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Frugal Innovation in India's Space Sector and Its Socio-Economic Impacts

A. Introduction:

Frugal innovation is an approach for designing cost-effective and resource-effective solutions which aims to deliver maximum value. Such unique innovations are generally observed in developing economies due to confined opportunities and resources. India since independence has had innovative innovations in different sectors and has led to emergence of multiple organizations. India's space sector headed by Indian Space Research Organisation (**ISRO**) is an example of frugal innovation. Launch of Mangalyaan and Chandrayaan missions showcase the potential of Indian space sector.

This literature explores the impact of India's space sector in socio-economic development. It includes analysis of digital public infrastructures (**DPI**), information diffusion and price volatility attributed to space sector shocks. The literature investigates the impact of satellite-based information on agricultural productivity and Difference-in-Difference (**DiD**) analysis.

B. Frugal Innovation in India's Space Sector

1. The Concept of Frugal Innovation

Sanjay (2020) attributed the word "Jugaad" for the Indian way of performing frugal innovation. It focuses on affordability, simplicity and accessibility. It is an innovative way to execute innovation with minimal resources (pp. 1-26). Indian space sector is an example of frugal innovation. ISRO's **Mangalyaan** mission was launched on November 5, 2013. It was developed at a budget of **$74 million**. It is the cheapest Mars Mission in the world. **Chandrayaan-3** mission had a budget of **INR 600 crore** as compared to **INR 16,000 crore** of Russian moon mission. These are testimony of how advanced mission can be achieved with such low budget. These missions demonstrate technological power of ISRO and implication of principles of frugal innovation and minimizing unnecessary costs.

2. Implication in Space Sector

ISRO's jugaad includes development of technologies, maximizing the reuse of components and collaborations with private and public sectors. It's ability to create low-cost satellites and launch them using cost-efficient Polar Satellite Launch Vehicle (**PSLV**) demonstrates frugal innovation. Devezas (2012) India's PSLV launch vehicle which has a capacity LEO of 3250 kg, capacity GEO of 1050 kg and success rate **88%** has cost per launch **$16 million** (pp. 963-985). These innovations has made India a key participant in space sector and has positively affected various socio-economic sectors. Sanjay (2020) In 2006 ISRO was **sixth** largest space organization in the world (pp 1-26). The Indian government made a total investment of **279.3 billion** Indian rupees till **2006-2007**. The space expenditure of India as a percentage of **GDP** stood at **0.09%** in **2008**.

C. Socio-Economic Impacts on Digital Public Infrastructures (DPI)

1. Enhancing Digital Public Infrastructure

Digital Public Infrastructure (DPI) is the shared digital systems that facilitates in public service delivery, economic activities and social inclusion. Satellite based technologies have significantly contributed in the evolution of DPI in India. Expansion of telecommunication in rural and remote areas which lack in terrestrial infrastructure is attributed to satellite communication. The Indian National Satellite (**INSAT**) system established in **1983** is one of the largest communication satellite systems in Asia-Pacific region. It has nine operational communication satellites placed in Geo-stationary orbit. As per report by National Association of Software and Service Companies (NASSCOM) and Boston based management consulting from Arthur D Little International, India has a potential to become an **$8 trillion** economy by **2030** due to DPI.

Digital India is a program which aims to transform India into a digitally empowered society. Program has benefited from the advancement in satellite technology. The Indian Regional Navigation Satellite System (**IRNSS**) is also known as **NavIC** which supports applications like disaster management, vehicle tracking and mobile communication. NavIC is designed with a constellation of **7** satellites and a network of ground stations operating 24X7. These advancements in DPI have led to enhancement in financial inclusion, healthcare delivery and better access to education. All this has led to elevation of living standard across country.

2. Impact of Space Sector Shocks on DPI

Space sector shocks can have devastating effects on DPI. Interruption in satellite-based communication service due to satellite malfunction or launch failures can hamper functionality of banking operation, online education, telemedicine services or in general anything dependent on satellite operation. This leads to the need for robust and resilient infrastructure. Shocks can temporarily hamper service delivery but the overall trajectory of DPI development attributed to rapid developments remains positive due to recovery and continuous innovation.

D. Information Diffusion and Price Volatility in Agriculture

1. Role of Satellite Based Information in Agriculture

Agriculture sector is highly vulnerable to climate change and has significantly benefited from satellite-based information. Farmers in regions with access to weather forecasting, soil health monitoring and crop advisory services can make informed decisions about sowing, irrigation and harvesting which aids in crop yields and profitability. The satellites launch by ISRO which are designed for benefits of farmers and currently in operation are as follows:

