. The annual real sales revenue that was only Rupees 748 lakhs in 1988-89 accelerated to Rupees 3487 lakhs in 2007-08. During this period, the growth rate of annual real sales revenue was highly fluctuating, ranging between 36 and –18 percent. On comparing the growth rates of sales of data products (in numbers) and the sales revenue, it is evident that the growth rate of annual sales revenue is much higher during the period of analysis (see figure 3.3 and 3.4 for growth rates of sales and real revenue). Accordingly, the average real unit price of data products increases continuously from Rupees 5357 to Rupees 12608 during the period (see Table 3.2). One fact to infer at this point is that the product basket of NRSC has been continuously changing during the period. NRSC has been moving from standardized data products to more value added or derived data products[48].

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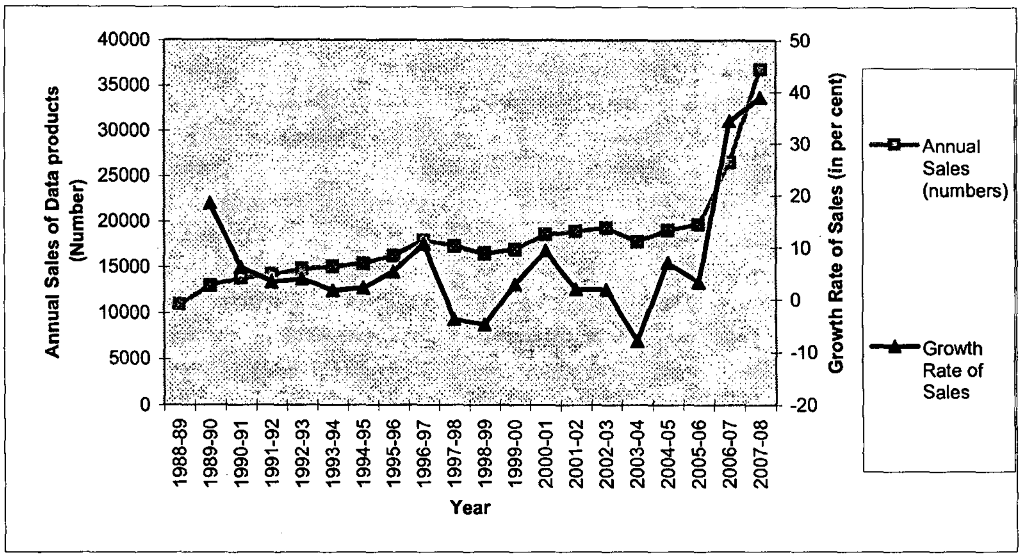
[46] There are fourteen different products on the basis of area of coverage. For more details see http://www.nrsa.gov.in/products/area_coverage.

[47] Nominal values are deflated using GDP deflator 1999-00 to get the real value.

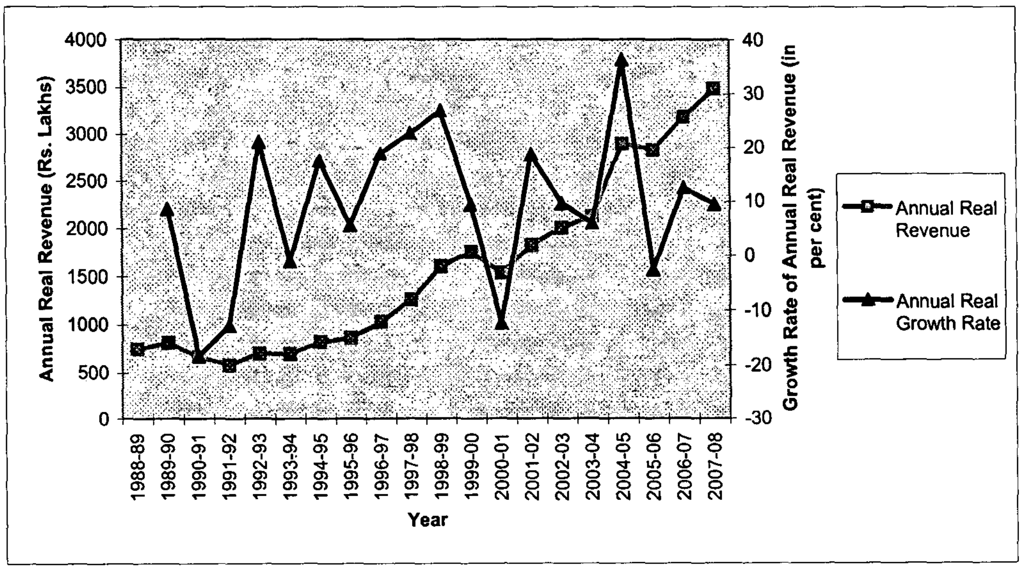
[48] Derived products are data products that are further processed or analysed, and are readily usable by the user.

Figure 3.3: Annual Sales of Data Products (Number)



Source: Unpublished data from NRSC

Figure 3.4: Annual Sales Revenue of NRSC (Rs. Lakhs)



Source: Unpublished data from NRSC

Table 3.2: Average Real Unit Price of Data Products

Period	*Average Real Unit Price* (Rs. thousands)
1988-89 to 92-93	5357
1993-94 to 97-98	5660
1998-99 to 02-03	9681
2003-04 to 07-08	12608

Source: own Compilation

NRSC classifies the data products' sales and revenue into six major sectors; Central Government, State Government, Department of Space, Industry, Academics and Foreign. NRSC does not maintain any database of sales on the basis of use of data products like agriculture, hydrology, land use/land cover etc.[49] Table 3.3 provides details on the annual sales revenue of NRSC across six different sectors detailed above. From the tables it is evident that Department of Space (DoS) is the major consumer of the data, accounting for more than 50 percent of the total sales revenue (however, figure 3.5 and 3.6 shows that the share of DoS has decreased from 58 percent in 1994-95 to 51 percent in 2007-08). Nonetheless, this phenomenon cannot be considered as an act of self-consumption. Agencies under DoS especially NRSC, undertake various projects for government departments and industries. The data sold to these projects are accounted under DoS. The government sector, central and state governments, is the second largest consumer of the data. The central and state governments together account for 24 percent of total revenue of NRSC in the year 1994-95 which increased to 32 percent in 2007-08 (see figure 3.5 and 3.6). On the other hand, the share of private sector is too low, only one percent in 1994-95. However, the sector's share accelerated to 8 percent during the period. This is primarily because of the emergence of new markets for the technology with the innovations in GIS and GPS technology. One reason for the low share of private sector in the total sales revenue is that the industries

[49] However, NRSC has started an effort to establish a dataset of sales on the basis of use or the purpose of the data.

that are undertaking infrastructure and development projects for governments acquire the data through the corresponding governments. This is because, for industries there is high level of screening for No Objection Certificate for high-resolution images, and also some restrictions and time delay for securing the data. Considering the other two sectors, foreign and academic, whilst the share of foreign sector decreased during the period[50] (from 13 to 5 percent) the share of academic institutions remained the same.

