Università
Ca'Foscari
Venezia

Master's Degree programme — Second Cycle
(D.M. 270/2004)
in Economia - Economics

Final Thesis

Ca' Foscari
Dorsoduro 3246
30123 Venezia

Indian Agriculture - Productivity, Climate Change and Institutions

An Essay in Agricultural Economics

Supervisor

Ch. Prof. Carlo Carraro and Ch. Prof.ssa Monica Billio

Candidate

Kedar Kulkarni
Matriculation number 855739

Academic Year

2015/2016

Declaration Page

I, **Kedar Kulkarni**, declare that this thesis titled,**'Indian Agriculture - Productivity, Climate Change and Institutions'** and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: Kedar Kukarni

Date: June 15, 2016

Acknowledgements

Firstly, I would like to express my sincere gratitude to my advisor **Professor Carlo Carraro** for the continuous support of my Master's thesis, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for carrying out this study.

Besides my advisor, I would like to extend my gratitude to **Professor Monica Billio** for her insightful comments and advises concerning the empirical analysis. Her experience and deep knowledge of the subject was invaluable in the completion of this thesis.

I would also like to thank **Professor Varghese Manaloor** at the **University of Alberta, Canada**. Professor Manaloor introduced me to the basics of research and to academia. Without his constant motivation, guidance and support it would not have been possible for me to conduct this study. Furthermore, I also thank **Professor Anil Gupta** at the **Indian Institute of Management, Ahmedabad** and **Professor Naresh Sharma** at the **University of Hyderabad, India** under whose mentorship I was able to carry out various research projects and enhance my skills in the subject.

I place on record my sincere thanks to my two classmates, **Enrico Natali** and **Raphael Max** at the **Ca Foscari University of Venice, Italy**. Your brotherhood and support has proven invaluable during my time here in Venice. Without your support and encouragement, I would never have been able to finish this thesis. I also thank my two other classmates, **Benedetta Cicuto** and **Yulia Lipanova** for their friendship and constant support throughout the program. Finally, I extend my gratitude to the professors and classmates in the **QEM program** for their valuable time and constructive discussions.

Last but not the least, I would like to thank my family: My mother, **Amba Kulkarni**, my brother **Achyut Kulkarni**, who have been an inspiration and pillar of support throughout my life and my late father **Pradeep Kulkarni** who always encouraged me in my academic endeavours. I would also like to dedicate this thesis to my late grandfather **Professor ABP Rao**. He was a brilliant academician and still remains an inspiration to all of us.

Abstract

Agricultural sector in India has recorded tremendous growth since Independence. This has been largely possible due to the new agricultural reforms and the arrival of the green and white revolutions. The impact of the new agricultural reforms can be felt in the massive increase in the productivity of coarse cereals and pulses which has enabled India to attain self-sufficiency in food grains. A by-product of this has been the gradual rise of energy inputs. In particular, fertilizer consumption, diesel use and electricity consumption, have seen a dramatic rise post 1960. There also has been a large scale substitution of capital for labour. This is a direct consequence of the increasing population size and food grain demand as India strives to maintain self-sufficiency. However, more importantly, the extravagant use of energy inputs and substitution of capital for labour coupled with new agricultural technology has had an adverse effect on the climate. This thesis makes an attempt to analyse the growth in Indian Agriculture and derive its implications in relation to energy use and CO_2 emissions. The specific objective is to estimate the relationship between carbon emissions and agricultural productivity. Although agricultural production in India has witnessed a tremendous growth, it is unclear whether the high intake of energy has an adverse impact on climate. Over the past years, the northern states of India have blossomed partly due to favourable climatic conditions, while the western and southern states have experienced drastic climatic conditions that have adversely impacted agricultural productivity, repercussions of which are felt in farmer suicides and rural to urban migration. This thesis also investigates this issue by throwing light on the role of institutions in the development of agriculture and its implications on climate change. The peculiar case of Maharashtra is studied to understand the role of institutions in agricultural growth and climate change. The findings of the study show the presence of a positive relationship between agricultural productivity and the level of carbon emissions. Further, the study also finds that states with good institutions are able to perform better than their competitors endowed with bad institutions.

Keywords: Agricultural Productivity, Climate Change, Institutions, Instrumental Variables

JEL Classification: C32, C33, Q18, Q54, Q58

Contents

List of Figures

List of Tables

Chapter 1

Indian Agriculture - An Introduction

Agriculture in India occupies a prime position in the economy and workforce. It is the engine of the country's growth as it contributes around 14% to the total GDP. It is also diverse in that it employs over 60% of the total workforce in India barring caste, creed, religion, gender and origin. India is primarily a rural economy since around 58% of the total rural households depend on the primary sector for livelihood. Although agriculture provides for the most of the nation's food grains, it also contributes heavily towards the country's exports. Fortunately, India is blessed with the quality and different variety of soil which enables it to grow more than 250 types of crops. This is almost four times that of any developed nation on the planet. It is the largest producer of spices and ranks as the second largest exporter of fruits. On the agricultural production front, it is the third biggest producer in the world. The last three decades has seen her attain self-sufficiency in foodgrains. This has been achieved owing to the reconstruction of the primary sector and the introduction of new policies as part of the 'Green Revolution' and the 'White Revolution'. From attaining self-sufficiency to becoming a global leader in the world agricultural market, Indian primary sector has transformed leaps and bounds. This has been possible largely due to the high energy input use and substitution of capital for labour.

However, despite the consistent inputs of energy, agriculture in India wears a deserted look. The sector currently faces two big challenges. Firstly, the ever increasing population has pressurized the industry to produce more and more every year in order to meet the demands of the population. Maintaining self-sufficiency is crucial to India's development. The second big challenge faced by the industry is the poor state of farmers and agricultural labourers. The past decade has seen a tremendous increase in rural migration and farmer suicides. One of the main reasons cited for this is climate change.The growing population size and foodgrain demand has compelled the agricultural sector to invest more in energy and technology. Heavy dependency on non-renewable energy sources and technology by the industry in order to meet the increasing demands for foodgrains has resulted in the sector adversely affecting the climate. Mitigation of climate change is therefore key to India's development. Agricultural sector presents a key area where the mitigation potential can be realized. This thesis tries to establish a relationship between productivity, energy intensity and carbon emissions. Further, the role of institutions in bringing about this crisis is analysed and the policy implications are suggested.

1.1 Indian Agriculture - An Historical Perspective

Agriculture has predominantly occupied a major role in Indian history and continues to do so. The first traces of agriculture in India date back as far as 9000 BC with the onset of Neolithic revolution which saw the introduction of practices like row plantation, cultivation of major crops such as wheat and barley along with the rearing of cattle. India is also known as the 'land of rivers' and it isn't difficult to see why the initial civilizations settled along the rivers, the most prominent being Indus Valley Civilization which based itself around the river 'Indus'. Understandably, the settlers took to the cultivation of crops and domestication of animals. The tropical climate in the region also went a long way in them realizing this occupation. India witnesses double monsoon – June to September and November to January. This caused the settlers to grow two types of crops – Rabi and Kharif, a practice still prevalent. Over the next century, the farmers introduced myriad of crops ranging from cereals to fruits to oilseeds. The middle ages saw the invasion of the Persians and the Muslims in the region. The Muslims brought with them much sophisticated techniques while also introducing the intermediaries – Zamindar and Jagirdar (Middlemen and Landlords). These intermediaries would go on to stay for another six centuries, causing havoc to the agricultural labourers. However, on a positive note, the introduction of the Muslim rule paved the way for agricultural trade. While the Romans and the Mediterranean rulers had good trade relations with the Indian merchants, it was only with the introduction of the Muslims that the farmers were able to reap the benefits of free trade. The Islamic regime also strengthened land management and led to cultivation of multiple crops – cotton, sugar etc. – which introduced the Indian farmers to the western market as trade blossomed. The free trade route opened the country to the colonial powers who started to regularly trade with the Indian farmers. Gradually, they entered the country and established their own company before taking control of it with their divide and rule policies. English, French and Portuguese were the most prominent colonial powers although the Britishers overpowered the others over time. Various eminent agricultural economists have lambasted the colonial powers for their treatment of the agricultural sector. The initial years were one of the most productive years in Indian Agriculture as the British Raj saw an increase in land cultivation, improved irrigation techniques and introduction of commercial crops. However, growing cash crops such as Cotton and Jute proved detrimental to the Indian farmers as they were left with relatively nothing owing to the British trade policies. Cities like Manchester and Liverpool in the United Kingdom grew tremendously with the onset of cotton and jute industries which came at an expense of the Indian farmers. Further, agricultural performance during the interwar period proved dismal as India was hit with a famine. The eastern state of Bengal was affected the most resulting in millions of death. After Independence, the first government took massive steps in revolutionising the primary sector. The period from 1960-1975 saw many 'production revolutions' including Green Revolution, Operation Flood and Blue revolution. Deregulation of the economy in the year 1991 resulted in significant growth as the agricultural sector benefitted from newer innovations in biotechnology and agricultural production. The last two decades has seen further influx in FDI, increased productivity and improved technology.

A country that was a mass producer of food grains once upon a time witnessed a massive decline in its primary sector with the foreign invasions as it struggled to attain self-sufficiency. With the arrival of Independence, she rediscovered itself through production revolutions and free market economy re-establishing itself on the world market. Sixty years after Independence, the agricultural sector looks promising. Currently, the primary sector's share in the total GDP is about 14% whereas at the time of independence it was close to 60%. While the direct impact of agricultural sector on the GDP share has declined immensely, it continues to be a pillar of strength for the secondary and tertiary sectors. However, the industry is faced with numerous challenges and it is imperative for the policy makers to address them in order to maintain its growth. Firstly, the ever growing population poses a great problem as the country is faced with the issue of sustaining self-sufficiency of food grains. Secondly, the growing demand for food grains means farmers are likely to consume more fertilizers and energy sources which could have adverse impact on the environment. Lastly, the problem of migration and farmer suicides needs to be addressed as well. Last decade has seen 100,000 farmers commit suicide owing to various reasons – climate change being one of them. Today, the southern states of India, Maharashtra, Karnataka, Telengana and Andhra Pradesh are experiencing a decline in their water resources. The sight of barren lands leave the farmers with no hope resulting in suicides. The problem is further worsened by inadequate institutions. This study is an attempt to address the above issues and economics serves as the perfect lens to view and then analyse them.

The rest of the chapter is structured as follows. In section two, an overview of the agricultural sector post-independence is presented. Section three deals with the various institutional policies that were introduced by several governments that revolutionized the agricultural sector. Section four presents the motive to carry out this research and captures the main idea of the thesis. It then proceeds to outline the essential research questions this thesis attempts to address.

1.2 An Overview of the Indian Agriculture

India's high dependency on the agricultural sector renders it as an intriguing case for study. It accounts for around 50% of its total workforce and contributes significantly to the national GDP (14%) (Agricultural Research Databook, 2015). At the time of Independence, Indian Agriculture employed 72% of its total workforce and contributed about 50% to its national income. It was backward, traditional and stagnant. Feudal land relations were still prevalent, the technology was primary and outdated, and as a result the productivity per hectare was low (Prasad, 2009). Pandit Jawaharlal Nehru, the then Prime Minister, said "Everything can wait but not agriculture." Hence the first task of the first Government of Independent India was to modernize the Indian Agriculture. In other words, it aimed to bring in technological and institutional changes. So began a series of initiatives and policies to develop Indian Agriculture. The first of these policies was framed in the year 1948 with the abolition of the intermediaries such as the Zamindars and Jagirdars. These intermediaries acted as a medium of tax collection during the Muslim and colonial rule. A Zamindar was a landlord who employed a peasant on his land and taxed him heavily. The primary role of a Jagirdar was more or less the same as that of a Zamindar. However, unlike the Zamindar, Jagirdari was not a hereditary post. The year 1951 marked the beginning of the planned economic development with the launch of the First Five Year Plan. It mainly focussed on agriculture and community development since India was faced with severe problems in the area of food security and high inflation. The 1960's and 70's marked an important period in the history of Indian Agriculture with the arrival of 'White' and 'Green' revolution3. This new strategy implemented modern techniques like high-yielding varieties of crops, multiple cropping, modern farm practices and spread of irrigation facilities. The biggest achievement of this strategy was the attainment of self-sufficiency in food grains (Rao, 1996). Other developments in the context of Indian Agriculture during the early post-independence period include better irrigation facilities, emergence of new crops and a desire among the farmers for a better standard of living. These developments have transformed a country with concerns of poverty and starvation to a country of self-sufficiency and a net exporter of food grains – Rice and Wheat. However the most important aspect of Indian Agriculture is its contribution to the secondary and tertiary sectors since the secondary sector takes the output from the primary sector and tertiary sector buys the finished goods from the manufacturing sector indirectly linking itself to the primary sector. Hence, growth of these two sectors and, subsequently, the growth of the overall economy depends on how the agricultural sector is performing to a considerable extent.

1.3 Agricultural Policy in the Post-Independence Period

The agricultural policy after the independence can be categorized into 3 phases. The first one is between 1947 to the mid-sixties. The second phase is from the mid-sixties till the economic reforms. The third phase is the post-economic reforms period (1991-92).

The first phase was characterised by land reforms, community development, and development of major irrigation projects and restructuring of rural credit institutions. The most important achievement was the abolition of intermediaries which was done through the tenancy act of 1948. In a nutshell, the tenancy act resulted in the transfer of ownership of the land to the actual cultivators from the *zamindars*. This policy provided the incentive to the cultivators to put in their best effort and maximize production. During this period, decentralised planning and the Intensive Area Development programmes were also initiated for regenerating Indian Agriculture that had stagnated during the British rule (Tripathi & Prasad, 2009). In Spite of all these developments, India was still dependent on foreign countries to feed their ever-growing population.

The second phase began in the mid-sixties with the launching of Green Revolution or the new agricultural strategy. This strategy was restricted to only a few regions covering crops like wheat and rice during the initial period of its implementation but gradually it spread to the other parts of the country. The 1970's and 1980's saw a great stride in productivity of all inputs. Consumers started preferring non-food grain items of food like milk, poultry, meat, fish, vegetables and fruits. These were clear signs of increasing diversification of agriculture in the 1980's (K.L.Krishna & Kapila, 2008). But the biggest achievement of this strategy was the attainment of self-sufficiency in food grains. Agrarian reforms during this period took back seat while research, extension, input supply, credit, marketing, price support and spread of technology were the prime concern of policy makers (Rao, 1996).

The third phase began with the implementation of the macroeconomic reforms in the year 1991-92. This involved de-regulation, reduced government intervention in the economic activities and liberalization. Liberalisation of trade led to improvements in terms of trade for agriculture. The domestic market opened up during this period. However the decreasing investment by the public sector due to rise in subsidies and decline in tax-GDP ratio since the implementation of the reforms is an area of concern. As a result agricultural growth has slowed down because of declining input-use, factor productivity and profitability during the post-reform period.

1.4 Research Questions

Agricultural production and input use in Indian agriculture has recorded remarkable growth in the post Green Revolution period. Wheat production, in particular, has had a dramatic increase in the use of fertilizers and mechanical power. There has been a substantial increase in the use of diesel and electric power for irrigation and other agricultural operations. Along with food security issues, the cost of energy inputs and environmental concerns from use of these inputs are of concern in Indian agriculture. There is a need to produce sufficient food grain to meet the demands of a growing population and at the same time develop a sustainable approach to food production. Increased food grain production in India has been achieved through the expanded use of increasingly sophisticated inputs, such as farm machinery, fertilizers, herbicides, and irrigation. All these involve the use of commercial energy. Although there has been a relatively small decline in labour use, the increased use of capital and to some extent the substitution of capital for labour has increased the reliance of agriculture on non-renewable energy resources (Manaloor & Sen, 2009). This thesis makes an attempt to analyse the growth in Indian Agriculture and derive its implications in relation to population growth, energy use and CO_2 emissions. The specific objective is to estimate the relationship between carbon emissions and agricultural productivity. Although agricultural production in India has witnessed a tremendous growth, it is unclear whether the high intake of energy has an adverse impact on climate. Over the past years, the northern states of India have blossomed partly due to favourable climatic conditions, while the western and southern states have experienced drastic climatic conditions that have adversely impacted agricultural productivity. This leads to the following research questions:

1) What is the impact of agricultural productivity on climate change?