S. No	Satellite	Launch Date	Cost Incurred (Cr)	Objective
1	Resourcesat-2	20.04.2011	138.71	To provide multispectral images for inventory and management of natural resources, Crop production forecast, wasteland inventory, Land & Water Resources development, and Disaster Management Support.
2	Resourcesat-2A	07.12.2016	106.11	To provide multispectral images for inventory and management of natural resources, Crop production forecast, wasteland inventory, Land & Water Resources development, and Disaster Management Support.
3	Cartosat-1	05.05.2005	248.49	To provide high resolution images for Cartographic mapping, Stereo data for Topographic Mapping & DEM, and host of DEM Applications – Contour, Drainage network, etc.
4	RISAT-1	26.04.2012	375.38	To provide all weather imaging capability useful for agriculture, particularly paddy and jute monitoring in kharif season and management of natural disasters.
5	Kalpana-1	12.09.2002	71.30	To provide meteorological data to enable weather forecasting services.
6	INSAT-3D	26.07.2013	206.00	Designed for enhanced meteorological observations, including vertical profile of the atmosphere in terms of temperature and humidity for improved weather forecasting and disaster warning.
7	INSAT-3DR	08.09.2016	116.38	Designed for enhanced meteorological observations, including vertical profile of the atmosphere in terms of temperature and humidity for improved weather forecasting and disaster warning.

Satellite driven platform Meghdoot app which is a joint initiative of the Indian Meteorological Department (**IMD**), Indian Institute of Tropical Metrology (**IITM**) and Indian Council of Agricultural Research (**ICAR**) delivers localized weather forecasts and advisories directly to farmers. The app provides district wise advisories on crop and livestock management issued by Agro Met Field Units (**AMFU**). The accessibility of such information has led to reduced uncertainty and mitigated risks associated with agricultural activities. This has resulted in stabilizing income and reducing price volatility in the markets.

Remote Sensing Technology if used in important user domains in agriculture would have resulted in benefits of about **INR 100 billion** for the year **1998–1999** and improved land use mapping would have increased the contribution of agriculture to Indian **GDP** by about **INR 120 billion** for the year **1998–1999.**

2. Impact on Price Volatility

Timely and accurate access to information reduces the unpredictability in agricultural markets. Better forecasting and advisory services can help farmers plan their activities effectively. It will lead to smooth supply of produce to the market which will reduce price spikes. Timely information has an important impact on stabilising prices of perishable commodities where oversupply or undersupply can result in significant price fluctuations.

E. Design of Control Trial Using Difference-in-Differences (DiD) Methodology

1. Methodology Overview

Difference-in-Difference (DiD) approach is used here to analyse the impact of satellite-based information on agricultural productivity. This method compares changes in agricultural productivity over time between treatment group and control group. Treatment group receives satellite-based information whereas control group does not receive any such information.

- **Treatment Group:** Regions which have access to satellite-based agricultural advisories which include weather forecasting, soil health data and other relevant information. For our further study **Krishna** district in **Andhra Pradesh** is selected as a Treatment region.

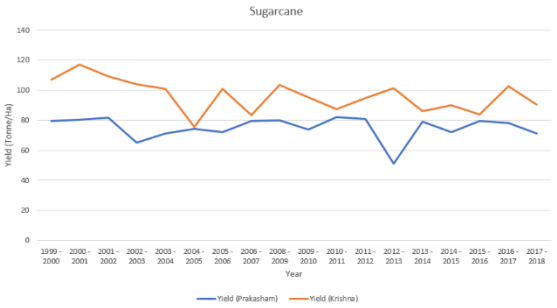
- **Control Group:** Similar regions that have not received such information or have limited exposure to it. For further analysis **Prakasam** district in **Andhra Pradesh** is selected as a Control region.

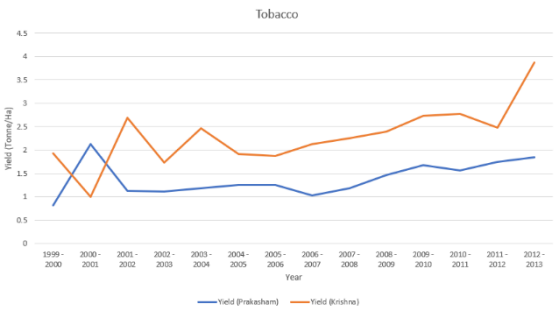
- **Data Collection:** Crop yield, crop diversity and cropping intensity is tracked for both groups as an outcome variable for several years before and after the introduction of satellite-based information. Data on rainfall and soil moisture content is also collected. Data is scrapped from various official government sites. References are provided at the end of literature.

  For the district of Krishna and Prakasam, yield of **Sugarcane** from **1999-2018** and yield of **Tobacco** from **1999-2013** is analysed. **Rainfall** and **Soil Moisture** content for both the district from **2018** to **2024** scraped.