Table 3.3: Sector Wise Sales Revenue of NRSC (Rs. Lakhs)

	Central Govt.	State Govts.	Academic	Private	DoS	Foreign
1994-1995	70	72	26	8	333	74
1995-1996	142	61	23	17	370	57
1996-1997	106	109	39	26	508	88
1997-1998	146	245	58	41	594	86
1998-1999	242	235	63	74	653	276
1999-2000	255	305	53	65	831	245
2000-2001	330	140	65	120	871	65
2001-2002	365	292	60	170	888	173
2002-2003	364	481	71	152	1114	38
2003-2004	449	348	120	243	1186	95
2004-2005	757	631	143	261	1566	110
2005-2006	933	396	121	290	1676	117
2006-2007	1042	476	103	285	2161	119
2007-2008	764	791	180	385	2418	257

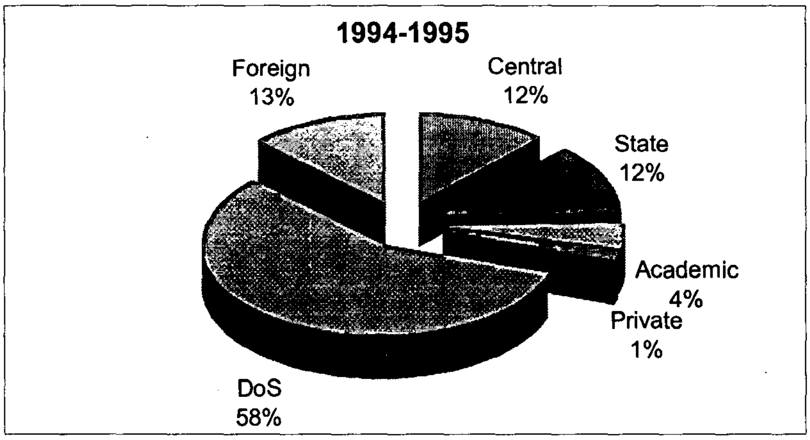
Source: Unpublished data from NRSC

In short, nearly one third of the total sales revenue of NRSC comes directly from government, and also an unidentified share indirectly

[50] Even though the share of foreign sector decreased, the sales revenue from this sector increased by 247 percent during the period.

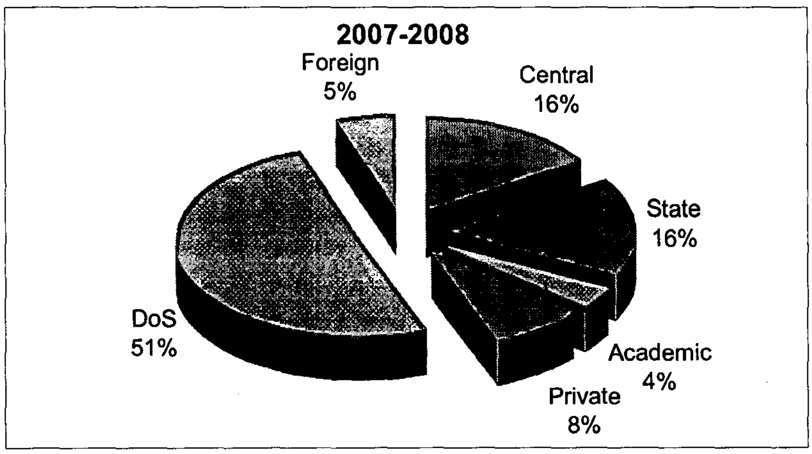
through DoS, indicating that the major consumer of the government-produced technology is government itself.

Figure 3.5: Sector Wise Sales Revenue of NRSC (1994-95)



Source: Own compilation from Table 3.3

Figure 3.6: Sector Wise Sales Revenue of NRSC (2007-08)



Source: Own compilation from Table 3.3

Table 3.4 provides details on the contributions of six different sectors to the growth of sales revenue of NRSC, from the year 1995-96 to 2007-08.

Table 3.4: Sectoral Contribution to Revenue Growth

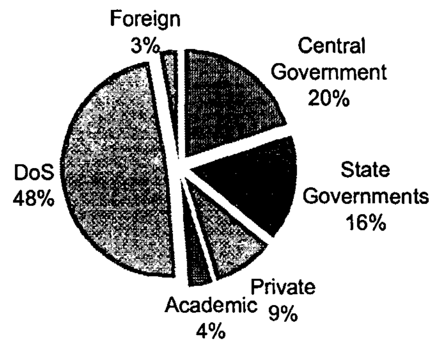
(in per cent)

Year	Central Govt.	State Govts.	Private	Academic	DoS	Foreign	Annual Growth Rate
1995-1996	10.73	-1.64	1.34	-0.30	5.51	-2.53	13.11
1996-1997	-4.11	5.48	1.03	1.71	15.75	3.54	23.40
1997-1998	3.42	11.62	1.28	1.62	7.35	-0.17	25.13
1998-1999	6.22	-0.65	2.14	0.32	3.82	12.31	24.17
1999-2000	0.74	3.99	-0.51	-0.57	10.15	-1.77	12.03
2000-2001	4.71	-10.37	3.46	0.75	2.51	-11.31	-10.25
2001-2002	1.80	7.80	2.57	-0.26	0.87	5.54	18.33
2002-2003	-0.05	8.51	-0.81	0.50	10.18	-6.08	12.25
2003-2004	3.48	-5.45	3.73	2.01	2.95	2.34	9.05
2004-2005	8.88	8.16	0.52	0.66	10.96	0.43	29.61
2005-2006	4.98	-6.65	0.82	-0.62	3.11	0.20	1.84
2006-2007	2.60	1.91	-0.12	-0.43	11.59	0.05	15.60
2007-2008	-5.80	6.57	2.09	1.61	5.36	2.88	12.70

Source: Own compilation from table 3.3

The major contributor is DoS. 48 percent of the growth of sales revenue of NRSC during the period is contributed by DoS (see figure 3.7 for percentage wise contribution of different sectors to the aggregate sales revenue growth). The government sector together contributes 36 percent (central and state governments contribute 20 and 16 percents respectively), followed by the 9 percent contribution of the private sector. As discussed earlier, DoS consume remote sensing data for the projects undertaken by the agencies under the department, from different government departments and industries. In this context, to the Indian remote sensing industry the government sector contributed more than one third of growth directly and an unidentified share indirectly through DoS. Consequently, we can infer that the engine of growth of Indian remote sensing industry is the government sector.

Figure 3.7: Sectoral contribution to aggregate revenue growth: 1994-95 to 2007-08



Source: Own compilation from table 3.4

3.5. Conclusion

In this chapter, we reviewed the evolution of Indian remote sensing programme and the technical features of Indian satellite RST, and made out that India's expertise in RST is mainly developed as an application oriented technology. Analysis of Indian remote sensing industry makes it apparent that the growth rates of sales of data products were low for a long period of eighteen years. Nevertheless, it shows high growth rates of 34 and 39 percent respectively for the last two years (2006-07 and 2007-08). On the other hand, the sales revenue of NRSC in real terms, show relatively higher growth rates during the period of analysis. Also, the real unit price of data products has been increasing over the period and the industry was moving towards more value added and derived products from standardized products. It is also apparent that DoS and government are the major consumers of data products. The private sector had a relatively small position or share in the industry, however the sector managed to increase its share from 1 percent to 8 percent during the period of analysis. In short, the major consumer of the government-produced technology is government sector itself. Similarly, the government sector (excluding DoS) is the highest contributor of revenue growth of NRSC, signifying that the engine of growth of Indian remote sensing industry is government sector.

Chapter Four

The Speed and Level of Diffusion

4.1. Introduction

As the title indicates, the present chapter is an attempt to measure the diffusion of RST in our economy, and in one of its potential market- urban planning. The chapter is structured as follows: Section 4.2 addresses the methodological issues involved in the measurement of diffusion. The next section deals with the measurement of diffusion of RST in India. Section 4.4 deals with the measurement of diffusion of RST in urban planning. Section 4.5 concludes the chapter.