2) Does the impact of agricultural productivity on climate change differ from region to region? If yes, why? In other words, do institutions have a role to play? how?

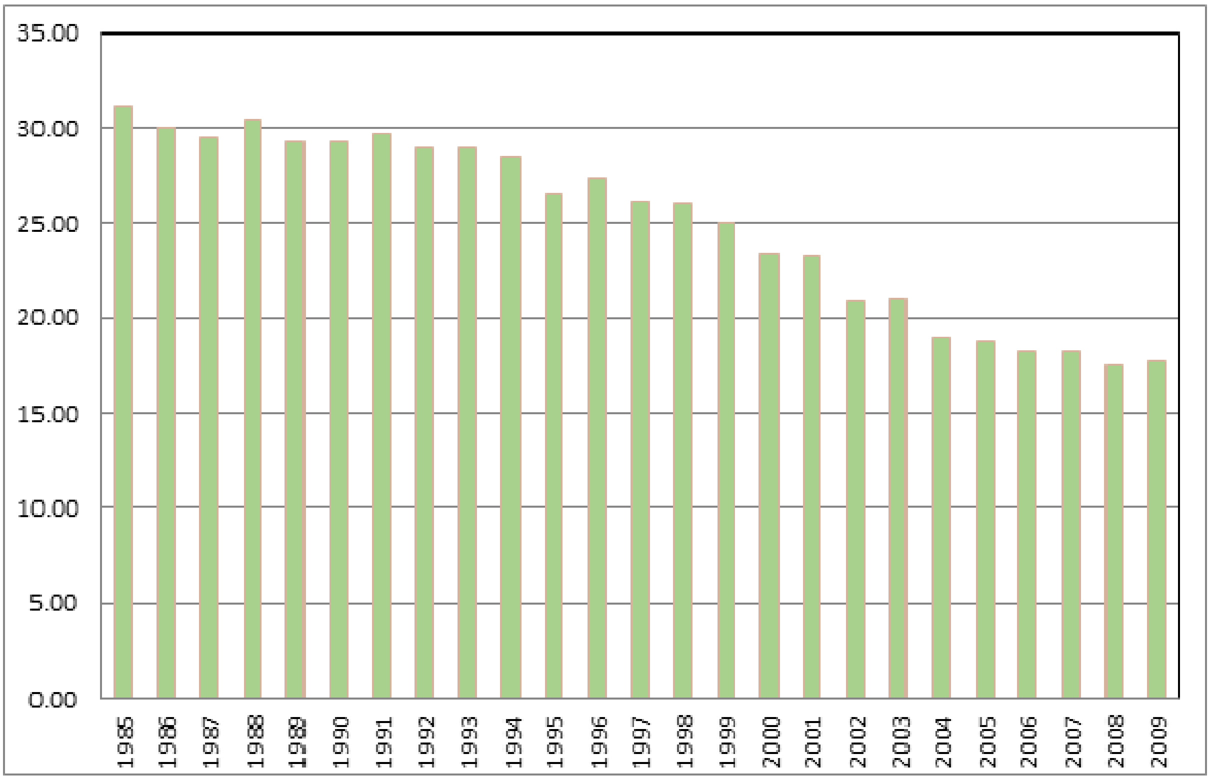
Chapter 2

An Insight into the Agricultural Economy

2.1 Agricultural Growth

The population of India in 1985 and 2009 was 755 million and 1154 million respectively. The annual growth rate when calculated turned out to be 2.2%. The Indian economy was growing at an annual growth rate of around 5% during the late 80′s and as low as 1% in the year 1990-91. Following the introduction of Economic reforms in 1991, the annual GDP growth rose to 5% in the year 1991-92.

Figure 2.1: Percentage Share of Agricultural GDP as a total of National GDP



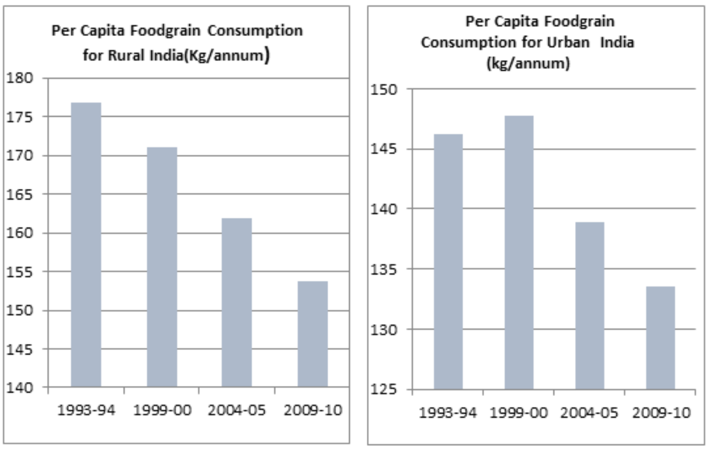
Source: Ministry of Agriculture (2015)

The decade of 1990 saw an average growth rate of 6.2%. The 2000's was a relatively good period too as the economic growth reached near to the double figures in the later part of the decade. A close look at the figure 2.1 implies that the % share of Agriculture in total GDP in the year 1985 was 31% which has come down to 17% in the year 2009. The slow growth of this sector can be attributed to a number of factors such as illiteracy, insufficient finance, inadequate marketing of agricultural products. Moreover, the small size of farms has resulted in low productivity. Also modern technology and agricultural practices have not yet been adopted in most of the regions which has led to this decline. Insufficient irrigation facilities still prevail in most of the regions and as a result farmers are required to depend on the rainfall which is, unfortunately, unpredictable. The growth in the agriculture sector may well be judged by the increase in agricultural production over time. Three factors account for the increase in the total production of agricultural output: (a) increase in the total area under various crops, (b) increase in the yield rate of various crops and (c) substitution of more remunerative crops in place of less remunerative crops. (Mishra, 2007).

2.2 Per Capita Food Consumption

The per capita food consumption has been calculated for both rural and urban India. The fig 2.2 show a decreasing trend in the per capita food consumption in both the regions. The reasons cited for the downfall are structural imbalances, low productivity and diversified food basket. Structural imbalances include high minimum support price, substitution of capital for labour among others. Of late, people have started migrating from rural to urban areas. Their incomes have increased as a result of which demand for high value food crops such as rice and wheat has risen. This has also caused the demand for millets, which is often considered as poor man's food, to go down. Moreover, the early 1980's saw the consumers preferring non-foodgrain items such as vegetables and fruits, meat, poultry and fish diversifying the food basket.

Figure 2.2: Per Capita Food Consumption in Urban and Rural India



Source: Ministry of Agriculture (2015)

2.3 Cropping Pattern

The cropping pattern in India (see Table 2.1) has experienced a drastic change. The increasing demand for food as a result of growing population has pressurized the agricultural sector to increase its production. This has led to crop intensification and substitution of commercial crops with food crops. The share of area under foodgrains in Gross Croppted Area (GCA) as shown in table declined by 11.62% mainly due to a decline in the area under coarse cereals. Wheat gained importance but had an area allocation of only 10.42 percent in TE 1970-1971. However, it increased steadily to 14.18 percent in TE 2007-2008 (Kannan & Sundaram, 2011).

Rice area remained more or less constant. Interestingly, area no longer planted to foodgrains was used to cultivate oilseeds (4%) as well as fruits and vegetables (2.86%) between TE 1970-1971 and TE 2007-2008. The shift from coarse cereals to high value crops is likely to increase farm output and farmers' income. However, in dry land regions, it exposes the cultivators to serious weather-borne risks because high value crops have higher water requirements (Bhalla & Singh, 2009). The increase in total oilseeds area does not reflect a general rise in area across all oilseed crops. It appears to be limited only to rapeseed and mustard, sunflower, and soybean. Favorable market conditions for refined oil and protein-rich soya food might have encouraged farmers to allocate more area to these crops (Srinivasan, 2005). Groundnut area declined from 4.42 percent in TE 1970-1971 to 3.20 percent in TE 2007-2008. However, the area planted to commercial crops like cotton almost remained constant at 4.5 percent. Sugarcane area increased marginally from 1.62 percent in TE 1970-1971 to 2.47 percent in TE 2007-2008 (Kannan, 2011). Rice is one of the most consumed agricultural products in India. It is a staple food and hence widely grown across the country. India is a net exporter of Rice, accounting for almost 20% of the world's rice production. It is grown in different parts of the country, nearer to the deltas. Assam, Northern Andhra Pradesh, West Bengal, Maharashtra, Uttar Pradesh, Orissa and Madhya Pradesh are the highest producing states in the country. Given the dual monsoons, it is grown twice, and sometimes, thrice a year. Rice production has increased tremendously since the green revolution. From 27.6 Million Tonnes in 1951 it has increased to 80 million tonnes in 2009, almost thrice the amount. This has been possible due to modernization of agriculture and implementation of better irrigation facilities. Naturally, the area under rice cover has remained the same.

At the national level, the area under paddy has more or less remained the same. The Production has increased and so has yield. The All-India stats shows an increase in the production of paddy (CAGR= 1.2%). Andhra Pradesh, West Bengal, Uttar Pradesh, Punjab, Assam, Gujarat and Kerala are the states where the yield has increased considerably since 1985. On the other hand the data shows a decreasing trend in the yield in the states of Madhya Pradesh and Bihar. States like Maharashtra, Tamil Nadu have done moderately well in the case of Paddy as far as yield is concerned.

In the case of production, the numbers more or less follow the same trend as in case of yield.

The All-India trend for Wheat in Table 2.1 shows a positive growth since 1985. About 91% of wheat is produced by 6 states namely Bihar, Rajasthan, Punjab, Madhya Pradesh, Uttar Pradesh and Haryana. Uttar Pradesh and Rajasthan produce more because of the large area sown to wheat (50%) while Punjab and Haryana have a high productivity. The climatic conditions required for the proper growth of this crop are temperate but most of India is tropical. Hence the productivity of this crop is concentrated mostly in these few states which favour its growth. The numbers depict the area sown to wheat was more or less the same during the 1980's. The production has increased largely owing to the shift from other crops to wheat and by yield growth. The fertilizers use has reduced in the past few years and better irrigation facilities, modern technology and HYV area seems to be playing an important role in the increasing pattern of yield.

Table 2.1: Share of Area Under Major Crops - Percentage of GCA

Crops	TE 1970-71	TE 1980-81	TE 1990-91	TE 2000-01	TE 2007-08
Rice	23.02	23.18	23.00	23.82	22.57
Wheat	10.42	12.98	13.04	14.28	14.18
Coarse Cereals	28.48	24.25	20.48	16.17	15.14
Total Cereals	61.93	60.41	56.53	54.27	51.88
Pulses	13.50	13.23	12.94	11.49	11.93
Total Food grains	75.43	73.63	69.47	65.76	63.81
Total Oilseeds	9.85	10.11	12.51	12.96	13.93
Groundnut	4.42	4.14	4.64	3.68	3.20
Cotton	4.70	4.27	4.08	4.70	4.68
Total Fibers	5.41	5.08	4.64	5.27	5.18
Sugarcane	1.62	1.62	1.90	2.23	2.47
Tobacco	0.27	0.25	0.22	0.21	0.19
Spices	1.04	1.23	1.32	1.52	1.55
Potato	0.31	0.43	0.51	0.69	0.76
Onion	-	0.14	0.17	0.24	0.36
Total Fruits and Vegetables	2.24	2.77	3.57	4.35	5.10
Fodder Crops	4.15	4.50	4.59	4.55	4.26
Gross Cropped Area	100	100	100	100	100

Source: Ministry of Agriculture (2015)

Maize is essentially a kharif crop and is largely dependent on rains. The area under Maize relatively remained steady in the 1980's and 1990's around the 6 million mark although it has increased to 8 million lately. States of Uttar Pradesh, Madhya Pradesh, Rajasthan and Punjab account for about 75% of its area and production. The production has increased considerably since 1985. This can be largely attributed to it being able to fit in conveniently in the crop-rotation process. Also the implementation of modern technology and rising demand of the food have increased its production. Maize is used in the preparation of poultry feed and extraction of starch too. So apart from being an essential human food, it has other important uses too. That could possibly be the reason for the demand of this crop to rise. Hence we can see the increase in its production over the past few decades although it has been a little volatile because of the variations in yield. The yield pattern shows an increasing trend after the green revolution. The modern technology, better irrigation facilities and HYV area have played an important role in the growth of the yield of maize. There is a steady rise in the average yield per hectare in addition to the area and production.

Coarse Cereals are mostly cultivated in the regions of Maharashtra, Gujarat, Rajasthan, Madhya Pradesh, Tamil Nadu and Karnataka. The data analysed show that the area under cultivation has stagnated over the years. But even under the threat of stagnated area, the production of coarse cereals has continued with positive growth rates in quite a few districts of the country (Bhalla, 2001). The coarse cereals are considered 'inferior' goods in the country and relatively very less importance was given to it post green-revolution. The decline can be characterised by the preference of consumers and producers for higher value food grains. While reviewing the growth and growth prospects of coarse cereals, Jodha listed their three "permanent constraints": (I) their cultivation mainly in moisture deficient areas, making their yields both low and uncertain;(ii) their lower value per unit; and (iii) the limited market or demand for them, being confined to regions where they are grown and to low income groups (Nandkarni, 1986).

It is well documented that area growth was the major source of production growth until the early 1960s (Bhalla, 2001; Vaidyanathan, 2010). Rice and Wheat grew at a tremendous rate due to the introduction of high-yielding variety of seeds. During the green revolution as seen from Table 2, wheat and rice productivity had a CAGR of 3.19% and 3.10%. Interestingly, all major crops had a relatively higher growth (see Table 2.2). Along with technology, new institutional mechanisms including provision of better irrigation facilities, a government procurement system, guaranteed price support, and supply of inputs at subsidized rates enabled farmers to adopt improved cultivation methods (Kannan, 2011).