2. Findings and Implications

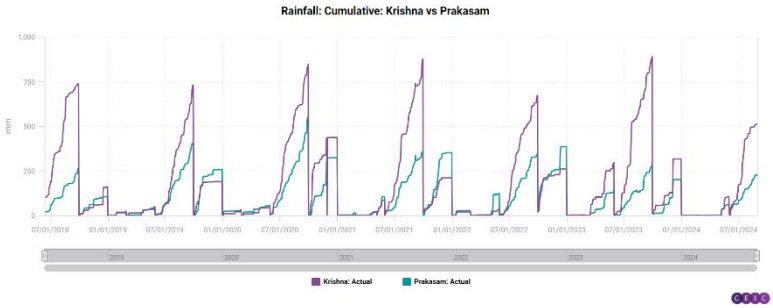
Yield of both sugarcane and tobacco is significantly more in the Krishna district in comparison to Prakasam district. Graphical depiction of yield in sugarcane and tobacco is provided below:



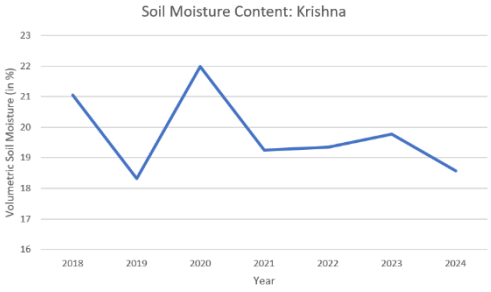


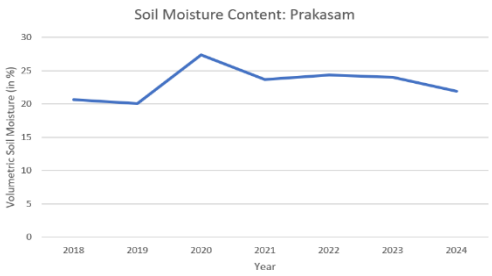
Above graph of sugarcane and tobacco demonstrated that post treatment years have led to continuous better yield in treatment region if compared to control region. It shows that having weather forecasts and agricultural advisory has a positive impact and crop producers are in a better state in treatment region in comparison to control region.

Rainfall analysis shows that Krishna district receives move rainfall throughout the year which is approximately double in amount. Rainfall prediction is one of the crucial findings of satellites. Having rainfall advisory beforehand certainly help farmers take precautions in adverse situations. Below cumulative graph of rainfall analysis for both the district is provided.



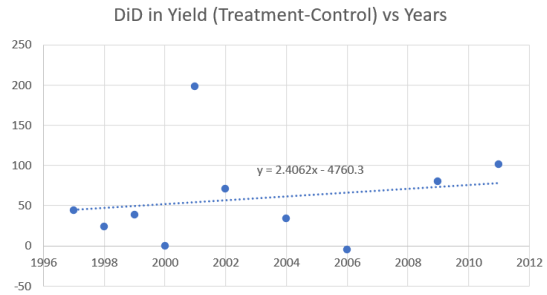
Soil Moisture Content is another crucial parameter in the production of crops. Relevant precautions can be made if known previously. For instance, in both the districts around February-May soil moisture content decreases and relevant focus on irrigation can lead to better yield of crops.



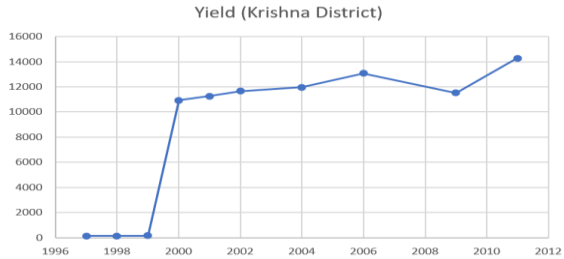


Analysis of Difference-in-Difference method will demonstrate the influence of satellite on the development in agricultural productivity.

The Difference-in-Difference plot below is the difference between Treatment Yield and Control Yield versus Year. Trend line of the scatter plot below has a **slope** of **2.4062**, which signifies **positive** development in the yield of treatment region Krishna district when compared to control region Prakasam.



This demonstrates that there is increase in agricultural productivity with the development satellites. There is this development in post-treatment phase in comparison to pre-treatment due to advancements



made in space technology but post-treatment phase is random in itself which is still better pre-treatment phase. The stagnation of DiD post-treatment signifies there is no further rapid improvision in the satellite technology and there is future scope of innovation. Yield in crops for Krishna district is represented in the plots below.

Launch of revolutionary **IRS1C/1D** in **1995,1997** and **INSAT-2E** in **1999** has led to rapid development sector. As can we seen in the plot above, there is massive spike in the yield of treatment district Krishna. All this has led to improvements in land cover monitoring, crop production, soil moisture analysis, weather advisory, real-time decision making and drought monitoring which has improvements in agriculture sector.

F. Conclusion

Indian's cost-effective innovation in space sector has led to overall development of the nation. Different sectors like agriculture, telecommunication and meteorology have seen rapid growth since the emergence of space program. It has elevated quality of life for people living in rural and underdeveloped places. The DiD analysis illustrates the role space technology has played for growth in agriculture sector. Enhancements in space technology will further improve India's infrastructures and different sectors.

G. References

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14. Rainfall Data: Link
15. Soil Moisture Data: Link