4.2. Methodological Issues Involved in the Measurement of Diffusion

As discussed in chapter two (section 2.2), the diffusion of a technology at a particular point of time can be measured by two alternative ways: inter adopter and intra adopter methods of measuring diffusion. In inter adopter method, the diffusion is measured by the ratio of actual number of adopters to the potential number of adopters at a particular time. Alternatively, the diffusion ratio can be coined by taking the share of output, capacity or employment of labour to which the technology accounts for in relation to the industry's (or economy's) total output, capacity or employment. Here, the most difficult task associated with the measurement of diffusion is to determine or define the potential level of diffusion of a technology. In the case of RST, its use range in different areas, from natural resource maintaining and monitoring to archeology. Hence we are not in a position to determine the potential diffusion of the technology. Alternative suggestion to overcome this difficulty is to aggregate the potential diffusion in different sectors[51] (Stoneman, 2002). Nonetheless, in case of RST its use is not confined to certain sectors and the areas that demand remote-sensing applications is ever expanding. This is primarily because, in different areas RST is used as a unique, complementary or substitute tool. This complementarity and substitutability nature of RST made the technique employable in infinite number of areas. Unavailability of data on the actual use of the technology in various sectors is also a major concern. In short, it is difficult to assess exactly the areas of applications of the technology and determine the potential level of diffusion in each application[52].

In this context, to measure the speed of diffusion of RST in India, we employ average annual growth rate of real revenue[53] of NRSC as a proxy. The annual growth rate of sales also might indicate the spread of the technology across its potential adopters[54]. But, as discussed in chapter three (section 3.4) the data products are not homogenous in nature; they are differentiated in terms of quality and quantum of information they provide. As the price of data products reflects these features[55], the annual growth of sales revenue of NRSC can be a better indicator. Therefore, we use the average annual growth rate of real revenue as an indicator that denotes the speed at which the technology is spreading in the economy.

[51] In case of RST, there are also methodological limitations in measuring the actual use or potential diffusion in some sectors or areas of application. (For e.g. in predicting natural disaster) (See, Sankar and Rao, 2007).

[52] Absence of data on different applications or use wise sales of data products is also a limitation.

[53] Nominal values are deflated using GDP deflator 1999-00 to get the real value.

[54] As NRSC is a monopolist supplier, the rate of growth of sales indicates the speed at which the technology is spreading in the economy.

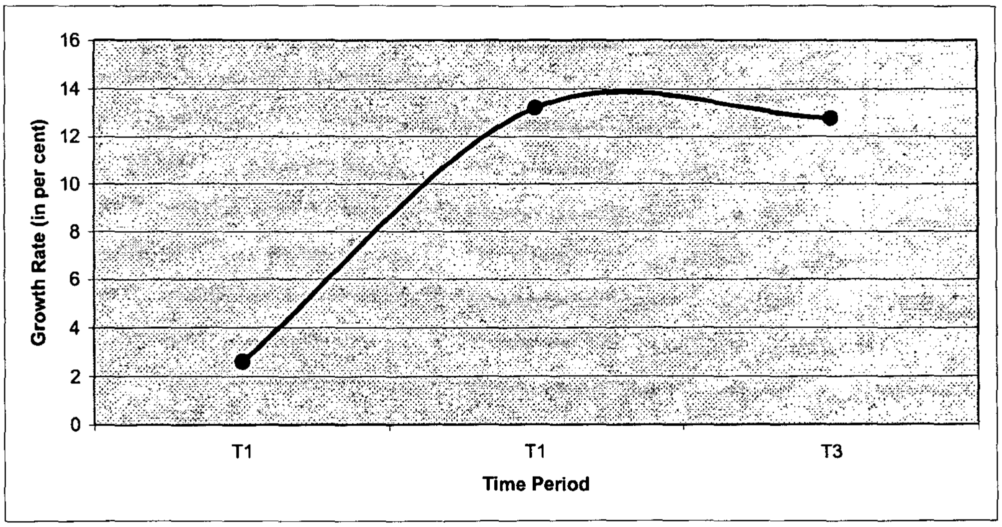
[55] The features of data products differ on the basis of level of processing, output scale and area of coverage.

4.3. Diffusion of RST

The era of operational RST[56] can be classified into three phases. The first phase is consisting of early operational IRS satellites such as IRS-1A, 1B, and P2. The period of high-resolution IRS satellites are considered as the second phase of the technology. The final phase is the period of theme specific satellites designed with sensors for specific applications[57]. The three time periods are from the year 1988 to 1994, 1995 to 2000 and from 2001 onwards.

The average annual growth rates of real revenue of NRSC for the three periods (from the year 1989-90 to 1994-95 [T_1], 1995-96 to 2000-2001 [T_2], and 2001-2002 to 2007-2008 [T_3]) are given in figure 4.1[58].

Figure 4.1: The Speed of Diffusion



Source: Own Compilation

[56] Operational RST indicates the satellite RST after the launch of IRS-1A in 1988.
[57] See, Navalgund, et al. (2007).
[58] Since we are adopting the growth rate of average annual real revenue of NRSC as a proxy to the speed of diffusion of RST in India, we excluded the share of foreign sector in the sales revenue before calculating the growth rate of annual real revenue.

Considering the growth rates as a proxy that indicates the speed of diffusion, we can infer that in the initial period (T_1), the speed of diffusion was comparatively low (2.6 percent). Similarly, in the second period, T_2, the speed of diffusion is accelerated to 13.18 percent and the speed is sustained in the third period, T_3, at a rate of 12.75 percent.

The speed of diffusion indicates the time required between two levels of diffusion (Nabseth and Ray, 1974). Since we are informed of the speed of diffusion with its corresponding time periods, the level of diffusion can be identified if we are informed of the initial level of diffusion. However, in our case, there is no information on the initial level of diffusion. In this context, we assume that the initial level of diffusion is at six percent[59] of the potential diffusion in the year in which our analysis establishes[60]. We also assume that the potential level of diffusion of the technology is constant. Table 4.1 shows the measurement of level of diffusion in three different time periods. It is evident from the table that with the given speed of diffusion in each period, the levels of diffusion in three different periods were 7.00, 14.71, and 34.10 percent respectively. Figure 4.2 represents diffusion curve of RST. The diffusion curve reveals that the spread of the technology was at a low level during the initial time period, and also it increased slowly. The 'taking-off'[61] of the curve occurs at the end of the second period (T_2), and thereafter the level of diffusion is increasing continuously at a higher rate. It is also evident that the curve is now at the middle part (steep portion) of the 'S' curve. On the other hand, the technology took more than twenty years to diffuse across thirty

[59] From late seventies onwards, remote sensing techniques were in use in India. Kumar (1991) finds that in 1988, out of the total remote sensing data products used/sold in the country, six percent were from IRS satellites. In the light of this fact, we assume that the technology had penetrated to six percent of its potential market.

[60] The analysis begins from the year 1988-89, so the assumption is that the technology has diffused up to 6 percent of its potential level (of diffusion) at this time period (say, T_0).

[61] Golder and Tellis (1997) define the concept 'take-off' as the point at which the empirical diffusion curve appears to have its greatest inflection relative to the initial growth rate.