Table 2.2: Compound Annual Growth of Area, Production and Yield of Crops in India

Crop	1980-81 to 1989-90			1990-91 to 1999-2000			2000-01 to 2010-11		
	A	*P*	*Y*	*A*	*P*	*Y*	*A*	*P*	*Y*
Rice	0.41	3.62	3.19	0.68	2.02	1.34	-0.10	1.51	1.61
Wheat	0.46	3.57	3.10	1.72	3.57	1.83	1.28	2.16	0.87
Jowar	-0.99	0.28	1.29	-3.53	-3.07	0.48	-3.27	-0.54	2.82
Bajra	-1.05	0.03	1.09	-1.46	0.95	2.44	-0.26	2.40	2.66
Maize	-0.20	1.89	2.09	0.94	3.28	2.32	2.81	5.65	2.77
Ragi	-1.23	-0.10	1.14	-2.85	-0.80	2.10	-2.87	-1.00	1.93
Small Millets	-4.32	-3.23	1.14	-5.40	-5.88	-0.51	-6.16	-3.49	2.82
Barley	-6.03	-3.48	2.72	-2.62	-0.64	2.03	-0.79	0.67	1.46
Coarse Cereals	-1.34	0.40	1.62	-2.12	-0.02	1.82	-0.75	2.80	4.24
Total Cereals	-0.26	3.03	2.90	0.04	-0.02	1.59	0.09	2.01	3.19
Gram	-1.41	-0.81	0.61	1.26	2.96	1.68	4.61	6.32	1.64
Tur	2.30	2.87	0.56	-0.66	0.89	1.55	1.18	2.05	0.87
Other Pulses	0.02	3.05	3.03	-1.61	-1.58	0.04	0.03	0.96	0.94
Total Pulses	-0.09	1.52	1.61	-0.60	0.59	0.93	1.62	3.35	1.90
Total Food grains	-0.23	2.85	2.74	-0.07	2.02	1.52	0.37	2.12	2.89
Sugarcane	1.44	2.70	1.24	-0.07	2.73	1.05	1.12	1.64	0.52
Groundnut	1.67	3.76	2.06	-2.31	-1.25	1.08	-0.87	1.24	2.13
Sesamum	-0.52	3.20	3.74	-5.52	-4.84	0.72	2.08	2.68	0.59
R & M	1.95	7.28	5.22	0.71	0.78	0.07	3.05	5.37	2.26
Sunflower	25.69	21.32	-3.47	-2.97	-3.20	-0.24	0.19	2.31	2.12
Soyabean	17.10	17.96	0.73	10.23	13.06	2.56	5.35	9.14	3.60
Nine Oilseeds	2.47	5.36	2.49	0.17	1.42	1.42	2.13	5.16	3.01
Total Oilseeds	1.51	5.20	2.43	-0.86	1.63	1.15	2.14	4.60	3.59
Cotton	-1.25	2.80	4.10	2.71	2.29	-0.41	2.60	13.80	10.91
Jute	-2.38	0.91	3.37	1.48	2.32	0.83	-0.92	0.44	1.37
Mesta	-4.24	-3.59	0.67	-2.47	-2.08	0.40	-6.38	-6.09	0.29
Jute & Mesta	-2.90	0.16	2.96	1.81	1.81	0.87	-1.71	-0.08	2.38
Total Fibres	-1.50	2.46	3.98	2.45	2.21	-0.27	2.15	11.76	9.55
Potato	2.90	5.17	2.20	3.84	5.44	1.54	4.76	5.28	0.49
Tobacco	-2.79	-1.05	1.79	1.56	1.00	-0.55	3.74	5.12	1.34
Non Foodgrains	1.12	3.77	2.31	1.18	2.69	1.09	2.16	3.67	2.49
All Principal Crops	**0.10**	**3.19**	**2.56**	**0.27**	**2.29**	**1.33**	**0.91**	**2.50**	**3.25**

Source: Ministry of Agriculture (2015)

2.4 Livestock

Livestock is one of the fastest growing sectors in India. Within the livestock sector, poultry has grown rapidly. The growth of milk and egg production is studied in Table 2.3. Milk production

Table 2.3: Milk and Eggs Production

Year	Milk (Million Tonnes)	Eggs (Billion Nos.)
1990-91	53.90	21.10
1991-92	55.70	21.90
1992-93	58.00	22.90
1993-94	60.60	24.20
1994-95	63.80	25.90
1995-96	66.20	27.20
1996-97	69.10	27.50
1997-98	72.10	28.70
1998-99	75.40	29.50
1999-00	78.30	30.40
2000-01	80.60	36.60
2001-02	84.40	38.70
2002-03	86.20	39.80
2003-04	88.10	40.40
2004-05	92.50	45.20
2005-06	97.10	46.20
2006-07	100.90	50.70
2007-08	104.80	53.60
2008-09	108.60	55.40
2009-10	112.50	59.80

Source: Ministry of Agriculture (2015)

grew at around 5% per year from 1985-2007 and egg production grew at 5.5% per year during the same period (see in Table 2.3. In the last decades the livestock sector has been one of the fastest growing sectors in Indian agriculture, currently accounting for about 25 % of agricultural GDP as compared to less than 14 % in 1980. Both demand and supply side factors are responsible for the growing importance of livestock in Indian agriculture. These drivers include income growth and urbanization, advances in production and processing technology and improvements along the supply chain (Khan & Bidabadi, 2004; Narrod et al., 2009; Pingali, 2007).

2.5 Land Use Analysis

The geography of India is diverse. It is a peninsula in that the western region meets the Arabian Sea, the southern part of the country is touched by the Indian Ocean and the eastern coast lying on the Bay of Bengal. The northern part of India does not have any water body in its vicinity and is protected by the Himalayan mountain ranges. The total geographical area of the country is 329 Million Hectares. Being an agriculture dominated country, it is conspicuous that the majority of the geographical area is under agriculture.

Table 2.4: Land Use Analysis

Classification	Area (Million Hectares)	Share of Geographical Area
Forests	69.63	23%
Area under non-agricultural use	26.31	8%
Barren and unculturable land	17.02	6%
Permanent Pastures and other grazing lands	10.34	3%
Culturable waste land	12.76	4%
Fallow Land	24.86	7.5%
Net Sown Area	141.36	43%
Gross Irrigated Area	88.42	33%

Source: Ministry of Agriculture (2015)

Forests occupy almost one-fourth of the geographical area and therefore are an important carbon sink. The net irrigated area is almost 19% while the total irrigated area is 33% of the geographical area. The farmers in India depend mainly on canal irrigation and the monsoons. Given the threat of global warming, the demand for irrigation is increasing year after year (See Table 2.4). The irrigation area is studied in the next section. This section of the chapter analyses the gross area under irrigation all over india. This is done in three categories - Cropwise, Statewise and Sourcewise.

2.5.1 Gross Area under Irrigation - Cropwise

Among the food grains under irrigation, rice, wheat and pulses have shown an increasing trend whereas Jowar (Millet) and Barley show a decreasing trend. Maize and Bajra's area has remained unchanged for the past 2 decades (see in Table 2.5). The increasing trends shown in the cases of rice, wheat and pulses is a consequence of the Green revolution where better irrigation techniques were implemented and emphasis was on these crops. However around only 30% of the total cultivable land has the facility of artificial irrigation. So the dependency on rainfall, which is very uncertain in terms of quantity, place and time, by most of the farmers clearly reflects the decreasing trends in most of the crops. Also, Millets were not a top priority during the Green Revolution. This could possibly be the reason for the decrease in their productivity. The total gross irrigated area, at present, is 85 Million Hectares . The average annual rainfall is 1170 mm. Taking 70% of the rainfall as effective for crop consumptive use, the gross water use is about 1.45 m per ha of the gross irrigated area. This is very high as compared to water use in irrigation systems in the developed countries; say USA, where water allocation is about 3 feet. This overuse in the country reflects a low irrigation efficiency of about 25% to 35% in most irrigation systems, with efficiency of 40% to 45% in a few exceptional cases (Planning Commission, 2015). The 11th plan has listed six reasons for low irrigation efficiency 1) Completion of dam works ahead of the canals, 2) Dilapidated irrigation systems, 3) Unlined canal systems with excessive seepage, 4) lack of field channels, 5) lack of field drainage and 6) low rate for water.

Table 2.5: Gross Area under Irrigation - Cropwise

Year	Rice	Jowar	Bajra	Maize	Wheat	Barley	Pulses	Total Food Crops	Total Non-Food Crops	Total Irrigated Area
1985-86	17667	735	554	1085	17295	689	2085	46128	8154	54282
1990-91	19469	794	548	1162	19511	530	2608	52134	11070	63204
1995-96	21468	780	595	1384	21539	505	3048	58062	13290	71352
2000-01	24337	826	783	1483	22798	529	2695	64183	12038	76221
2005-06	24723	776	857	1713	23914	438	3458	67968	15448	83416

Source: Ministry of Agriculture (2015)

2.5.2 Gross Area under Irrigation by State

Two crops – Rice and Wheat – acquired the most area under irrigation. Area irrigated under rice was pretty high in the states of Andhra Pradesh, Bihar, Punjab, Uttar Pradesh and Tamil Nadu while the area irrigated under wheat was high in the northern parts of India i.e. Punjab, Uttar Pradesh, Haryana and Bihar.

Table 2.6: Gross Area under Irrigation - Statewise

State	Rice	Wheat	Total Cereals	Total Foodgrains	Sugarcane	Cotton	Total Pulses	Total Area under all Crops
Andhra Pradesh	96.8	69.1	80.8	58.1	94.3	19.1	1.5	46.3
Bihar	57.2	91.7	69.1	63.1	23.7	-	3.2	60.6
Gujarat	57.4	89.5	49.5	42.2	100.0	49.0	12.3	41.7
Haryana	99.9	99.5	90.1	88.5	99.2	99.7	12.3	86.0
Himachal Pradesh	62.2	19.3	19.2	19.0	50.6	30.5	46.7	19.2
Karnataka	73.7	51.9	34.3	25.8	99.9	14.0	14.2	29.4
Kerala	67.4	-	66.4	65.2	78.9	-	6.4	16.5
Madhya Pradesh	15.4	83.9	48.6	44.4	99.8	43.2	-	32.2
Maharashtra	26.4	74.8	20.8	17.5	100.0	2.7	37.0	19.6
Orissa	46.4	100.0	43.5	35.1	100.0	5.3	9.7	36.7
Punjab	99.4	98.6	98.1	98.0	96.2	99.9	14.2	97.7
Rajasthan	41.7	99.3	32.9	28.0	96.5	95.8	87.5	36.4
Tamil Nadu	92.7	75.4	71.7	58.4	100.0	35.7	15.7	55.9
Uttar Pradesh	77.2	97.6	81.1	74.9	92.2	95.9	4.3	75.5
West Bengal	48.4	74.0	49.5	48.4	44.6	100.0	25.7	56.9
ALL INDIA	56.9	90.9	54.3	46.8	93.5	35.1	13.9	44.6

Source: Ministry of Agriculture (2015)

The Table 2.6 depicts the irrigated area of the major crops in the top fifteen agricultural states of the country. It should come as a no surprise that rice cultivation requires great amount of water and hence it is given priority in the states where it is produced the highest. Further, two states – Haryana and Punjab have the highest area under irrigated land while Maharashtra and Kerala have the least. However, it should be noted that the contribution of Maharashtra's agriculture to India's total agriculture is much higher than that of Kerala's.

2.5.3 Net Area under Irrigation by Sources

Two different types of irrigation exist in India – Surface water and Ground water irrigation. The former provides water from canals and tanks while the latter provides it through different types of wells. These two techniques account for 85% of the area under irrigation in the primary sector. The total area under irrigation during 1984-85 was 42,185 hectares which has increased to 60,857 hectares in 2006-07. This is largely due to the increase in the number of tube wells. However the area under canal irrigation has remained stagnant over this period. The canals are either built by the government or private enterprises. There has been a significant drop, about 50%, in the private canals during the last two decades.

Table 2.7: Net Area under Irrigation - Sources

Year	Canals		Tanks	Tube Wells and Other Wells	Other Source	Total
	Government	Private				
1984-85	15805	470	3021	20394	2455	42145
1985-86	15715	465	2765	20418	2502	41865
1986-87	16039	456	2677	20822	2575	42569
1987-88	15286	460	2523	21796	2827	42892
1988-89	16640	462	2996	23214	2836	46148
1989-90	16646	478	2941	23886	2751	46702
1990-91	16973	480	2944	24694	2932	48023
1991-92	17327	464	2991	26037	3048	49867
1992-93	17001	456	2854	26383	3599	50293
1993-94	17181	455	2828	27060	3816	51340
1994-95	16799	481	3276	28912	3533	53001
1995-96	16561	559	3118	29697	3467	53402
1996-97	16889	220	2821	31794	3388	55112
1997-98	17186	211	2597	32110	3106	55210
1998-99	17099	212	2795	34001	3329	57436
1999-00	16852	194	2540	34645	2912	57143
2000-01	15762	203	2455	33828	2885	55133
2001-02	15057	209	2191	34972	4359	56788
2002-03	13836	206	1804	34140	3667	53653
2003-04	14207	206	1914	36127	4292	56746
2004-05	14435	214	1725	34896	7546	58816
2005-06	15069	215	2080	35066	7447	59877
2006-07	15116	235	2044	35908	7554	60857

Source: Planning Commission (2015)

2.6 Agricultural Trade

India has remained a marginal player in world agricultural trade. Currently, it has a share of less than 1 per cent of the world trade in agriculture (Ministry of Agriculture (2015)).

Table 2.8: Agricultural Imports and Exports as percentage of total Imports and Exports

Year	Total Agricultural Imports	Total National Imports	% Share of Agricultural Import in National Imports	Total Agricultural Exports	Total National Exports	% Share of Agricultural Imports in National Exports
1990-91	1205.86	43170.82	2.79	6012.76	32527.28	18.49
1991-92	1478.27	47850.84	3.09	7838.13	44041.81	17.8
1992-93	2876.25	63374.52	4.54	9040.3	53688.26	16.84
1993-94	2327.33	73101.01	3.19	12586.55	69748.85	18.05
1994-95	5937.21	89970.70	6.60	13222.76	82673.4	15.99
1995-96	5890.10	122678.14	4.80	20397.74	106353.35	19.18
1996-97	6612.60	138919.88	4.76	24161.29	118817.32	20.33
1997-98	8784.19	154176.29	5.70	24832.45	130100.64	19.09
1998-99	14566.48	178331.69	8.17	25510.64	139751.77	18.25
1999-00	16066.73	215528.53	7.45	25313.66	159095.2	15.91
2000-01	12086.23	228306.64	5.29	28657.37	20136.45	14.23
2001-02	16256.61	245199.72	6.63	29728.61	209017.97	14.22
2002-03	17608.83	297205.87	5.92	34653.94	255137.28	13.58
2003-04	21972.68	359107.66	6.12	37266.52	293366.75	12.70
2004-05	22811.84	501064.54	4.55	41602.65	375339.53	11.08
2005-06	21499.22	660408.90	3.26	49216.96	456417.86	10.78
2006-07	29637.86	840506.31	3.53	62411.42	571779.28	10.92
2007-08	29906.24	1012311.70	2.95	79039.72	655863.52	12.05
2008-09	37183.03	1374435.55	2.71	85951.67	840755.06	10.22
2009-10	59528.34	1363735.55	4.37	89341.33	845533.64	10.57

Source: Planning Commission (2015)

Agricultural trade in India has witnessed an unprecedented growth during the past 50 years. From being a high importer of food grains, it has achieved self-sufficiency and is a net exporter of few agricultural products. At present, the agricultural imports account for 4.37% of the total national imports whereas the agricultural exports account for of the total national exports (see in Table 2.8). India's agricultural trade has grown swiftly since the new macroeconomic reforms were implemented. Rice and wheat are the major food grains exported while it is a significant importer of edible oils and pulses.

2.7 Energy Consumption in Indian Agriculture

Indian agriculture has progressed leaps and bounds since independence. To transcend from the traditional tools, it was imperative to bring in modern techniques. This has been possible owing to the increasing dependency on energy resources such as electricity, fertilizers, fossil fuels and petroleum. This increase in energy use and its associated increase in capital intensive technology can be partially attributed to low-energy prices in relation to the resource for which it was being substituted (Gowdy et al., 1987). This section focusses on the different energy usages in the primary sector. The energy inputs can be categorized into direct energy use and indirect energy use.

2.7.1 Direct Energy Use

This refers to energy resources like petroleum, electricity etc. On one hand, the shift from human and animal power to mechanized power has increased the demand for petroleum products and on the other hand there is a growing demand for electrical energy for irrigation purposes in India. The mechanized power sources mainly include pump sets and tractors.

Table 2.9: Trends in Growth of Irrigation Pumps

Year	Diesel Pumps	Electric Pumps	Total
1951	83000	26000	109000
1956	123000	47000	170000
1961	230000	160000	390000
1966	471000	415000	886000
1972	1546000	1618000	3164000
1977	2359000	2438000	4797000
1982	3101000	3568000	6669000
1987	5968000	6349000	12317000
1991	4659000	9696000	14355000
1995	5100000	11700000	16800000
2003	7237400	8446300	15683700

Source: Agricultural Engineering Directory-2006

The pump sets can again be classified into diesel and electric pump sets. In the year 1951, the total number of irrigation pump sets was 1,09,000 out of which 83,000 were diesel pumps and 26,000 electric. By the year 2003, the total number was 1,56, 83,700 (see in 2.9). This included 72,37,400 diesel run pumps and the rest 84,46,300 were run on electricity. This shows a 99% increase in the total number of irrigation pump sets. Also noteworthy is the increasing use of electric pumps. This has been possible due to the greater access of electricity in the rural areas.

Farm machinery, specifically tractors, is by far the greatest consumer of fuel in field operations. The mechanization of farming has increased rapidly in India (De la Rue du Can et al., 2009). The tractor sales (see in 2.10) have shown a positive trend with the sales doubling in a span of 10 years. The annual tractors' sales were 1,64,770 in the year 1994-95 which grew to 3,52,827 in the year 2006-07. This has increased the demand for petroleum products especially Diesel Oil.

Electricity consumption from farmers is un-metered and billing is instead based on the water pump's horsepower rating. Hence, the exact consumption by the agriculture sector is unknown. Meters are increasingly installed on the transformers serving mainly these customers to allow better estimation of sales to agriculture. The second major fuel used is high speed diesel oil.

Table 2.10: Total Tractor Sales in India

YEAR	Tractor Sales (Number)
1994-95	16470
1995-96	191329
1996-97	222684
1997-98	258141
1998-99	262169
1999-00	273182
2000-01	251939
2001-02	217456
2002-03	168182
2003-04	189518
2004-05	246469
2005-06	291680
2006-07	352827
2007-08	346501
2008-09	347010
2009-10	440331

Source: Agricultural Engineering Directory-2006

The consumption of High Speed Diesel Oil (HSDO) (see in 2.11) has increased tremendously with a CAGR of 6.94% over the last four decades. The total consumption in the year 1970-71 was 3.84 million Tonnes which rose to 59.99 million tonnes in the year 2010-11. This is owing to the augmentation of diesel pump sets and tractors.

Table 2.11: Trends in Consumption of Petroleum Products in Agriculture

Year	HSDO	LDO
1	2	3
1970-71	3.84	1.09
1975-76	6.6	0.88
1980-81	10.35	1.12
1985-86	14.89	1.12
1990-91	21.14	1.51
1995-96	32.26	1.31
2000-01	37.96	1.4
2005-06	40.19	0.88
2006-07	42.9	0.72
2007-08	47.67	0.67
2008-09	51.67	0.55
2009-10	56.32	0.46
2010-11	59.99	0.46

Source: Agricultural Engineering Directory-2006

The total electricity consumption in the agricultural sector has also grown rapidly. The electricity consumed in the year 1984-85 was 23,422 Gwh which has augmented to 1, 07,776 Gwh in 2008-09 (see in 2.12). Nevertheless, the percentage share of electricity in agriculture as of the total consumption has been sluggish. In 1984-85, 19% of total electricity was used by the agricultural sector which grew to 31% in the year 1998-98. However there has been a decline in the consumption with only 22% of total electricity being consumed in the primary sector.

Table 2.12: **Electricity Consumption in Agricultural Sector**

Year	Consumption for Agricultural Purposes	Total Consumption	% Share of Agricultural Consumption to Total Consumption
1985-86	23422.00	122999.00	19.04
1986-87	29444.00	135952.00	21.66
1987-88	35267.00	145613.00	24.22
1988-89	38878.00	160196.00	24.27
1989-90	44056.00	175419.00	25.11
1990-91	50321.00	190357.00	26.44
1991-92	58557.00	207645.00	28.20
1992-93	63328.00	220674.00	28.70
1993-94	70699.00	238569.00	29.63
1994-95	79301.00	259630.00	30.54
1995-96	85732.00	277029.00	30.95
1996-97	84019.00	280206.00	29.98
1997-98	91242.00	296749.00	30.75
1998-99	97195.00	309734.00	31.38
1999-00	90934.00	312841.00	29.07
2000-01	84729.00	316600.00	26.76
2001-02	81673.00	322459.00	25.33
2002-03	84486.00	339598.00	24.88
2003-04	87089.00	360937.00	24.13
2004-05	88555.00	386134.00	22.93
2005-06	90292.00	411887.00	21.92
2006-07	99023.00	455748.00	21.73
2007-08	104182.00	501977.00	20.75
2008-09	107776.00	527564.00	20.43

Source: Central Electricity Authority (2012)

2.7.2 Indirect Energy Use

Indirect energy refers to the energy content of farm inputs, such as fertilizers, herbicides, farm buildings, and machinery (Manaloor, 2005). However in this study, indirect energy is used only in terms of fertilizers. This is because estimating the energy content of farm machinery and buildings is complicated and also the energy content of these inputs does not vary with production decisions (Manaloor, 2005). The data collected was in terms of NPK use. The total NPK use in the year 1950-51 was 70.6(000 tonnes) which has grown to 28,122 (000 tonnes) in the year 2010-11. The growth has been tremendous during the green revolution period where the emphasis was on high variety seeds and use of chemical fertilizers.

Table 2.13: All India Consumption of Fertilizers (N,P,K)

Year	N	P	K
1950-51	58.70	6.90	5.24
1960-61	210.00	53.10	29.00
1970-71	1487.00	462.00	228.00
1980-81	3678.10	1213.60	623.90
1990-91	7997.20	3221.00	1328.00
2000-01	10920.20	4214.60	1567.50
2010-11	16558.20	8049.70	3514.27

Source: Agricultural Research Databook (2015)

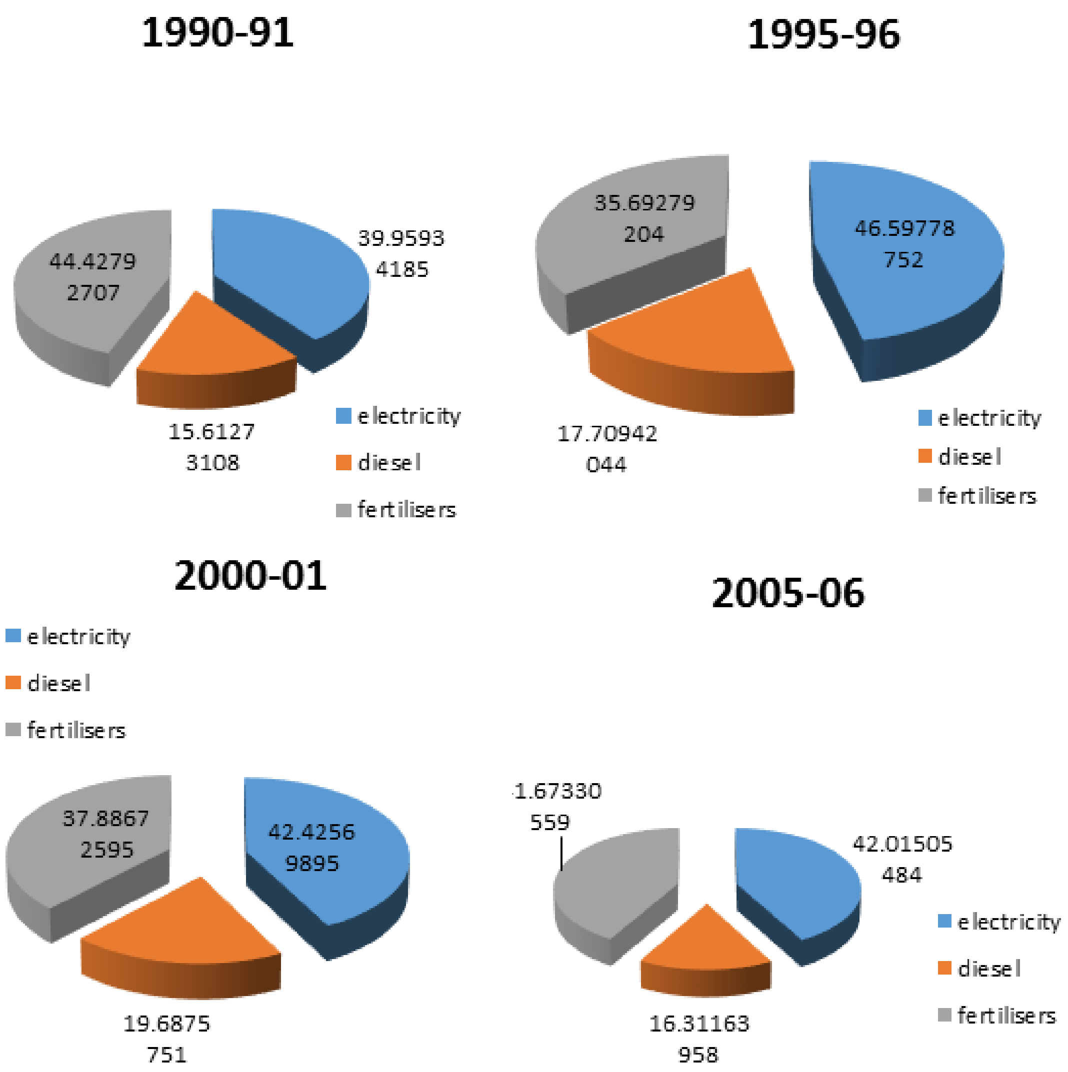
The increase in production and consumption is a result of the various Government initiated extension networks that started in the 1960s. The period of 1980-1990 saw a rising consumption of fertilizers thanks to the high subsidies provided by the Government (Roy et al., 1999). However post economic reforms, the usage of fertilizers has been relatively low as compared to the green revolution period.

2.8 Carbon Dioxide Emissions

Carbon emissions are calculated with respect to two aspects. First, the direct energy use i.e. Petroleum, electricity and secondly, indirect energy use, fertilizers. In case of direct energy use, the data for Petroleum and Electricity from the Government of India was available in primary units i.e. tonnes and Gwh respectively. So the first task is to convert the primary units into energy unit (GJ). The next step after the conversion was the calculation of carbon emissions using the CO_2 calculator . Petroleum consumption in agriculture is the amount of diesel oil used (High Speed

Diesel Oil and Light Diesel Oil). The energy equivalent was approximated from the graph. The carbon emissions were then calculated using the CO_2 calculator (see in A.1). The same methodology was applied in case of electricity. In case of fertilizers, indirect energy use, the calculations were complex. The data was available in terms of NPK. The NPK data was subsequently converted into the energy units for each N, P and K. The energy invested in producing, storing and transporting fertilizers is assumed to be 60,700 KJ per kilogram of Nitrogen, 12,560 KJ per kilogram of phosphate and 6,700 KJ per kilogram of potash. The breakdown of energy in nitrogen fertilizer is 90 per cent natural gas, 5.2 per cent liquid fuels and 4.8 per cent electricity. The energy embodied in phosphate is 47.4 percent electricity, 26.7 percent liquid fuel and 25.9 percent natural gas. Potash contains 42.1 percent electricity, 31.3 percent liquid fuel and 26.7 percent natural gas (Pimetel, 1980; Lockeretz, 1980).

Figure 2.3: Pie Chart Description of the Carbon Dioxide emissions



Source: Author's Calculations

The pie-charts exhibit the carbon emissions from the agricultural sector for 4 periods: 1990-91; 1995-96; 2000-01; 2005-06. Fertilizers and electricity constitute the majority (83%) of the emissions whereas that from diesel has been the lowest (17%) in all the 4 years. However there has been an increase in emissions from all the three energy inputs.

Based on the fig 2.3, the energy (in GJ) from Nitrogen, Phosphate and Potash was estimated in terms of natural gas, liquid fuels and total electricity. Using the CO_2, the carbon emissions were arrived at for the three variables. Adding up all the three variables would give us the total carbon emissions arising from fertilizers usage in the agricultural sector.

Table 2.14: Carbon Dioxide Emissions from Direct and Indirect Energy Use

	Energy Consumption			**Carbon dioxide Emissions (1000 Tonnes of CO_2)**			**% Share of CO_2 Emissions**		
Year	*E*	*D*	*F*	*E*	*D*	*F*	*E*	*D*	*F*
1990-91	181155600	175000000	534792297	31450	12888	34967	39.65	16.25	44.09
1995-96	308635200	290000000	640388163	53580	20363	41041	46.59	17.70	35.69
2000-01	305024400	350000000	726304268	52960	24576	47294	42.42	19.68	37.88
2005-06	325512000	312000000	853848061	56430	21908	55971	42.01	16.31	41.67

Source: Estimated by the Author

Chapter 3

Review of Literature

Indian agricultural sector has been at the forefront of the policy makers and economists since independence. Esteemed scholars and prominent agricultural economists like Hanumantha Rao, Partha Dasgupta, Renuka Mahadevan, Rohini Pande, P.Sainath etc. have discussed at large about the performance, growth and challenges of the sector. While this chapter reviews the literature pertaining to Indian agriculture, various studies by foreign economists and scientists have been carried out in agricultural and environmental economics that deem appropriate. The chapter is structured in four parts. In the first section, past works on productivity and growth of Indian agriculture are cited. Section two revisits the literature on energy use in Indian agriculture. The next section attempts to review the literature on agriculture and development. A special emphasis is placed on the previous research and agreements on climate change. In the final section, a brief review of the literature related to the hypothesis is presented.

3.1 Indian Agriculture – Productivity and growth

At the time of independence, the situation of agricultural sector was hopeless and lamentable. The first task therefore of the new government was to revolutionise the primary sector. Further, due to partition, a large part of fertile land that the colonial India possessed went to the now Pakistan. Hence, self-sufficiency was high on the agenda. The first government of India incorporated the 'Five Year Plans' as part of its development process. Agricultural sector was given top priority in the first three five year plans. During the first five year plan from 1950-55, agricultural sector boomed and the results were very satisfactory. However, the second five year plan (1956-61) was a big failure. Tendulkar (1981) states that the system failed because the government shifted its priority to Industrial development by introducing the industrial policy of 1956. The second five year plan's goals read "development involves transfer of a part of the working force from agriculture to tertiary activities." The revolution of Indian Agriculture began with the third five year plan (1961-66). Bhalla (2001) note that the introduction of new seed fertilizer technology was one of the key steps that transformed the primary sector. The new High-Yield Variety (HYV) method was incorporated by a majority of farmers, mostly in the northern part of the country. This new method led to the farmers adopting new patterns of cropping. Naturally, the area of cultivation as well as yield increased tremendously. Ledigensky (1976) is of the opinion that green revolution led to wealth inequality as the farmers with large farm profited while the small scale farmers were left to suffer. The impact of green revolution on labour was analysed by Aggarwal (1981). His study found that large scale farmers prospered with the advent of green revolution while the small scale labourers had to face the consequences of technical advancement in the primary sector as they lost their jobs. The NCAER (1980) studied the impact of new agricultural strategy on the primary sector. According to their report, the secondary sector grew tremendously owing to the introduction of new machinery thereby creating employment opportunities in the manufacturing sector. Singh (1979) highlights that machinery use has a direct effect on employment of agricultural labour. Lal (1976) studied the trend in real income of agricultural workers during the green revolution. His study finds that the real income of agricultural workers increased from 1956-1970. While it is true that the new agricultural strategy implemented as part of the green revolution, improved the agricultural sector drastically, the repercussions of it are still prominent today. Firstly, the substitution of labour with capital increased the unemployment rate in the primary sector and created a huge market of unskilled labour. The agricultural growth decelerated following the green revolution and the economic reforms of 1991. During the last two decades, the agricultural growth has decreased from 3.62 in 1991 to 1.97 in 2014-15. Further, the share of agriculture in the GDP has gone down to 14% in 2014 from 36.4% in 1991 (Chand et al., 2007). The role of state is very crucial in the deceleration of the primary sector. It was argued that the liberalization of the economy would integrate the agricultural markets with the global world and lead to an increase in production and growth of the sector. With the conversion to free market economy, the state's intervention gradually decline. Chand et al. (2007), Chand & Kumar (2004) and Chand (2005) mention the main factors resulting in the decline of the agricultural sector. Firstly, the area under cultivation declined owing to massive industrialization and urbanisation. Globalization, on one hand, introduced the local farmers to the outside world but at the same time the flawed trade agreements worsened their situation. Further, the development of irrigation and fertilizers deem inadequate. Even today, a large number of states regularly face water scarcity which lead to low productivity. To add to this, the changing crop pattern has only deteriorated the system. Large number of farmers have shift to cash crops from cereals and foodgrains which have resulted in them committing suicide. Lastly, the state's provision of electricity, machinery and institutional credits to the farmers has relatively declined with growing needs. Mishra (2008) argues that the crisis in agriculture had already begun in the 1980s and the economic reforms in 1991 only worsened it further. The pressure on agriculture to produce more and raise farmers' income is high. Second, the dependence of the rural workforce on agriculture for employment has not declined relative to the sector's contribution to GDP. This has resulted in widening income disparity between agriculture and non-agriculture sectors Chand & Chauhan (1999).