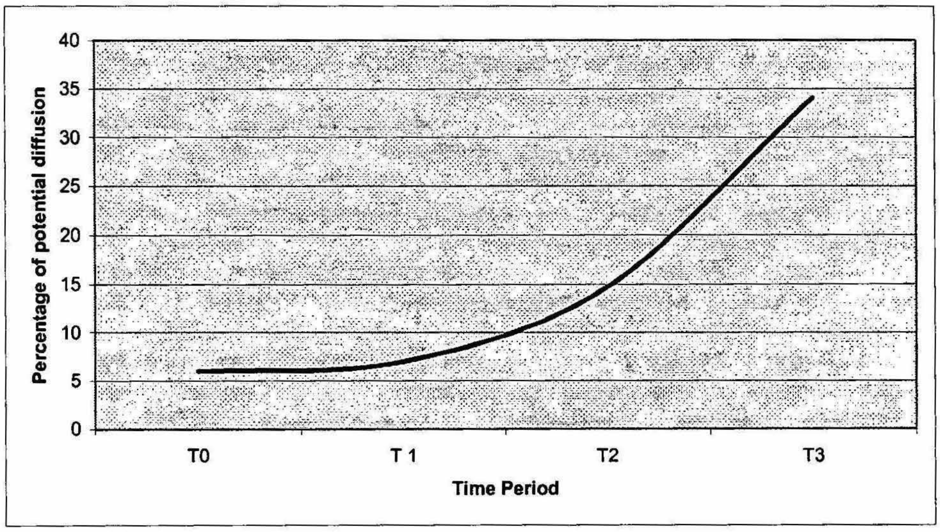
four percent of its potential level of diffusion. This implies that the speed of diffusion of RST in India is slow.

Table 4.1: The Level of Diffusion

Period	*No: Years*	*Speed of diffusion (in per cent)*	*Initial diffusion level in the period (in per cent)*	*Diffusion level at the end of period (in per cent)*
T_1	6	2.6	6[62]	7
T_2	6	13.18	7	14.71
T_3	7	12.75	14.71	34.10

Source: Own Compilation

Figure 4.2: The Diffusion Curve



Source: Own Compilation

4.4. Diffusion of RST in Urban Planning

The diffusion of RST in urban planning is measured by employing inter adopter method of measuring diffusion. Accordingly, the diffusion ratio can be

[62] Assumed value

measured using the ratio N_t/N^*, where N_t and N^* are the number of adopters at time 't' and the potential number of adopters respectively. The potential number of adopters of RST in urban planning is defined as the number of municipal corporations in India. We restrict our analysis to the municipal corporations by considering two features of the urban bodies: as they are assumed to have the ability to use the technology and need for the technology[63].

The municipal corporations in India, which have adopted RST as a tool for urban planning during the period 1996-2006 is given in Table 4.2. The table also reports the year of first adoption corresponding to the name of the adopting municipal corporation. The period of analysis is 1996 to 2006. This is because the era of utilizing RST as a tool in urban planning originates with the launch of IRS-1C[64] in 1995.

From Table 4.2, it is evident that only 51 municipal corporations out of 114[65] (in 2006) have adopted RST for the purpose of urban planning during the period of study. The early adopters of the technology were big metros and cities well known for scientific planning. Hence, the geographical characteristics and development dynamics of urban bodies could be some of the factors that influence the adoption decision[66]. The diffusion process of RST in urban planning is graphed in figure 4.3. The diffusion curve reveals two facts, i.e. the level of diffusion and the speed of diffusion. Regarding the level and speed of diffusion of RST in urban planning, the technology has

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[63] Ability to use represents infrastructure and funds available with the urban body. Need for RST indicates the magnitude of urban body's resources and the pressure over it, which in turn demand RS survey for effective spatial information.
[64] IRS-1C is launched with high-resolution sensors (5.8 meter) that consider applications in the areas that need high-resolution images like urban planning, infrastructure mapping etc.
[65] Source: information from All India Council of Mayors, New Delhi.
[66] But, limit in data sources prevent us on employing further analysis (such as rank effect model) to study diffusion in urban planning.

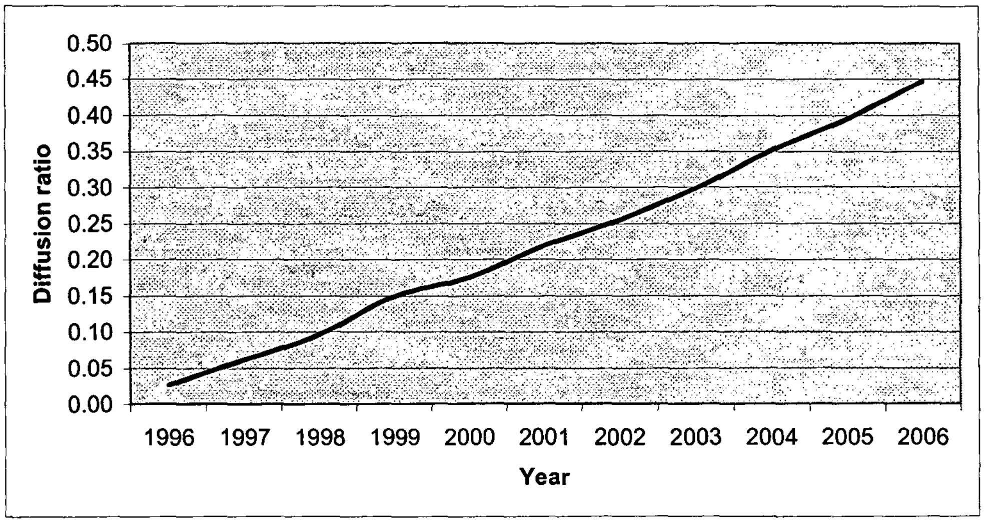
spread across forty five percent of its potential level, and the process took eleven years to attain this level of diffusion.

Table 4.2: Municipal Corporations that are Adopted RST

Municipal Corporation	Year of Adoption
Ahmedabad, Chandigarh, Delhi	1996
Bangalore, Greater Mumbai, Kolkata, Noida	1997
Agra, Kochi, Puri, Solapur	1998
Bhubaneswar, Guwahati, Imphal, Jodhpur, Pondichery, Thane	1999
Nainital, Kalyan-Dombivli, Nanded-Waghala	2000
Dehradun, Kota, Lucknow, Warangal, Nagpur	2001
Agarthala, Cuttack, Hyderabad, Navi Mumbai	2002
Asansol, Jaipur, Mangalore, Mysore, Panaji	2003
Bhopal, Gangtok, Aizwal, Thiruvananthapuram, Shillong, Pimpri-Chinchwad	2004
Gaya, Indore, Itanagar, Kohima, Raipur	2005
Ajmer-Pushkar, Chennai, Siliguri, Jhansi, Pune, Gurgaon	2006

Source: Unpublished data collected from NRSC, and Lok Sabha, (2005).
The source of year of adoption of six municipal corporations is the information from NRSC.

Figure 4.3: Trends in the Rate of Diffusion of RST in Urban Planning



Source: own compilation

4.5. Summing Up

In this chapter, by adopting the rate of growth of real revenue of NRSC as a proxy to the speed of diffusion of RST, we measured the level of diffusion of the technology in our economy. The level of diffusion, indicated by the diffusion curve, is almost thirty four percent of the potential level of diffusion, and it is now at the middle part (steep portion) of the 'S' curve. The technology took more than twenty years to attain this level of diffusion. We also measured the level of diffusion of RST in one of its potential market-urban planning. The diffusion of RST in urban planning required eleven years to cover forty five percent of potential adopters. Thus the findings imply that the speed of diffusion of the technology in both cases is slow, especially the speed of diffusion at aggregate level[67]. This fact also illustrates that the diffusion process of the same technology differs across areas of applications[68].

[67] The aggregate level implies the collective markets of the GPT (RST).
[68] For inter industry difference in the diffusion process of a particular technology see Vickery and Northcott, 1995.

Chapter Five
Factors Influencing the Diffusion Process

5.1. Introduction

This chapter is intended to serve as a platform for investigation of the factors influencing the diffusion process of RST in India. For the exploration, we employed qualitative field survey as the research method, and adopted semi-structured interview technique to collect relevant data.

The chapter is organized as follows: The following section describes the research methodology employed for data collection and analysis. Section 5.3 discusses the findings from the survey in detail from a diffusion perspective. Section 5.4 provides a temporal explanation to the diffusion process that we measured in the earlier chapter. The conclusion to the chapter is provided in section 5.5.

5.2. Research Methodology

5.2.1. The Sample

Like any other qualitative research method, semi-structured interview technique involves choosing of sample using either random or non-random method. In this study, a purposive sampling procedure is adopted to select the sample from the population of technology provider and different sections of adopters. At NRSC, the technology provider, ten separate interviews were held with the heads of different remote sensing application divisions, and NRSC Data Centre (NDC). Similarly, another interview was held with one scientist at Kerala State Remote Sensing and Environment Centre (KSREC). From the adopters' side, five interviews were conducted with different sections of adopters such as Government, Private and Academics. Table 5.1 provides the details of the interviews conducted with various personnel from different organizations.

Table 5.1: Information of Sample Selected

Organisation	*Category*	*Interview participant's position*	*No: Interviews*
NRSC, Hyderabad	Technology Provider (Public Sector)	Heads of different RS application divisions & head of NDC	10
KSREC, Thiruvanatapuram	Technology Provider & user assistant (Public Sector)	Scientist	1
Centre for Earth Science Studies (CESS), Thiruvanatapuram	adopter (Academic Institution)	Scientist	2
Reliance Gas Transportation Infrastructure Ltd.(RGTIL-IT)	adopter (Private Sector)	Project Manager	1
Thiruvananthapuram & Kollam Municipal Corporations	adopter (Public Sector)	The town planning officers	2

5.2.2. Data Collection

Semi-structured interview technique was used as the vehicle to collect data. The interviews were focused on the areas of information needed in this research, and the open-ended questions were mainly related to: (i) general observation and information on RST (ii) results of secondary data analysis (iii) Cost and benefit of adoption (iv) resources required for the use of the technology (v) interaction between technology providers and users, and (vi) general regulatory environment in the industry.

The interviews were scheduled as per the convenience of the interviewees, so that there would be minimum disruption and disturbances to their working schedules. Interviewees were provided with the basic idea and objective of the research in advance. Each interview lasted from 45 minutes to two hours, and with the consent of the interviewees some of them were recorded using voice recorder. Each interview was transcribed with the objective of collecting data without any distortion.

5.2.3. Data Analysis

One of the challenges in qualitative research is data analysis. There are, however, useful guidelines and techniques that will help a researcher to become better organized and effective, which can be selected on the basis of the objectives of the research (see Denzin and Lincoln, 2003). Since our methodology is exploratory in nature, we adopted analytical hierarchy approach that refers to the process through which qualitative findings are built from original data (Spencer et al, 2003). Accordingly, the analytical process requires three forms of activity: (i) Data Management; in which the raw data are reviewed, labeled and sorted; (ii) Descriptive Accounts; in which the analyst makes use of the ordered data to identify key dimensions, recognize the range and diversity of each phenomenon and develop classifications and typologies; and (iii) Exploratory Accounts. Exploratory accounts tend to be developed at the later stages of analysis. They may be derived from the finding pattern of association in the data and then attempting to explain why those patterns occur or building explanations from other evidence or interrogations of data. These might involve using explicit reasons and accounts including using a theoretical framework (deductive analysis) (Ritchie et al, 2003).

5.3. Factors Influencing Diffusion Process: Findings from the Survey

The findings from the survey on the factors influencing the diffusion process of RST are discussed under three different typologies: (i) the benefit from adoption, (ii) the information on the technology, and (iii) the regulatory framework.

5.3.1. The Benefits from Adoption

The benefits or improvement, RST provides[69] over the conventional methods of spatial data collection (for e.g. ground level survey) are broadly recognized as those including time effectiveness, cost effectiveness, more accurate information and the provision of new information that the conventional technologies or methods fail to provide[70].

Besides these advantages, RST provides a synoptic coverage and the data thus collected is easily storable and can be further treated for information in future. Another important feature of the technology is its 'repeatability' or 'reproducibility' of the process with enough ease.

The survey could identify (i) Improvement in the technology, (ii) Innovations in complementary technologies and (iii) Growth of complementary factors/infrastructure as the factors that influenced the perceived benefits from adoption (Time effective, Cost effective and more accurate spatial information).

5.3.1.1. Improvement in the Technology

The observational requirements in terms of spatial, spectral and temporal resolutions are different for different applications. In order to meet the observational requirements related to the assessment of natural resources and other applications, a series of satellites (Earth Observation System) have been launched over the period. Every launch of satellite was an improvement in the technology in terms of spatial, spectral or temporal resolutions. A brief

[69] The discourse on benefit of RST over conventional methods is on the basis of the discussions with technocrats at NRSC.
[70] Provision of new information is important in the fields where remote sensing is an exclusive tool of information, such as assessment of snow melting and impact of natural calamities, etc.

summary of the improvements of different IRS sensors over the preceding satellite sensors is as follows[71].

Starting from Bhaskara, the first experimental earth observation satellite launched in 1979, to the Cartosat-2 in 2007, spatial resolution of sensors has been improved from 1 Km to less than 1m (0.8 m). The evolution of earth observation satellites can be classified into three broad categories[72], viz. first generation of experimental satellites (Bhaskara-1 and 2), second generation of operational satellites (IRS series) and present generation of theme specific satellites (Oceansat-1, Resourcesat-1 and Cartosat-1 and 2). IRS-1A and IRS-1B with LISS-I and LISS-II systems were found useful in many national level resource management studies. A need[73] was felt to have a sensor with high spatial resolution for applications like urban mapping, infrastructure mapping, etc. Considering these needs, IRS-1C and 1D satellites were launched with panchromatic camera (PAN)[74], LISS-III camera and a wide field sensor (WiFS)[75]. The PAN camera was the highest spatial resolution (5.8 m) civilian system in the world at the time of launch of IRS-1C satellite in 1995. The LISS-III camera could detect moisture stress in crops and can discriminate snow from clouds. The WiFS camera was conceptualized from the need of frequent observation (temporal resolution) for monitoring of crops at national scale. This WiFS camera provided large area resolution at a temporal resolution of five days.

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[71] The discourse on the improvements in technology over the period is on the basis of interviews at NRSC.

[72] For more discussion, see Navalgund et al, 2007.

[73] The need was first identified at the apex bodies or decision-making institutions of the IRS programme.

[74] The data in the panchromatic region is useful in geological studies for mapping geological and geomorphologic features. Higher spatial resolution will be useful for urban planning studies, detecting urban fringe growth, updating the urban transportation infrastructure etc.

[75] This sensor is most useful for vegetation studies. The sensor provide vegetation index at regional level, thus helping in assessment of crop condition and drought monitoring.

While data available from the satellites IRS-1A/1B to IRS-1C/1D facilitated applications in the field of agriculture, forestry, land use-land cover, coastal zones etc., strong need was felt to design application-specific sensors for specific applications. This started the era of theme specific missions such as Oceansat-1, Resourcesat-1 and Cartosat-1 and 2. Oceansat-1 became the first Indian satellite primarily built for oceanographic applications. Resourcesat –1 (IRS-P6) is a mission primarily dedicated to agricultural applications in India. Cartosat-1 and 2 are satellites intended for cartographic applications.