3.2 Energy use in Indian Agriculture

From a traditionally agricultural society, Indian agriculture has progressed and transformed itself into a modern sector. India is the third largest consumer of electric energy in the world. Indian economic growth since independence can be attributed to the increase in consumption of energy resources such as Electricity, fuels and Petroleum. This is a consequence of the various policies implemented by the Indian government towards the modernization of Indian Agriculture. India has been successful in achieving national food security partly owing to the increased use of energy inputs in its agricultural setup. However there still remain many regions and areas where the productivity per hectare is low. Hence to achieve high productivity in these areas, it is imperative to use energy resources.

Energy is an indispensable input in agricultural production. The sources of energy can be direct or indirect. Agriculture uses energy directly as fuel or electricity to operate machinery and equipment, to heat or cool buildings and for lighting in the farm and indirectly in the fertilizers and chemicals produced off the farm (Uhlin, 1998). Energy's share in agriculture production varies widely by the kind of activities, production practices applied, geographic location of the production area and environmental conditions such as soil and climate factors (Esengun et al., 2007). The agriculture sector, like other sectors, has become increasingly dependent on energy resources such as electricity, fuels, natural gas and coke. This increase in energy use and its associated increase in capital intensive technology can be partially attributed to low-energy prices in relation to the resource for which it was being substituted (Gowdy et al., 1987).

There has been considerable research on the topic of energy use in agricultural sector. Scholars within India as well as outside of it have studied extensively the impact of climate change and energy use on agricultural productivity. Some of these researches are followed. Karkacier et al. (2005) investigated the impacts of energy use on agricultural productivity on Turkish agriculture. Using data from Turkish agriculture, Karkacier et al. (2005) showed that energy use and gross addition fixed assets are important determinants in agricultural productivity. Their results show a positive relationship between the two variables. Hatirli et al. (2005) analysed energy use and investigated influences of energy inputs and energy forms on output levels in Turkish agriculture during the period 1975–2000. The dependence of agriculture sector on energy sector to supply more food to increasing population and considering the limited natural resources, as well as the impact of using energy sources on environment and human health, it is imperative to investigate energy use patterns and energy efficiency in agriculture sector.

3.3 Agriculture and Climate Change

Climate change poses a major threat to the current population. Over the last two decades, international parties have joined hands to combat the challenge of climate change. Agriculture is heavenly dependent on climatic factors and hence is very vulnerable to climate change. Further, Indian agriculture is home to almost 60% of the population. Therefore, the issue of climate change is very significant to India's development. While the impacts of climate change on agriculture have been studied extensively, the mitigation potential of the sector has been underestimated. The debate around climate change and agriculture has often been biased towards the sector's vulnerability and adaptation to climate change impacts, although the agricultural sector itself has high potential for climate mitigation (Swain & Chernoz, 1981). Agriculture in India is heavily dependent on the monsoons. India has experienced low rainfall over the past decade leading to low productivity, and subsequent migration and suicides. Therefore, climate has a big role to play in the lives of the rural population.

Guiteras (2009) estimates the impact of climate change on Indian Agriculture. Using a panel data of 40 years covering over 200 Indian districts, Guiteras estimates that climate change for the next 30 years would reduce the major crop yields by 4.5-9%. The long-run impact is dramatic which would reduce the yield by 25% or more in the absence of long-run adaptation. He infers that climate change would induce significant costs on the Indian economy.

Pant (2009) studied the effects of agriculture on climate change and analysed empirically the effects of carbon dioxide emissions to the atmosphere. The results show that climate change has an adverse effect on agricultural practices. Further, the study also reveals that countries with high per capita income emit more carbon emissions than the ones in less developed countries.

Some studies have been conducted for evaluating the potential effects of climate change on agriculture in global level (Kane et al., 1992; Rosenzweig & Parry, 1994; Dawin et al., 1995), regional level (Adams et al., 1990, 1993; Mendelsohn et al., 1994) and farm level (Kaiser et al., 1993; Easterling III et al., 1993). Some others are conducted in the effects of climate change on crop yields (Andersen & Dale, 1989; Dixon et al., 1994; Kaufmann & Snell, 1997; Wu, 1996). Increased temperature during growing season can reduce yields, because crops speed their physiological development producing less grain. Faster plant growth and modifications of water and nutrient budgets in the farm (Long, 1991) will render existing farming technology unsuitable. Change in crop physiology will make traditional practices inappropriate. There is a strong consensus that climate change is likely to have severe consequences for the agricultural sector and the rural poor in South Asia (Cline, 2007, 2008; World Bank, 2007). By 2080, Cline (2007) estimates a dramatic decline of 28.8% in agricultural output (with the favourable effect of carbon fertilisation), and 38.1% without carbon fertilisation. Kumar Kavi & Parikh (2001) estimate the functional relationship between farm-level net revenue and climate variables using time-scale and cross-sectional data. They suggest a loss of a little less than 8.4% in total net revenue from agriculture in a similar best-guess climate change scenario. TERI (2003) finds that agricultural productivity in India is sensitive to direct effects from changes in temperature, precipitation, and CO_2 concentration and indirect effects through changes in soil moisture and the distribution and frequency of infestation by pests and diseases. Kumar (2009a) re-enforces the climate sensitivity of Indian agriculture by claiming that climate change impacts are increasing over time, indicating the growing climate sensitivity of Indian agriculture.

Various studies have analysed the impact of climate change on agriculture. It is predicted that climate change can have an adverse impact in the following six ways. Firstly, climate change will lead to an increase in the atmospheric temperatures which could seriously affect crop yield. As temperature rises, evaporation from the soil accelerates and plants increase transpiration, i.e. lose more moisture from their leaves. The combined effect is called "evapotranspiration" (Cline, 2008: 24). Though there will be higher precipitation, as will be discussed later, the effects of evapotranspiration will override higher precipitation effects and water availability. Aggarwal (2008) projects a loss of 4-5 million tonnes in Indian wheat production with every 1°C rise in temperature throughout the growing period, given current land use. Secondly, climate change will increase the concentration of CO_2 in the atmosphere. One positive impact of an increase in CO_2 concentration is that it is expected to increase the rate of photosynthesis and hence, the crop yield. However, this phenomenon of 'Carbon fertilisation' will only increase the yield of C3 crops (Rice, Wheat) but not C4 crops (Sugarcane, Maize etc.). Thirdly, the water resource would be deeply affected. Indian agriculture acquires a substantial amount of water through rainfall. Since climate change will lead to unpredictable rainfall, the demand for groundwater is expected to rise. Fourthly, climate change would have a big impact on food production. Due to population growth, it is estimated that by 2020 the requirement for food grains in India will increase between 30% and 50% compared to 2000 (Paroda & Kumar, 2000). Lastly, climate change would increase rural poverty and force the rural population to migrate to urban areas for better employment opportunities and livelihood (Raleigh et al., 2008).

Mitigating climate change is therefore imperative for agriculture. Improving energy efficiency and minimizing greenhouse gases arising from agricultural sector is one way of addressing the issue of climate change. Agriculture has vast potential to reduce atmospheric greenhouse gases. It is projected that agricultural sector can reduce the GHGs as much as 50% to 90% by 2030 (Strategies for Mitigating Climate Change in Agriculture, 2015). Substitution of fossil fuels with renewable energy, carbon sequestration through crops and soils while emphasis on biofuels and biotechnology should be the way ahead. Soil organic carbon (SOC) pool is the largest among terrestrial pools and the restoration of SOC pool in arable lands represents a potential sink for atmospheric

CO_2 (Jarecki et al., 2005). Restoration of SOC in arable lands represents a potential sink for atmospheric CO_2 (Lal & Kimble, 1997). Strategies for SOC restoration by adoption of recommended management practices include conversion from conventional tillage to reduced tillage, increasing cropping intensity by eliminating summer fallows, using highly diverse crop rotation, introducing forage legumes and grass mixtures in the rotation cycle, increasing crop production and increasing carbon input into the soil (Lal et al. (1998); Lal (1999); Desjardins et al. (2001); Hao et al. (2002)).

Bronick & Lal (2005) suggest that the combination of conservation tillage, increasing carbon inputs and increasing the complexity of the agricultural system combining different crops and animals improves carbon aggregation and SOC concentration. Improved management practices such as reduced tillage, manure application, mulching, composting, summer and winter fallowing, crop rotations and agro-forestry (Lal et al. (1999); Bruce et al. (1998)) as well as changes in land use, including the conversion of degraded croplands to grasslands or pasture, increase the rate of CO_2 uptake from the atmosphere.

Combating climate change is high on India's agenda. Although a developing country, India's attitude towards the issue has been well appreciated by the international parties. India ratified to the Kyoto Protocol in 1996 while at the COP 21 in Paris it pledged to cut its emissions by 33-35% by the year 2030. Starting with the agricultural sector would be a key moment if India has to reach its pledged goals.

3.4 Literature Review of the Hypothesis

Economics serves as a useful tool in analysing the impact of climate change on agriculture as well as in assessing the factors that affect CO_2 emissions from the agriculture. One of the pioneering works done in this regard is by Mendelsohn et al. (1994)., who examine the effect of development on climate sensitivity of agriculture. Using a Ricardian approach, their empirical studies show that increasing development has an adverse impact on climate sensitivity. Key & McBride (2007) use an instrumental variable approach to estimate how production contracts affect farm productivity. Using the availability of contracts as an instrument, their study indicates that farm productivity is directly proportional to production contracts. Pant (2009) studied the effects of agriculture on climate change and analysed empirically the effects of carbon dioxide emissions to the atmosphere. He incorporates a multiple regression model to show the adverse effect of agricultural practices on climate change. Further, the study also reveals that countries with high per capita income emit more carbon emissions than the ones in less developed countries. Following the literature, it is reasonable to proceed with an empirical approach that uses the energy consumption from direct and indirect sources as an instrument variable instrumented on agricultural productivity.

An Instrumented Variable- two stage least squares approach is used to estimate the model.

The second part of the thesis attempts to find the causes for the poor performance of certain states despite having similar resources as their counterparts, who do exceedingly well. This phenomenon is similar to the concept of 'Resource Curse', first diagnosed by Sachs & Warner (2009). The literature on why 'more leads to less' is well represented in Sachs & Warner (2009), Glyfason (2001), Torvik (2001) and Mehlum et al. (2006). Using the multiple regression approach, they attempt to show that resource abundant countries often have slow growth while the countries with low resources do very well. Torvik (2009) studies this issue further and emphasizes on the role of institutions in solving the resource curse. Using data from 90 countries, his study indicates that countries with good institutions manage to escape the resource curse while the ones with bad institutions fail to do so. This thesis incorporates the variable 'Institutional quality' in the Instrumental Variable regressions to understand the role of state institutions in mitigating climate change. India's political system is such that each state has the freedom to frame its own agricultural policy while retracting funds from the centre without any interference by the central government. In other words, the implementation of agricultural policy is the state's responsibility unless the policy is a centrally sponsored scheme.

Chapter 4

Empirical Model

The availability of secondary data on Indian agriculture is restricted to past 60 years. Further, data on some variables that are incorporated in the empirical model is not readily available and had to be created. As for the methodology, the Instrumental Variable Regression approach is used to assess the impact of agricultural productivity on climate change. The instrumental variable method makes it credible to assert that the observed association is a causal relationship rather than simply a correlation (Key & McBride, 2007).

4.1 Data

Secondary data on Indian agriculture is obtained from the Ministry of Agriculture (2015). International databases such as FAO (2016) Database, World Bank (2016) Databank are approached for macro-level statistics. To empirically test the impact of agricultural productivity on climate change, yearly data is taken for the period of 1950-2010. The data obtained can be divided into three categories – Agricultural Growth and Productivity, Energy Consumption and Climate Change.

To identify agricultural productivity and growth, yearly data on agricultural productivity per hectare is obtained from the Directorate of Economics and Statistics, Ministry of Agriculture, India. Further, the share of agricultural production in the total GDP is extracted from the World Bank database. Agricultural land and forest area as percentage of total geographical area is taken from the World Bank database. Moreover, data in terms of total land area and forest area is obtained from the Ministry of Agriculture, India. Gross statistics on agricultural productivity, agricultural land use and forest area (all in hectares) are considered since the data on dependent variable i.e. carbon dioxide emissions is available in terms of kg per hectare. As seen in the table 4.1, the mean area of agricultural land use is 179 million hectares while the mean area of forest area is 66 million hectares. Agricultural productivity has increased considerably since independence averaging 1786 Kg per hectare.

Table 4.1: Summary Statistics of Agricultural Data

Variable	Observation	Mean	Maximum	Minimum	Std.Dev
Land (Million Hectares)	51	161.4	164.2	156.5	2190488
Forest Area (Million Hectares)	51	66.5	70.26	54.24	3621481
Agricultural Productivity (Kg/Ha)	51	1786.8	3020.494	844.24	731.295

The second category is the energy consumption in Indian agriculture. The main variables of the study are Fertilizer consumption, electricity consumption, irrigation area. Data on NPK use per year is extracted from the economics directorate. Moreover, fertilizer consumption as percentage of total energy use is obtained from the FAO database. Annual Electricity consumption data is taken from the Central Statistical Office, India. Data on Net irrigated area is obtained from the agriculture ministry for the period 1950-2014. Data on Irrigated area as percentage of total arable land is obtained from the FAO database. It is clear from the table 4.2 that energy consumption has increased manifolds over the past five decades.

Table 4.2: Summary Statistics of Energy Consumption

Variable	Observation	Mean	Maximum	Minimum	Std.Dev
Fertilizers (Kg/Hectare)	51	161.4	164.2	156.5	2190488
Electricity Use (KJ/Hectare)	51	66.5	70.26	54.24	3621481
Capital Formation (Kg/Ha)	51	1786.8	3020.494	844.24	731.295
Irrigated area (Million Hectare)	51	2927.6	601.381	4209.5	2160.3

The last category is the climatic variables. Carbon dioxide emissions and precipitation statistics are obtained from the FAO database and Indian meteorological department respectively. Since, the precipitation statistic is in absolute terms, it is converted into an index - The standard precipitating index. Using the index, the rainfall data is split into normal and extreme rainfall. It is to be noted that extreme rainfall takes into account both drought and flood situations. The methodology and reasoning for this is explained in the next section. The rationale behind this is to analyse the impact of excess rainfall on climate changes.