The improvements in the technology were in terms of spatial, spectral and temporal resolutions[76]. The improvement in the spatial and spectral resolution could provide more micro level spatial information of improved quality to the user community. In other words, the improvement in resolutions provided information of higher quality in the existing applications and secondly it facilitated new innovative applications in the fields where higher spatial resolution is needed (for e.g. in urban planning). On the other hand, it is apparent that the improvements in Indian remote sensing satellites and sensors alleviated our dependence to foreign satellite data. This resulted in tremendous fall in prices of the data products, as data products from Indian satellites cost only one-tenth cost of foreign satellite data products. As the temporal resolutions of the satellites improved, more frequent observations and monitoring of resources were made possible and the turn around time also came down. To sum up, improvement in the technology had its impact on all the three characteristics of the benefits of adoption; time effectiveness, cost effectiveness and provision of accurate and new information.

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[76] For detailed information on the improvements in technical characteristics of sensors, see Table 3.1.

5.3.1.2. Growth of Complementary Technologies

The survey could identify two complementary technologies of RST, such as GIS and GPS that are influencing the diffusion process of the technology. Innovations in these two complementary technologies enhanced both quality as well as quantum of information that can be derived using remote sensing data. Scientists at NRSC observe that as GIS and GPS developed, scientists' community could design innovative applications of RST in various fields such as planning, engineering, business, electricity/gas utilities, transportation etc. Many of the new applications designed fall under the domain of private sector. In short, innovations in complementary technologies that took place during the late 1990s and 2000s served two purposes; it resulted in the emergence of new areas of applications and potential markets, and it enhanced the quality and quantum of information that can be derived from RST, thereby enhancing the benefit from adoption.

5.3.1.3. Complementary Inputs

Two important complementary inputs of using remote sensing data are the softwares that are employed for digital image analysis and skilled employees for interpreting the digital image[77].

The survey identifies that there is a shortage of skilled employees who can read and interpret the digital image efficiently, particularly during the earlier phases of RST. One of the interviewees remarks, "*the industry still experiences a shortage in man and machine*". Underdevelopment of skilled employees who can productively use the data products resulted in low productivity and low rate of adoption of the technology. Indian Institute of Remote Sensing (IIRS) at Dehradun was established with the objective of

[77] Interpretation comprises detection, identification, description and assessment of significance of an object and pattern imaged.

supplying quality employees to the industry. Earlier IIRS was involved in providing training on using RST in different areas of applications. The training programmes include:

- University Faculty Training Programme, started in 1994.
- Special short-term courses on users demand.
- Other certificate programmes on mapping and monitoring of natural resources, and Geoinformatics.

In 2002, IIRS started offering M Tech in remote sensing and GIS, and M Sc programme in Geoinformatics. Total number of student enrolment at IIRS up to the year 2007 is 6483. In 2007, IIRS started offering training on remote sensing, GIS, and GPS to university students through Edusat[78]. The programme is initiated with the association of twenty universities in the country. In 2007, two six weeks courses were offered and 1242 students had undergone training. During the present decade, major universities in the country started offering courses in applied remote sensing with the objective of supplying quality employees to the industry. A lot of private institutions also were established during 2000s offering diplomas and training programmes on remote sensing and GIS. Remote sensing was also added as a subject to the syllabus of almost all pure and applied sciences postgraduate programmes. NRSC is also involved in offering regular training programmes to the employees of user agencies on how to read and interpret digital satellite images.

Since 1995, the data products from NRSC became digital, which is easy to handle and store. Digitization also enhanced the quality of the image. A lot of softwares were developed during the period to assist the process of analyzing the digitized image. New softwares are helping innovative applications of GIS and GPS on remote sensing data. At present, software that allows GIS

[78] Edusat is a satellite intended for an interactive satellite based distance education system.

application cost 30 to 40 lakhs. This increases the cost of adopting RST and other complementary technologies as a source of spatial information. Therefore two facts identified regarding complementary factors are: the shortage of skilled employees retarded the efficient or productive use of the technology and diminished the perceived benefit of adoption thereby slowing the diffusion process. Secondly, the need of complementary softwares generates some additional cost on adoption, again influencing the net benefit of adoption.

5.3.2. Information

As discussed in the theoretical frame, information on a new technology primarily takes three forms: (i) information on the availability of a new technology, (ii) information on how to employ/use the new technology, and (iii) information on the experience with the technology.

A large multidisciplinary team of scientists develops applications of RST in various fields like agriculture, urban planning, hydrology, fisheries etc. Soon after each mission, seminars will be conducted at national level and state level inviting the officials at various levels of different potential user agencies. In these seminars the innovative applications designed, and their nature and characteristics are detailed. These seminars become a major platform of interaction (channel of information) between technology providers and users, and provide users with knowledge of availability of the technology, its compatibility with the users' needs and also provide information on how it can be employed efficiently. Likewise, soon after each mission a user handbook is released. The user handbook details both the technical as well as application features of the satellite, and provides information on the data products that are available and the procedure for ordering and obtaining data products.

A set of institutions or innovation diffusion agencies, which are engaged in the development and dissemination of RST, has been established in India. NRSC (the sole acquisitor and distributor of remote sensing data), functions at national level. At regional level, Regional Remote Sensing Service Centers (RRSSC) were established at Bangalore, Nagpur, Kharagpur, Jodhpur, and Dehradun for speedy operationalization of RST as an integral component of natural resources inventory monitoring and management. State Remote Sensing Service Centers (SRSSC) at state level assists the state level user agencies. Village Resource Centers (VRC), established at village level (aims for digital connectivity to remote villages) provide multiple services such as telemedicine, tele-education and other remote sensing applications through a single window. These three institutions geographically define their markets or field of services and provide infrastructure that facilitate information, delivery, service etc.

NRSC adopts the strategies including advertisements, training[79], seminars, workshops and various publications including periodicals, users' manual/handbook (Channels of information) to provide information on the availability of a new technology and information on how to employ the new technology. But the choice of adoption also depends on the information available about other users' experience with the technology. One of the respondents in the survey point out an example of a series of seminars organized by a farmers' organization in Andra Pradesh, in which farmers who used information provided by RST, shared their experiences with non-users. These kinds of seminars become the platform of interaction between users and non-users in which the users explain their experience with the technology. However, the survey identifies that the scope of interaction between a user and non-user is limited in the case of RST, as most of the user agencies are

[79] A classic example can be the training organized by NRSC for the Taxi cab drivers at Rajeev Gandhi International Airport, Shamshabad (Hyderabad), aiming at enabling them to use GPS.

government departments at different levels. One of the scientists at NRSC, point out that there are interactions between different government departments at same level, on the other hand interaction between departments at different levels is limited. Similarly, in the market of urban planning, no interaction has been taken place between the two urban bodies surveyed- one user and other nonuser.

The employment structure of the user agencies (Governments) attracts special attention in the case of impact of information on spreading the technology. NRSC and other innovation diffusion agencies conduct workshops/trainings to the employees of the user agencies with the objective of creating awareness on the benefits of RST, and the mode of employing the technology. Scientists at NRSC observes that there is lot of instances that these trained employees get transferred or retired soon after the interaction with NRSC, thereby alleviating the impact of the provided information on technology diffusion. One of the respondent at NRSC point out that when the new generation who are acquainted with the Information Communication Technologies (ICTs) and are convinced on the benefits of new technology, entered the government services the information on the technology among the user agencies enhanced and helped to eliminate the 'resistance'[80] that prevailed in the initial phase of the technology. Another fact is the launch of 'Google Earth'. Interviewees, both from technology provider and adopter side, detect that 'Google Earth' popularized the significance of satellite images on providing accurate spatial information[81].

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[80] 'Resistance' implies opposition from the part of bureaucracy towards the use or adoption of a new innovation, either technological or organizational. For example, the introduction of computer in public enterprises/offices met stiff opposition from the bureaucracy during late 80s; at present, Indian Railway is the largest user of computers in the country.