Table 4.3: Summary Statistics of Climatic Variables

Variable	Observation	Mean	Maximum	Minimum	Std.Dev
Carbon Dioxide (Kg/Ha)	51	2927.6	601.381	4209.5	2160.3
Normal Rainfall	51	0.217	1.03	-1.022	0.55
Excess Rainfall	51	0.156	2.29	-2.17	0.87

To understand the role of institutions in the development of states, region wise statistics is taken for the period 2003-2014. Nine major agricultural states of India are considered. Punjab, Haryana and Uttar Pradesh from the north, Maharashtra, Madhya Pradesh and Rajasthan from the west and Karnataka, Andhra Pradesh and Tamil Nadu from the south. Again, the data can be divided into three categories. Firstly, data on agricultural productivity per hectare, agricultural growth is obtained for the above states from the ministry of agriculture. The second category i.e. data on energy consumption statistics on fertilizer use, irrigated land and electricity consumption is taken from the directorate of economics. Regarding the climate data, neither carbon emissions per state nor precipitation statistics for the above states were available. Therefore, the carbon emissions had to be constructed using the energy consumption statistics. Lastly, an institutional index is constructed for the above states. The index is similar to the rule of law and ranges from 0-1 with zero being the worst institution while 1 the best.

Table 4.4: Summary Statistics of Agricultural Productivity, Climatic Variables and Energy Consumption for nine major agricultural states

Variable	Obs	Mean	Maximum	Minimum	Std.Dev
Agricultural Productivity (Kg/Ha)	90	2138.1	4339	836.21	1033.526
Agricultural Land (% of Total Area)	90	70.511	85.6	56.07	10.27
Forest Area (% of Total Area)	90	13.53	28.23	0.88	8.33
Fertilizer Use (Kg/Ha)	90	147.45	285.41	30.23	65.13
Irrigated Area (Hectares)	90	5681.9	13928.5	2147	3181.64
Electricity Use (KJ/Ha)	90	441406.5	60033.2	8425992	882314
Carbon Emissions (Kg/Ha)	90	3328.392	11266.3	536.78	2773.94
Institutional Quality	90	0.447	.34	0.59	1.404

4.2 Theoretical Model

This study applies a rigorous econometric model to understand the relationship between climate change and agricultural productivity. The **Instrumental Regression** method is followed. The dependent variable chosen is carbon dioxide emissions while the explanatory variables are agricultural land, forest area, agricultural productivity and precipitation index. This section is divided into three sub-sections. In the first sub-section, the theory of Instrumental Variable Regression is presented. Next, the methodology behind creating the indices are explained. In the last section, the theory of panel data regression and its application in this study are explained. Further, the construction of institutional quality index is explained.

4.2.1 Instrumental Variables

The Instrumental Variable (IV) approach is used when the BLUE assumptions of OLS regressions do not hold true since the OLS prediction stands inconsistent as the explanatory variable and error term are correlated. To eliminate this error correlation, Instrumental Variable regression methodology is applied. Before proceeding to understand the mathematics behind this, let us get familiar with some important terminologies. Variables that are correlated with the error term are called Endogenous Variables while the variables that are uncorrelated with the error term are called Exogenous Variables. A valid instrumental variable must satisfy two conditions. Firstly, it has to be relevant. If an instrument is relevant, then it is correlated with the regressor. Secondly, it has to be exogenous i.e. it has to be uncorrelated with the error term.

The mathematics behind the IV regressions is straightforward. Consider a dependent variable Y, an independent variable X and the error term u. Now we could have two cases. X and u are uncorrelated while Y is correlated with u. Then the OLS is consistent. If X and u are correlated, then the OLS estimator is inconsistent because of u's indirect effect on y through x. Introduce the instrument Z. If Z is correlated with X but not with u then the estimator is consistent. Also, Z has an indirect effect on Y through X similar to u.

Mathematically, the population regression model relating the dependent variable with the explanatory variables is

$$Y_i = \beta_i X_i + u_i \tag{4.1}$$

Then, the OLS estimator is

$$\begin{aligned} \beta_{ols} &= \beta + (X'u)X'X; Corr(X,u) = 0 \\ \beta_{ols} &= Bias + (X'u)X'X; Corr(X,u) \neq 0 \end{aligned} \tag{4.2}$$

If they are correlated then an additional 'instrument' variable, Z, is used to separate the correlated part with the uncorrelated part.

$$X_i = \alpha_i Z_i + v_i \tag{4.3}$$

The mathematics of the Instrumental Variables Regressions (Two Stage Least Squares) is as follows:

First Stage: Regress each X on Z and save the predicted values

$$\begin{aligned} \alpha &= (Z'Z)^{-1}Z'X \\ X &= Z\alpha \\ &= Z(Z'Z)^{-1}Z'X \\ &= P_z X \end{aligned} \tag{4.4}$$

Second Stage: Regress each X on Z and save the predicted values

$$\begin{aligned} Y &= X\beta + u \\ \beta_{2SLS} &= (X'P_zX)^{-1}X'P_zY \end{aligned} \tag{4.5}$$

The validity of the instruments can be asserted by reasoning they are relevant instrument and exogenous. In other words, the correlation between the instruments and the explanatory variable is non-zero and the error terms and instruments are not correlated.

$$\begin{aligned} corr(Z_i, X_i) &\neq 0 \\ corr(Z_i, u_i) &= 0 \end{aligned} \tag{4.6}$$

The parameters are exactly identified if the number of endogenous variables is equal to the number of instruments. If the number of endogenous variables exceeds (less) the instruments, then it is a case of overidentification (underidentification).

In this study, the Instrumental Variables Two Stage Least Squares (IV-2SLS) methodology is approached. The following variables are of concern

Dependent variable – C, Carbon di oxide emissions (Kg/Ha)

Exogenous Variable 1 – AL, Agricultural Land use (Percentage of total geographical area)

Exogenous Variable 2 - FA, Forest Area (Percentage of total geographical area)

Exogenous Variable 3 – Norm, Normal Rainfall (SPI Index)

Exogenous Variable 4 – Ext, Exctreme Rainfall (SPI Index)

Endogenous Variable – AP, Agricultural Productivity (Kg/Ha)

Instrumental Variable 1 – F, Fertilizer Consumption (Kg/Ha)

Instrumental Variable 2 – GCFC, Capital Formation (Rs Crore)

Instrumental Variable 3 – EL, Electricity Consumption (KJ/Ha)

Instrumental Variable 4 – I, Irrigated area (% of total agricultural area)

In a simultaneous-equations framework, we could write the model we just fit above as

$$\begin{aligned} AP_i &= \pi_0 + \pi_1 GCFC_i + \pi_2 EL_i + \pi_3 I_i + \pi_4 F_i + v_i \\ C_i &= \phi_0 + \phi_1 AL_i + \phi_2 FA_i + \phi_3 Norm_i + \phi_4 Ext_i + \phi_5 AP_i + u_i \end{aligned} \tag{4.7}$$

In the first stage, the energy intensity variables are used as instruments for agricultural productivity, controlling for agricultural land use, forest area and precipitation index.

$$AP_i = \alpha + \beta_1 AL_i + \beta_2 FA_i + \beta_3 Norm_i + \beta_4 Ext_i + \beta_5 F_i + \beta_6 EL_i + \beta_7 I_i + \beta_8 GCFC_i + v_i \tag{4.8}$$

As emphasized by Angrist & Krueger (2001), in two-stage least squares, consistency of the second-stage estimates does not depend on using the correct first-stage functional form (Kelejian, 1971). Recall, Z_i is exogenous i.e. the variables F_i, EL_i, I_i and $GCFC_i$ are uncorrelated with ui, the error term of the main regression equation. The other component of the regression equation (1) is the error term v_i, which is correlated with u_i.

$$E[u_i | F_i, El_i, GCFC_i, I_i] = 0 \tag{4.9}$$

The second stage regression estimates the impact of agricultural productivity on climate change.

$$C_i = \alpha + \beta_1 AL_i + \beta_2 FA_i + \beta_3 Norm_i + \beta_4 Ext_i + \beta_5 AP_i + u_i \tag{4.10}$$

The two stage least squares is the default method for regressing over-identified models. However, two other methods are also widely used. The first is the Generalized Method of Moments (GMM). In this method, different weights are assumed for the variables in the covariance ratio. The other common method is the Limited Information Maximum Likelihood (LIML). In studies where the sample size is small, this estimator proves to be more efficient.

The IV regression techniques does pose certain limitations. Firstly, it is based on common sense and intuition. It is not impossible to show that the correlation between the instrument and the error term is zero. One has to use his common sense to decide if it makes sense to consider such an instrument. However, the existence of correlation between the instrument and the regressor can be easily tested from the First-Stage regressions. Lastly, an instrument could also be weak and in such a case the results of the IV regression wouldn't differ much from the OLS regressions.

Past studies have shown that climate change has a significant impact on agricultural production. This has been studied in chapter 2 with a thorough review of the literature. The instrumental variables regression model to evaluate the effects of agricultural productivity on climate change have been explored in the methodology section of chapter 4. The following hypothesis were tested.

Table 4.5: Hypothesis - IV and OLS

SN	Hypothesis	Variable	Method of Testing
1	Higher the productivity, higher the emission of CO_2	AP	Multiple Regression and Instrumental Variable Regression
2	Higher the proportion of land under agriculture, less is the emission of CO_2	AL	Multiple Regression and Instrumental Variable Regression
3	Higher the forest area, lower is the emission of CO_2	FA	Multiple Regression and Instrumental Variable Regression
4	More the normal rainfall, lower is the emission of CO_2	Norm	Multiple Regression and Instrumental Variable Regression
5	More the extreme rainfall, higher is the emission of CO_2	Ext	Multiple Regression and Instrumental Variable Regression

Agricultural production in India is heavily dependent on energy use. Irrigation area, fertilizer consumption, electricity use and technological inputs have increased manifolds since green revolution. Fertilizer use is a main source for the increase in greenhouse gases (Park et al., 2012). Nitrous oxide which accounts for around 5% of all the greenhouse gases is emitted due to anthropogenic activities wherein large amount of fertilizer is added to the soil to increase crop yield (EPA, 2010). Irrigating crops has a negative impact on regional temperatures, although it is not expected to considerably affect the global mean temperatures (Clim, 2010).Green revolution has also resulted in an increase in the use of machinery such as power pumps, tractors which heavily use diesel oil. 2.7 Kg of CO_2 per unit is emitted when 1 litre of diesel is burnt.

Agricultural land use is a major source for soil carbon sequestration. Advanced land management techniques and agricultural practices such as no-till, conventional tillage and crop rotation can strengthen the soil quality which can absorb the atmospheric CO_2 while also enhance water-holding capacity and crop yield.

Another major source are forests. Forests make for great carbon sinks as carbon is captured not only in the tree biomass but also by forest soils (Sedjo & Sohngen, 2012). This study also introduces two new variables – Normal Rainfall and Excess Rainfall as a measure of precipitation. Rainfall can have both positive and negative impact on the carbon cycle. There is a vast literature focussing on the effect of climate change on precipitation levels but there is minimal literature that talks about the impact of rainfall on carbon levels. NASA's earth observatory notes that rain can actually enhance the carbon sink (Lovett, 2002). Further, rainfall can reduce fire emissions, a major factor in reducing carbon uptake. A case study of Australia from 2010-2014 suggests that increased rainfall suppressed the fire emissions by 30% contributing to the country's giant carbon sink. Lastly, rainfall is a major factor in soil erosion although anthropogenic activities also result in accelerated erosion. Lal (2004) argues that soil erosion has a positive impact on carbon levels. In short, increased rainfall would help the country's carbon sink and eventually one can sequester more carbon from the atmosphere. Further, excessive rainfall might lead to soil erosion which in turn may lead to greater carbon level. If we assume that the carbon emissions arising from the erosion are negligible and are vastly offset by the giant carbon sink created by increasing rainfall, the intuition would be that more the rainfall, more the carbon sink and hence the less carbon emissions per hectare.

4.2.2 Standardized Precipitation Index

The standardized precipitation index (SPI) was developed by Tom McKee, Nolan Doeskin and John Kleist in 1993. The SPI tool was formulated to monitor extreme rainfall situations such as Drought or Flood. Rainfall deviation from normal, a long term mean, is the most commonly used indicator for drought monitoring. In India, on the basis of rainfall deviations, four categories namely ±20% deviation as normal, -20 to -60% deviations as deficit, -60% and below as scanty, above 20% as excess are used for evaluating the rainfall patterns across the country (Indian Meteorological Department). Other indices that are commonly used are Palmer Drought Severity Index (PDSI) and the standardized precipitation index (SPI). Lately, SPI is being widely used because of its simple methodology and easy interpretability. Especially when the data obtained is a time series, then SPI comes handy. The SPI method is used to represent the precipitation patterns in different regions of a country with a single numerical value. In short, with just one index, it indicates that a particular region can experience both extreme wet and extreme dry conditions in one or more time scales. Bordi et al. (2001) calculated the time series rainfall data from 1948 to 1971 in the Mediterranean with the SPI technique to analyse the regional drought patterns. Naresh Kumar et al. (2009) applied the SPI index to study the drought patterns in India.

Mathematically, SPI is a normalized index representing the probability of occurrence of an observed rainfall amount when compared with the rainfall climatology at a certain geographical location over a long-term reference period (Man-chi, 2013). The methodology is simple (see in A.9). Firstly, a time series of the precipitation statistics is generated. Then, the statistics is fit to a cumulative frequency distribution. In this study, gamma distribution is selected. The third step is to calculate the Long term average of the rainfall data and then its standard deviation. Lastly, the SPI is calculated using the formula

$$
\begin{aligned}
LongtermAverage &= Average(RainfallSeries) \\
StandardDeviation &= StandardDeviation(RainfallSeries) \\
SPI &= \frac{Actual\ Rainfall - Long\ Term\ Average}{Standard\ Deviation}
\end{aligned} \tag{4.11}
$$

The SPI ranges from +3 to -3. The table is used to detect the drought or extreme climatic conditions in a particular year

Table 4.6: Standard Precipitation Index

SPI	Drought Category	Flood Category
0 to ± 0.99	Mild Drought	Mild Flood
± 1.00 to ± 1.49	Moderate Drought	Moderate Flood
± 1.50 to ±2.00	Severe Drought	Severe Flood
± 2.00 or less/more	Extreme Drought	Extreme Flood

Source: Mckee et al. (1993)

The SPI has many advantages in rainfall variation analysis. Firstly, only rainfall data is needed to compute it. It can also be applied in countries with diverse or varying climatic zones. Indeed, it is a great fit for a country like India which is surrounded by the Himalayas in the north and the Arabic Sea and Indian Ocean in the south while the central part of the country is a plateau. Further, it also enables rainfall data to be quantified over various time scales such as 3-, 6-, 12-, 24- month rainfall. SPI-3 measures rainfall conditions over a 3-month period, the anomalies of which impact mostly on soil water conditions and agricultural produce; while SPI-24 measures rainfall conditions over two years, as prolonged droughts can give rise to shortfalls in groundwater, stream flow, and fresh water storage in reservoirs (Man-chi, 2013).

4.2.3 Panel Data Regression

An important challenge faced by the agricultural sector is the increasing growth inequality in the rural areas between its major agricultural producing states. This study tries to analyse the role of institutions in combatting climate change and the consequences of having bad institutions. The data collected is from the Ministry of Agriculture, India. The same variables as above are examined except that they are now collected at the regional level. Nine major agricultural states of India are considered for the study over a period of 10 years 2004-2013. Since the behaviour of the observed elements are analysed across a period of time, we have a Panel Dataset. Here, we introduce two new variables – *Institutional Quality* and the interaction term *Institutional Quality*Yield*. While the former is an index ranging from 0-1 with 0 being the worst institution, the latter is included to understand the role of institutions in mitigating climate change. The theory of panel data regression is presented in the next sections.

Consider the panel data regression equation

$$Y_{it} = \beta_1 X_{it} + \beta_2 W_{it} + \beta_3 T_{it} + \beta_4 S_{it} + u_i + v_{it} \tag{4.12}$$

Here,

$$E\left[v_{it} \left| X_{it}, W_{it}, S_{it}, T_{it}\right.\right] = 0 \tag{4.13}$$

If all the explanatory variables are observed, then a multiple regression can be used to identify the coefficients. However, if it is not observed by the econometrician, then it requires that an external instrument Z_i that is uncorrelated with the error term, v_{it} and exogenous variables W_i, T_i, S_i but correlated with $X_i$such that

$$\begin{aligned} corr(Z_{it}, v_{it}) &= 0 \\ corr(Z_{it}, X_{it}) &\neq 0 \end{aligned} \tag{4.14}$$

Panel Data analysis is usually one of the following three. Firstly, an OLS regression across sections ignoring the time variant effects. A fixed effects model treats the fitted observations such that they differ between cases but do not vary over time. It helps in controlling for unobserved heterogeneity when the heterogeneity is constant across time. Further, the individual specific effect has to be correlated with the individual variables. Random effects model is used when there is heterogeneity over time and also between cases. In the random effects model, the unobserved heterogeneity is controlled for by assuming the individual variables are uncorrelated with the individual specific effect. The crucial distinction between fixed and random effects is whether the unobserved individual effect embodies elements that are correlated with the regressors in the model, not whether these effects are stochastic or not (Green, 2008).

Pooled OLS: This model neglects any time variant or time-invariant effects. The entities from different time periods are pooled together and the regression is performed on the newly pooled data.

$$Y_{it} = \alpha + X_{it} + u_i + v_{it} \tag{4.15}$$

Fixed Effects Regression: This model is used to eliminate the unobserved individual time-invariant effects. This is done using the *within transformation*.

$$\begin{aligned} Y_{it} &= \alpha + X_{it} + u_i + v_{it} \\ Y_{it} - \overline{Y_i} &= X_{it} - \overline{X_i} + u_i - \overline{u_i} + v_{it} - \overline{v_i} \end{aligned} \tag{4.16}$$

Random Effects Regression: This model is used to eliminate the unobserved heterogeneity. This can be done using a first differencing methodology.

Given the balanced nature of the panel dataset, the pooled OLS regression is first approached. The fixed effects and random effects Instrumental Variable regression are performed in the next stage. In this study, it is assumed that the energy inputs have a significant impact on the yield. Therefore, the **Panel Data Instrumental Variable** approach is followed. The instrumented variables are fertilizer consumption, electricity use and irrigated area. Notice that all the three variables imply energy intake. The endogenous variable considered is agricultural yield, as in the previous case.

Finally, the *institutional quality index* is created. It is a weighted average of economic freedom, governance, legal structure and the ease of awarding institutional credit. An important variable in this study is the interaction term – *agricultural productivity*institutional quality*. While the first analysis tries to estimate the impact of agricultural productivity on climate change, the second is an attempt to see if institutions can play a major role in ameliorating carbon emissions. The general hypothesis is that good institutions are energy efficient and hence increase the agricultural productivity while reducing carbon emissions. The inclusion of the interaction term would provide an insightful and rigorous analysis of the recent drought situations which have resulted in migration and farmer suicides.

In this study, the Instrumental Variables Two Stage Least Squares (IV-2SLS) methodology is approached. The following variables are of concern

Dependent variable – C, Carbon di oxide emissions (Kg/Ha)

Exogenous Variable 1 – PAL, Agricultural Land use (Percentage of total geographical area)

Exogenous Variable 2 - PF, Forest Area (Percentage of total geographical area)

Exogenous Variable 3 – IQ, Institutional Quality (An index from 0-1)

Exogenous Variable 4 – Yield*IQ, The interaction term

Endogenous Variable – Yield, Agricultural Productivity (Kg/Ha)

Instrumental Variable 1 – F, Fertilizer Consumption (Kg/Ha)

Instrumental Variable 2 – EL, Electricity Consumption (KJ/Ha)

Instrumental Variable 3 – I, Irrigated area (% of total agricultural area)

the fitted model then becomes,

$$C_{it} = \alpha + \beta_1 PAL_{it} + \beta_2 PF_{it} + \beta_3 IQ_{it} + \beta_4 Y_{it} * IQ_{it} + \beta_5 Yield_{it} + u_{it} \tag{4.17}$$

In a simultaneous-equations framework, we could write the fitted model as

$$\begin{aligned} Y_{it} &= \pi_0 + \pi_1 I_{it} + \pi_2 EL_{it} + \pi_3 F_{it} + v_i \\ C_{it} &= \phi_0 + \phi_1 Y_{it} + \phi_2 PF_{it} + \phi_3 PAL_{it} + \phi_4 IQ_{it} + \phi_5 Y_{it} * IQ_{it} + u_i \end{aligned} \tag{4.18}$$

The introduction of the variable 'institutional quality' is crucial in our study. This variable would give a deeper insight in two ways. Firstly, it would tell us how good an institution should be to mitigate climate change and secondly, it would provide an accurate reason as to why some states are able to grow better than others. The table 4.7 presents the institutional quality for the given period of the nine major agricultural states in India.

Table 4.7: **Institutional Quality Index**

State	Institutional Quality
Andhra Pradesh	0.49
Haryana	0.63
Karnataka	0.41
Maharashtra	0.40
Madhya Pradesh	0.36
Punjab	0.60
Rajasthan	0.37
Uttar Pradesh	0.51
Tamil Nadu	0.57

The hypothesis for the panel data IV regression is presented in the table 4.8

Table 4.8: Hypothesis - Panel Data Regressions

SN	Hypothesis	Variable	Method of Testing
1	Higher the productivity, higher the emission of CO_2	Y	Panel Data IV Regression
2	Higher the proportion of land under agriculture, less is the emission of CO_2	AL	Panel Data IV Regression
3	Higher the forest area, lower is the emission of CO_2	FA	Panel Data IV Regression
4	Better the institution, lower is the emission of CO_2	IQ	Panel Data IV Regression
5	Higher the interaction term, lower is the carbon emission	Y.IQ	Panel Data IV Regression

Chapter 5

Results

This chapter presents the results of regression analysis performed using the statistical software STATA to analyse the aforementioned research questions. Before looking at the results, some relevant hypothesis is presented and the rationale behind them is discussed. This chapter proceeds in the following way. Firstly, the hypothesis and results of the empirical analysis of agricultural productivity on carbon emissions are discussed in the first section. The second section takes a deeper look into the role of institutions in the development of major agricultural states while combatting climate change while the last section investigates the curious case of Maharashtra – a severely drought affected region in India.

5.1 OLS Regression

The data summarized in the chapter before is first tested for stationarity. This is done for two reasons. Firstly, to avoid spurious regressions and secondly, to achieve significant t-statistics. In order to validate the hypothesis testing, the unit root tests are performed. Incidentally, most of the variables were found to be non-stationary. Therefore, the variables were transformed by taking their first difference so as to achieve a stationary dataset. The augmented dickey fuller test (see in table 5.1) was applied to obtain the error corrected model.

As seen from table 5.1, Normal Rainfall and Extreme rainfall are Integrated of order 0 while Carbon emissions, forest area, land use, agricultural productivity, capital formation and fertilizer use are integrated of order 1. Only two variables had two unit roots – Irrigated area and electricity consumption.

Therefore, the new model specification was

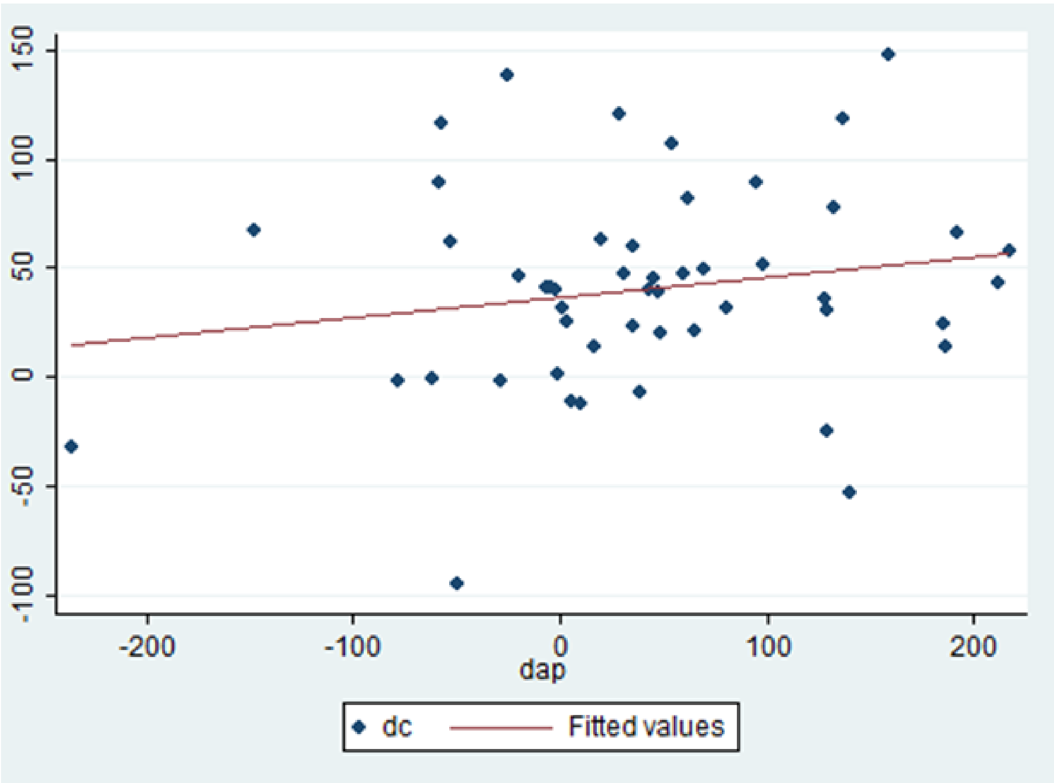
$$\Delta c_i = \Delta al_i + \Delta foa_i + \Delta ap_i + norm_i + ext_i + u_i \tag{5.1}$$

Table 5.1: Augmented Dickey Fuller Test

Variable	Characteristic
norm	I(0)
ext	I(0)
c	I(1)
al	I(1)
foa	I(1)
ap	I(1)
f	I(1)
gcfc	I(1)
i	I(2)
el	I(2)

The regression analysis was performed for the new model specification, the results of which are presented in table 5.2 The figure 5.1 indicates that there exists a positive relationship between agri-

Figure 5.1: Scatter Plot representation of Productivity and Carbon Emissions



cultural productivity and climate change. However, is agricultural productivity the only determinant in assessing the carbon emissions? Moreover, is it an exogenous variable or an endogenous variable?

Table 5.2: OLS Regression of Productivity on Carbon Emissions
(see in B.1)

Dependent Variable Carbon Emissions	
Agricultural Land	-130.276
	(3.52)**
Forest Area	-32.066
	(2.03)*
Normal Rainfall	-4.160
	(0.45)
Extreme Rainfall	25.542
	(3.96)**
Agricultural Productivity	0.102
	(1.76)
Constant	44.693
	(7.42)**
R^2	0.47
N	50

* $p < 0.05$; ** $p < 0.01$

As evident from the table 5.2, agricultural land use, forest area and normal rainfall have a negative effect on the emissions of CO_2. Further, agricultural productivity and extreme rainfall have a positive impact on the level of carbon emissions. The results are in accordance with the hypothesis put forward in the previous section.

A 1% increase in the agricultural land use would lead to a 130.2 unit decrease in the level of carbon emissions. However, the agricultural land is fixed in India and the prospect of any unused land being turned into an agricultural field is highly unlikely. On the contrary, more and more agricultural land is being grabbed by the corporates and converted to real estate or sold to the big multinational companies for development. Shamshabad, a small district in the state of Telengana is a living example of this. The repercussions of this are still felt in the city whose carbon emission level are increasing day by day. Bangalore, once known as the green city of India, is now a dead city. The lakes therein have all dried up while the number of parks and trees have gone down tremendously over the past five years. Agricultural land serves as a major source of carbon sink. Therefore it is imperative for farmers and the local institutions to -extract maximum utility out of it.

Forests also have a negative impact on the emissions of Carbon Di oxide. A 1% increase in the forest area would decrease the carbon levels by 32.06 units. This is again a significant number as forests are an important source to sequester carbon. India's forest area is currently 23% of its total geographical area. However, most of the forest area is occupied by non-agricultural states mainly in the north east and central India. On the other hand, crucial agricultural regions such as Andhra Pradesh, Maharashtra, and Tamil Nadu have lost their forest cover because of fast-paced construction. Each of these states are competing on the industrial front which has resulted in loss of agricultural land and forest cover.

The interpretation of the precipitation variables is interesting. Normal rainfall has a negative effect on the carbon dioxide emissions. A 1% change in the rainfall pattern would lead to a 4.160 unit decrease in the carbon dioxide level. India has witnessed a change in its monsoon pattern over the past decade. It is becoming increasingly difficult for the farmers to adopt to such sudden changes in the climate. Moderate or low rainfall is the ideal situation as it helps increase the soil quality and the carbon sink. Unfortunately, this has not been the case in the past decade as the majority of agricultural states have witnessed extreme climatic conditions. The variable, extreme rainfall, indicates either a flood or drought like situation. Major agricultural states like Andhra Pradesh, Karnataka, Maharashtra have been exposed to more and more such situations in the past five years. A look at the table 5.2 indicates that a 1% increase in such situations would lead to a 25.542 unit increase in the CO_2 emissions. Drought poses a major challenge to the farmers as lack of rainfall is resulting in low agricultural yield which in turn is increasing migration and farmer suicides.

Lastly, the most important variable – agricultural productivity is analysed. The regression analysis indicates that a 1% increase in the yield would lead to a 0.102 unit increase in the carbon emissions. Agricultural productivity in India has grown tremendously over the past five decades largely due to the green revolution and the increase in energy inputs such as fertilizers, electricity and diesel use. Further, capital is being substituted for labour which has also resulted in a small technological innovation in the agricultural sector.

Following the OLS regressions, tests for heteroskedascticity and serial correlation were performed. The Durbin Watson alternative test (see table 5.3) was performed to check for serial correlation. The test assumes the null hypothesis to be of no serial correlation. As seen from the table 5.3, the probability is 0.06 which is greater than 0.05 at the 95% confidence level and hence the null hypothesis of no serial correlation cannot be rejected. Hence, we can assert that there is no presence of serial correlation.

Table 5.3: Durbin Watson test for Serial Correlation

Lags(p)	F	Df	Prob >F
1	3.694	(1,43)	0.0613

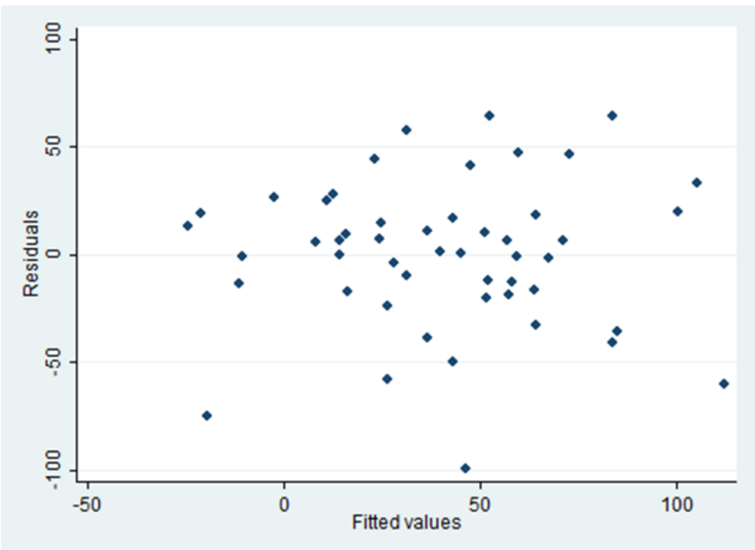
The Breusch-Pagan test (see table 5.4) assumes the null hypothesis of constant variance i.e. homoskedasticity. The table 5.4 provides a detailed view of the test performed. The probability value is 0.33 which is greater than 0.05 at the 95% confidence level and hence the null of constant variance cannot be rejected. In other words, there is no presence of heteroskedasticity. The OLS regression is unbiased when there is no correlation between the error term and explanatory variable. In the above equation, agricultural productivity stands insignificant at the 5% and 1% significance level. Further, there could be a problem of the error term being correlated with this variable.