[81] One of the scientists perceived that, as Prof. A.P.J. Abdul Kalam became the President of India, the information on the significance of the RST, spread widely among government departments.

5.3.3. The Regulatory Environment

Recognizing the advantage or benefits of RST, Governments (both central as well as states) are mandating remote sensing survey or data in certain areas. National Forest Policy 1988 stipulates that remote sensing data has to be imbibed into the forest plan. National Environment Policy stipulates that for environmental clearance of any commercial or development projects, detailed project appraisal with satellite data detailing project's impact on environment is required. Similarly, Haryana Government mandated satellite image for registration of the deed of acquired land for any development purposes. In order to maintain and ensure effectiveness of water-bodies scheme (under Bharath Nirman), central government made the use of remote sensing survey a mandatory. Besides these singular cases, remote sensing data are utilized in some national programmes like Integrated Mission for Sustainable Development (IMSD), National Natural Resource Information System (NNRIS), National Natural Resource Maintenance System (NNRMS) etc. Scientists at NRSC cites the above mentioned government interventions as the reason for the relatively high share of government sector in the total sales of remote sensing data.

Nevertheless, a respondent from the adopters' side observes that Government's regulatory policies (in terms of security concerns) not only hinder the diffusion of RST but also hold back the growth of private sectors' share in the industry. Remote Sensing Data Policy (RSDP) and Map Policy are the policies that characterize the regulatory environment. We had a Map Policy[82] prior to 2005, which was highly restrictive. Around 43 percent of the total geographical area of the country falls under restrictive or sensitive area category, and there were restrictions on the supply of topographical maps of

[82] This input is provided by a scientist from adopters' side.

Survey of India (SoI). Topographic maps of SoI are required for geo-referencing satellite data, field verification and transfer of thematic boundaries. The regulation made the user community to depend exclusively on government agencies (that are provided with the base maps) for derived products. In addition to this, more significantly, data integration in a GIS environment requires a sound map base, which is met by the information available in topographic maps. So, a restriction in topographic maps of SoI retards the growth of GIS industry, and accordingly impedes the diffusion of remote sensing data. In May 2005, liberalised New Map Policy was announced that envisages two series of maps: the Defence Series Maps (DSMs) and the Open Series Maps (OSMs). While the DSMs will be exclusively for defence forces and authorized government departments, the OSMs are open to the user community.

Another policy related to the diffusion of RST in India is Remote Sensing Data Policy (RSDP). The survey could detect that during the years prior to RSDP 2001, the industry faced stiff regulations on disseminations of data products. All satellite images were cleared for public dissemination only after the Department of Defence (DoD) masks certain sensitive areas. The ordered data products were usually delayed due to the procedure associated with the clearance of DoD. Thus, the features of regulations such as regulated access, masking of data, and time consuming to receive the data were hindering the spread of the technology during initial two phases of the technology. In this context, RSDP 2001 was announced with the aim of providing augmented access to satellite data and to minimize the masking of data. The RSDP 2001, again vests the exclusive authority with NRSC to acquire and disseminate all aerial and satellite remote sensing data from Indian as well as foreign satellites, eliminating the scope for competition[83]. The policy put regulations on dissemination of data of resolution 5.8 meters and better. All images of resolution 5.8 m or better will be screened before dissemination so that images of sensitive areas are excluded. The private sector has only regulated access to data that have resolution better than 1 meter (Cartosat Data), subject to the approval of High Resolution Image Clearance Committee (HRC). One of the respondents perceives two aspects of regulation: first, regulation on aerial and high-resolution images, and secondly restricting access to private sector or industry. Accordingly, regulation on high-resolution images and private sector is a major explanation for the slow speed of diffusion of RST. Therefore, the diffusion of a public sector technology is impeded by public policies.

5.4. Explaining the Diffusion Curve

From the above discussed survey findings, we are able to explain diffusion process over time. In the initial period (T_1), the technology had just finished its experimental phase, and was not adapted well to different applications. As Rosenberg (1976) describes in economic history perspective of technology diffusion, the innovation was crude in nature providing low improvement over its substitute techniques. During this period, the market of complementary inputs was not developed, and the complementary technologies were also not available. These features resulted in very low worth of the three characteristics of benefit from adoption, viz. provision of accurate and new information, time effectiveness and cost effectiveness. During this period, information of three different sorts was not available to the potential adopters. The public policies were also regulatory in nature, not favouring the diffusion. These facts explain the lower tail of the diffusion curve evidenced during the initial phase (T_1) of the technology.

[83] Competition is an important market feature in US and other foreign countries' remote sensing industry.

The second period (T_2) is the period of takeoff of the diffusion process. During the second period, where high-resolution IRS satellites were launched, improvement in the technology had its impact on all the three characteristics of benefit from adoption. Similarly, the period witnessed emergence of GIS and GPS that further enhanced the benefit from adoption and designed new innovative applications of RST. The information infrastructure was also found improved during the period with the establishment of diffusion agencies at different levels. Even though there was conscious attempt to increase the supply of skilled employees by making the science of the technology a part of academic curricula, the industry experienced a supply gap of skilled employees during the period. The regulatory environment was sluggish to recognize the technological improvement during the period, and it continued to be restrictive in nature. The developments during the period (i.e. improvements in benefit from adoption and information; the regulatory environment and lack of capability to use as constraints) determined the diffusion process of the technology and the period witnessed the 'early expansion' of diffusion curve.

The third period (T_3) witnessed a change in regulatory environment: RSDP in 2001and Map Policy in 2005. The final time period is also characterized by continued improvements in RST, complementary technologies and information infrastructure. However, supply gap of complementary inputs continued to exist during the period.

5.5. Conclusion

In this chapter, we investigated the factors influencing the diffusion process of RST in India. On the basis of field survey with semi-structured interview as a tool, qualitative data are collected both from technology adopters as well as providers. On analyzing the qualitative data by means of the theoretical frame, it is found that the factors that influence the diffusion process are broadly related to the benefit from adoption of the technology, the information on the technology and the regulatory framework. The regulatory environment in the industry, characterized by RSDP and Map Policy, is more concerned on the security aspect than the diffusion aspect. The old Map Policy restricted the supply of topographical maps of SoI. The survey identifies that this restriction constrained the GIS industry, and impeded the diffusion of RST indirectly. On the other hand, two facets of regulations by RSDP include: regulations for high-resolution and aerial remote sensing data, and regulations for private sector. Thus, the survey identifies the regulatory environment as the key factor that impede the diffusion of RST in India, signifying that the diffusion of a government produced technology is impeded by government policies. Similarly the survey identifies that the provisions of complementary inputs that signify the capability to use or adopt the technology are still not in accordance with the demand conditions in the industry. Consequently, the lack of capability to use of potential adopters (which in turn reduce the benefit from adoption) hinders the diffusion process of the technology. From the discussion on the determinants of diffusion, it is apparent that the improvement in the technology (incremental innovation) and innovations in the complementary technologies enhanced the extent of benefit from adoption over time. Similarly, the provision for information i.e. information on the availability and information on how to employ it, has improved over time encouraging the diffusion process.

Chapter Six
Summary and Conclusion

6.1. Overview

This study began with the goal to analyse the diffusion and identify the factors influencing the diffusion process of RST in India. Right from the Nehruvian era, the distribution of national R&D expenditure between government and private sector has been highly skewed, and major public sector research institutions account for the lion share of national R&D expenditure. On the other hand, the technological innovations of these public sector research institutions are not successfully diffused in the economy. Given these facts, we choose to investigate the dynamics of diffusion of a public sector technology-RST- in India.

This dissertation is comprised of six chapters. In chapter one, we introduced the context that motivated the study and outlined the research problem. Chapter two critically examined the various theoretical strands in the literature of diffusion of innovation and put forth the theoretical frame of the study. In chapter three, we provided a synoptic overview and analysis of Indian remote sensing industry. In chapter four, we measured the diffusion of RST in India at aggregate level and also in one of its potential market-urban planning. Chapter five deals with the objective of identifying the factors influencing the diffusion process. The analysis was based on the qualitative data from the field survey among both technology providers and adopters.

Though in different chapters the findings are summarized, here we present the broad overview of them. A concise account of the findings is provided in the next section (section 6.2) of the present chapter. Section 6.3 discusses some of the limitations of this study and outlines some possible directions of further research.

6.2. Research Findings and Discussions

The technical capability in RST, achieved by ISRO and its sister organisations is application oriented. However, the study identifies that the sales of remote sensing data products (in terms of number of products) were increasing at a low rate for a long period of eighteen years (i.e. from 1988-89 to 2005-06). In the context of a liberalized policy environment and favorable price cuts for data products, the last two years (i.e. 2006-07 and 2007-08) experienced high growth rate of 34 and 39 percent respectively. On the other hand, we identified that the real revenue from sales of data products increased during the period, signifying that the product basket of NRSC was diversifying towards more value added products. Analysis of sector-wise sales revenue of NRSC, suggests that the government sector (excluding DoS) is the major consumer of remote sensing data products. The share of private sector in the industry is at low level (8 percent in 2007-08). The survey enquired two possible explanations for this phenomenon; policy regulations that influence the accessibility to the technology, and secondly, lack of market for the technology in private sector or the public sector technology has only limited role in private sector. It is found that the market for the technology in private sector is promising with the innovations in technologies like GIS and GPS. However, there are regulations for private industry, particularly in case of high-resolution images, complemented by old map policy that constrained the growth of GIS industry[84]. In short, the study concludes that the major consumer of the government-produced technology is government sector itself, and the role of private sector in the industry is constrained by regulatory

[84] For example, GIS-BPO is a Rupees thousand crore industry in India. Around 250 firms (TCS, Infotech, Rolta India Ltd., etc.) in India employ around 20,000 executives to provide GIS and GPS service to the world (Anonymous, 2005).

policies to some extent. In addition to this, the study identifies the government sector as the engine of growth of Indian remote sensing industry.

By adopting the rate of growth of real revenue of NRSC as a proxy to the speed of diffusion of RST, we measured the level of diffusion of the technology in our economy. By assuming 6 percent initial level of diffusion, it is estimated that the level of diffusion of the technology is at 7 percent, 14.71 percent and 34.1 percent of potential diffusion in three consecutive time periods. It is also noted that the diffusion curve is now at the steep portion of the 'S' curve. Thus, the study identified that the level of diffusion of the technology is only around one third of its potential diffusion and the process was also time consuming. Using inter adopter (firm) method of diffusion, we measured the level of diffusion of RST in one of its applications- urban planning. The diffusion curve exemplified that the level of diffusion of RST in its market of urban planning is 45 percent of the potential diffusion. Again, the study concludes that the speed of diffusion of RST both at the aggregate level (i.e. the collective market for the technology) and in one of its market (i.e. in urban planning) is slow.

On the basis of data collected from field survey, the study identified the factors influencing the diffusion process of RST. It is found out that the factors influencing the diffusion process are broadly related to the regulatory environment, information on the technology and benefit from adoption. The regulatory environment, characterized by the Remote Sensing Data Policy and the Map Policy, impeded the diffusion process of the public sector technology over time[85]. The regulatory environment is exemplified as regulations for high-resolution and aerial remote sensing data, and regulations for private sector. Accordingly, the study concludes that the diffusion of a government-

[85] However, the study recognizes the liberalisation of Map Policy in 2005, and of RSDP in 2001.

produced technology is mainly impeded by government policies. This attempt from the government is mainly due to a security concern. But the arguments from adopters highlight that satellite image of Indian soil is freely available in foreign market at 60-centimeter resolution, and secondly the service of 'Google Earth'. Another key determinant of diffusion process of RST is capability to use. Two important complementary inputs for the efficient use of the technology are skilled employees and software for data analysis. The study finds that there is still a supply gap of complementary inputs in the economy resulting in lack of capability to absorb the technology efficiently, which in turns influences, the benefit from adoption. Thus, the study concludes that lack of 'capability to use' impeded the diffusion process of RST.

Other than capability to use, factors that influenced the benefit from adoption of RST are the improvement in the technology and innovations in complementary technologies. The analysis of survey data demonstrates that the improvement in innovation had its impact on the characteristics of benefit from adoption (i.e. time effectiveness, cost effectiveness and accurate information). Similarly, innovations in GIS and GPS, the complementary technologies, enhanced the quality and quantum of information that can be derived using RST, and exposed new areas of applications. On the other hand, the study finds that the channels of information from the technology provider (and also from the external environment) were developed overtime and were effective to provide information on the availability and effective employment of the technology. Accordingly, the study concludes that the factors that are related to the benefit from adoption and information on the technology has emerged and/or improved over time, thereby encouraging the diffusion process.

From this study on diffusion on public sector innovation, it is evident that for a successful diffusion of a public sector innovation, government has to undertake three different roles or responsibilities: (i) As an innovator: the government has to constantly improve the innovation so that benefit from adoption is continuously enhanced over time. (ii) As a capacity builder: the government has to prepare the economy capable enough to absorb the new technology or innovation. To create or enhance the capability to adopt a new technology, the government has to ensure adequate supply of complementary inputs, infrastructure, knowledge, and institutions. (iii) Finally, the government as a facilitator: to make the spread of the new innovation from the government research agencies to the potential adopters, the government needs to adopt a diffusion facilitating policy environment.

6.3. Limitations and Issues for Further Research

The study puts forward some suggestions for further research, which comes partly from the limitations of the present research, and partly motivated by the results of this study. The study is constrained by limitations in terms of availability of both data and time. Some of the limitations of the present research are as follows. First, in the measurement of diffusion of RST in one of its potential market- urban planning (section 4.4), it is clear that the early adopters of the technology were big metros and corporations well known for scientific planning. Thus, it is evident that the geographic and economic factors of the potential adopters are significant determinants of adoption of RST. However, the study could not employ further analysis (such as probit model) to identify the factors that influence the diffusion process because no established database is available on the characteristic features (i.e. land use-land cover, infrastructure facilities etc.) of municipal corporations in India. Secondly, majority of the samples selected from the population of potential adopters are from Kerala state. The study could not include samples from other regions of the country because of the time limit of the study. Third, the study did not provide vital consideration to the institutional factors such as bureaucratic interferences as the determinants of the diffusion process.

However, we recognize that institutional factors are also important in explaining the dynamics of diffusion of RST, as major consumer of the technology is the government sector.

In this context, by considering the socio-economic significance of RST, a study on the role of public sector technology in sustainable development is proposed. The significance of space technology, particularly RST in sustainable development is exemplified with the case of VRCs[86]. Moreover, RST is an important tool in Integrated Mission for Sustainable Development programme (a National Programme). RST is an (spatial) information provider. The basic advantage of the information that could be provided using RST are: (i) early information (timely), (ii) improved information (accurate), and (iii) new information. Therefore, the economics of information provided by RST is another area for further research.

[86] Village Resource Centers are institutions established at villages to provide services to the rural population including tele-education, telemedicine, communication, information on crops and weather etc.

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