Table 5.4: Breusch – Pagan test for Heteroskedasticity
(see in B.2)

Variables	Chi-Square	Prob >Chi-Square
Fitted values of dc	0.92	0.3368

The figure 5.2 gives an insight into the distribution of random error from the OLS regression. The residuals are centered on the zero throughout the fitted values. Therefore, it is safe to say that the model specificed is correct. Despite the model seeming a good fit for the empirical analysis, the IV regression is carried out. This is due to two reasons. Firstly, the OLS estimator seems bias because of a correlation between the error term and the predictor, agricultural productivity. Secondly, the intuition of agricultural productivity being highly dependent upon energy consumption. Therefore, the instrumental variable approach is followed. The endogenous variable is agricultural productivity while the instruments are fertilizer consumption, irrigated area, electricity use and capital. It is shown that the endogenous variables and the instruments are correlated while the error term is not correlated with the instruments.

Figure 5.2: Residual vs Fitted Values for the OLS regression



As seen from the table 5.5, there exists a high level of correlation between the instruments, Z_i and the endogenous variable X_i. The second important criteria is to show that there is no correlation between the instruments, Zi and the error term, v_i.

Table 5.5: Correlation Matrix of Endogenous Variable and Instruments

Instruments	Irrigation	Capital	Fertilizer Use	Electricity Use
Agricultural Productivity	0.9832	0.8220	0.9848	0.9729

The table 5.6 indicates that the residuals and the instruments are correlated but at a very minimal level. This result is good enough to assume that the corr (Z_i, v_i = 0)

Table 5.6: Correlation Matrix of Instruments and Residuals

Instruments	Irrigation	Capital	Fertilizer Use	Electricity Use
Residuals	-0.007	0.000	0.028	-0.01

5.2 Instrumental Variable Regression

Fertilizer use, capital, electricity use and irrigated area have an important role to play in the productivity per hectare. Further, the ever so increasing dependency on high energy inputs has led to an astounding increase in the consumption of fertilizers and machinery. Indeed, these variables make for a good instrument. The instrumental variable regression is performed in the next section using the Two Stage Least Squares approach.

The instrumental variable regression results (see in Table 5.7) are quite similar to the OLS regressions except that the standard errors of all the variables are much larger. More importantly, the variable agricultural productivity stands significant both at 95% and 99% confidence level. The interpretation of the results is similar to that of the Multiple Regression model.

A 1% increase in the agricultural land use would lead to a 156.65 unit decrease in the level of carbon emissions. Forests also have a negative impact on the emissions of Carbon dioxide. A 1% increase in the forest area would decrease the carbon levels by 34.73 units. Normal rainfall has a negative effect on the carbon dioxide emissions. A 1% change in the rainfall pattern would lead to a 3.090 unit decrease in the carbon dioxide level. The variable, extreme rainfall, indicates either a flood or drought like situation. The results indicate that a 1% increase in such situations would lead to a 24.148 unit increase in the CO_2 emissions. Drought poses a major challenge to the farmers as lack of rainfall is resulting in low agricultural yield which in turn is increasing migration and farmer suicides. Lastly, the endogenous variable – agricultural productivity is analysed. The regression analysis indicates that a 1% increase in the yield would lead to a 0.284 unit increase in the carbon emissions. There isn't much difference in the coefficients of the IV model from the OLS model. Therefore, if the instruments are proven to be weak, then OLS regression should be the main methodology of our study.

Table 5.7: IV-2SLS Regression of productivity on carbon emissions
(see in B.3)

Dependent Variable Carbon Emissons	
Agricultural Land	-156.6526
	(3.43)**
Forest Area	-34.7362
	(2.10)*
Normal Rainfall	-3.090
	(-0.32)
Extreme Rainfall	24.148
	(3.55)**
Agricultural Productivity	0.284
	(2.30)*
Constant	37.368
	(7.61)**
R^2	0.34
N	49

* $p < 0.05$; ** $p < 0.01$

Two tests are performed to check for validity of the instruments. Firstly, the Durbin Wu-Hausman test is performed for endogeneity. The null hypothesis for the DWH test is that variables are exogenous.

Table 5.8: Durbin-Wu Hausman Test
(see in B.6)

Test	Statistic	Prob >F
Durbin Score	3.39616	0.06
Wu-Hausman	3.12778	0.08
Robust Regression	4.24846	0.04

The probability score is 6%, 8% and 4% respectively which is less than 10% at the 90% level of confidence and 5% at the 95% confidence level. Therefore, we can reject the null hypothesis of exogenous variable. In other words, the chosen endogenous variable is valid (see table 5.8).

The difference between the Durbin and Wu–Hausman tests of endogeneity is that the former uses an estimate of the error term's variance based on the model assuming the variables being tested are exogenous, while the latter uses an estimate of the error variance based on the model assuming the variables being tested are endogenous. Under the null hypothesis that the variables being tested are exogenous, both estimates of the error variance are consistent (StataCorp, 2013). On the contrary, Wooldridge's Regression test rejects the null hypothesis at the 5% significance level. This discrepancy in the results could be attributed to the low number of observations. Therefore, we could continue to treat agricultural productivity as endogenous since the 2SLS estimates would be significant.

Table 5.9: Sargan Test of Overidentification
(see in B.5)

Test	Statistic	Prob >F
Score chisquare (3)	6.31933	0.0971

The probability score is 9% which is greater than 5% at the 95% level of confidence. Therefore, we cannot reject the null hypothesis of over identifying restrictions are valid. In other words, the chosen endogenous variable is valid (see table 5.9).

Table 5.10: Shea's Partial R^2 (see in B.7)

Variable	R-Sq	Adjusted R-Sq	Partial R-Sq	Robust F(4,40)	Prob >F
Productivity	0.2563	0.1076	0.2404	3.27755	0.0205

Minimum Eigan Value Statistic -3.1642

The R^2 and Adjusted R^2 statistics could be misleading because it could happen that the instrumented variable could be strongly correlated with the exogenous variables but weakly correlated with the included instruments. Therefore, the partial R-squared statistic is measured (see table 5.10). It measures the correlation between productivity and the additional instruments after partialling out the effect of the exogenous variables. In this case the partial R-squared statistic is 0.2404 which explains that the instruments exhibit a 24% variation in the first regression model. Further, the F statistic is significant since the Prob >F value is less than 5%. Therefore, the instruments jointly explain the endogenous regressor. Lastly, the Cragg & Donald (1993) minimum Eigen value statistic is 3.16. Stock & Yogo (2005) tabulated critical values of 5%, 10%, 20% and 30% models. Unfortunately, the F statistic of 3.27 does not exceed the critical values and hence we cannot reject the null hypothesis of weak instruments. Clearly, the instruments considered in the study renders weak. This brings us back to the OLS regression. In case the IV regression post-estimation shows the presence of weak instruments, then perhaps it is better to proceed with OLS regression since weak instruments tend to bias the results towards the OLS estimates.

OLS vs IV – The Durbin-Wu-Hausman Test for OLS consistency.

It is essential to check that the OLS estimator is unbiased otherwise it could lead to omitted variable bias. The Hausman test is performed the results of which are shown underneath. In the first stage (see table 5.11), the assumed endogenous variable, agricultural productivity, is regressed on the instruments.

$$AP_i = \beta_1 El_i + \beta_2 I_i + \beta_3 GCFC_i + \beta_4 F_i + u_i \tag{5.2}$$

Table 5.11: OLS Regression of reduced equation

Dependent Variable Agricultural Productivity	
Irrigation	-67.316
	(0.92)
Electricity	0.000
	(0.37)
Fertilizer	8.246
	(2.65)*
Capital	-0.007
_cons	38.022
	(2.39)*
R^2	0.21
N	49

* p <0.05 ; ** p <0.01

F test above shows that all the four instruments are statistically significant and have the explanatory power for the dependent variable. The next step is to calculate the residuals of the reduced equation and regress it on the structural equation.

$$C_i = \beta_0 + \beta_1 AP_i + \beta_2 AL_i + \beta_3 FA_i + \beta_4 Norm_i + \beta_5 Ext_i + u_i + v_i \tag{5.3}$$

Table 5.12: Augmented OLS Regression with residuals

Dependent Variable Carbon Emissions	
Agricultural Land	-155.053
	(3.56)**
Forest Area	-31.084
	(1.98)*
Normal Rainfall	-10.122
	(1.01)
Extreme Rainfall	22.449
	(3.46)**
Agricultural Productivtiy	0.301
	(2.19)*
Residuals_FirstStage	-0.247
	(1.77)
_cons	36.286
	(4.56)**
R^2	0.49
N	49

Minimum Eigan Value Statistic -3.1642

$$
\begin{aligned}
Test\ resfirststage &= 0 \\
F(1, 42) &= 2.47 \\
Prob > F &= 0.0835
\end{aligned}
\tag{5.4}
$$

The null hypothesis is that residuals are zero and therefore agricultural productivity is exogenous. This hypothesis cannot be rejected at the 10% level but not at the 5% level (from table 5.12). Therefore we can evidently say that agricultural productivity is indeed endogenous and proceed with the OLS regression.

In this section, we have seen a comprehensive empirical analysis of the impact of agricultural productivity on climate change in India. The outcome of the Instrumental Variables regression clearly shows that productivity has a positive impact on the level of carbon emissions. Moreover, the inclusion of energy variables in the form of instruments is crucial as it not only explains the variation in agricultural productivity but also indicates that the increasing dependency on energy inputs is causing the level of carbon emissions to increase drastically. The table 5.13 compares the OLS and IV regressions.

Table 5.13: Comparision of results of IV-2SLS and OLS regressions

	IV-2SLS	OLS
Dependent Variable – Carbon Emissions		
Agricultural Land	-156.6526	-130.276
	(3.43)**	(3.52)**
Forest Area	-34.7362	-32.066
	(2.10)*	(2.03)*
Normal Rainfall	-3.090	-4.160
	(-0.32)	(0.45)
Extreme Rainfall	24.148	25.542
	(3.55)**	(3.96)**
Agricultural Productivity	0.284	0.102
	(2.30)*	(1.76)
Constant	37.368	44.693
	(7.61)**	(7.42)**
R^2	0.34	0.47
N	49	50

* $p < 0.05$; ** $p < 0.01$

A quick glance at the table suggests that OLS estimates are slightly better than the IV-2SLS estimates. Further, the problem of weak instruments is significant in this study. To rectify the issue of weak instruments, other IV procedures have been suggested. The LIML estimator is very widely used in case weak instruments are detected. However, in this study it would be reasonable to proceed with the OLS estimates since they are more efficient and present successful results.

The next section showcases the results of the panel data IV regression performed to assess the role of institutions in the agricultural growth and mitigating climate change.

5.3 Panel Data IV Regression

The previous section of this chapter focusses on the energy inputs and their impact on climate change. Mitigating climate change is crucial to India since it has ratified to the Kyoto Protocol and also during the latest developments at the COP21 in Paris. It is here that the role of institutions and state policy renders important. This section of the chapter attempts to bring out the impact of institutions on climate change in the nine major agricultural states of India. Over the past decade, a few of these states such as Haryana, Punjab have done extremely well in the agricultural sector while the some states such as Maharashtra, Andhra Pradesh, Karnataka have failed to provide the adequate support to the farmers which has resulted in mass suicides and migration. Using a panel data IV approach, the impact of institutional quality on climate change is analysed.

The panel IV regression approach is applied. However, it is important to note that the panel size is very small (n=9, T=10). Classical panel data models require that as a rule of thumb 'n' be atleast 30. The summary of the panel dataset is presented below in table 5.14.

Table 5.14: Summary Statistics of the Panel Dataset

Variable		Mean	Std. Dev.	Min	Max	Observations
Carbon Emissions	overall	7.810776	.7593328	6.285588	9.329576	N=90
	between		.7313953	6.923467	9.062369	n=9
	within		.3094225	7.172897	10.21688	T=10
Agricultural Land	overall	70.511	10.27673	56.07	85.6	N=90
	between		10.78701	56.194	84.783	n=9
	within		1.009009	63.553	72.023	T=10
Forest Area	overall	13.53233	8.303881	.88	28.23	N=90
	between		8.75819	.939	28.201	n=9
	within		.072956	13.26533	13.70533	T=10
Instituional Quality	overall	.4475556	.0726437	.34	.59	N=90
	between		.0676297	.356	.566	n=9
	within		.0341444	.3595556	.5155556	T=10
Interaction Term *Institutional Quality*Yield*	overall	962.5146	486.6144	334.4847	2055.34	N=90
	between		490.4054	412.7013	1706.599	n=9
	within		143.5831	598.7915	1311.256	T=10
Yield	overall	2138.1	1033.526	836.21	4339	N=90
	between		1067.059	1017.548	4147.881	n=9
	within		211.4271	1481.466	2629.956	T=10

Panel datasets are complicated to analyse. Firstly, there is the problem of too small or too large dataset. This study considers nine regions (n=9) over a period of 10 years (T=10) for a total of 90 observations. This is largely owing to the difficulty in obtaining data for the major agricultural regions for the initial years of green revolution. More importantly, the data for some variables such as carbon emissions, precipitation level, and institutional index is not readily available and therefore it had to be constructed. Panel data estimation is a useful method as it helps in dealing with datasets that have a presence of heterogeneity and also examine the fixed or random effects in the longitudinal data. However, it is a common misconception that fixed or random effects approach should be employed whenever a panel dataset is on hand. The panel dataset considered is a balanced one as all variables have measurements in the entire time period. The objective of this section is to examine unobserved group and time effects on the dependent variable. Further, since the dataset is quite small, it is more sensible to start with a pooled OLS regression and then test for unobserved effects rather than directly jump into the fixed or random effects model.

5.3.1 Pooled OLS Regression

The pooled OLS regression is a linear regression without any fixed or random effects. It does not assume any difference in the slope and intercept across panels or time periods. If there is no correlation between the error terms and regressors, then the OLS estimators produce efficient and consistent parameters.

However, in this case we check for correlation between the variable 'productivity' and the energy inputs. As in the previous section, there is a weak correlation between productivity and irrigation, electricity consumption and a strong correlation between agricultural yield and fertilizer consumption. Therefore, the IV-2SLS pooled regression is attempted.

In the first stage regression, the endogenous variable agricultural productivity is regressed on the energy inputs. In the second stage regression, the dependent variable is regressed on the endogenous variable.

The results of the IV-TSLS (see table 5.15) pooled regressions are satisfactory and in accordance with the hypothesis. Firstly, the positive sign of agricultural yield indicates that productivity has a positive influence on the level of carbon emissions. The higher the agricultural productivity, the higher is the level of carbon emission. Agricultural land use and forest area have a negative impact on the level of carbon emissions as expected.

Table 5.15: IV-2SLS Pooled Regression of productivity on carbon emissions
(see in B.8)

Dependent Variable Carbon Emission	
yield	0.00814**
	(0.00339)
pal	-0.129
	(0.0819)
pf	-0.180*
	(0.101)
qi	35.22**
	(16.07)
yqi	-0.0173**
	(0.00774)
Constant	2.796
	(4.295)
Observations	90

Robust Standard Errors in Parenthesis

* p <0.1 ; ** p <0.05 ; ***p <0.01

The introduction of the variable 'Institutional Quality' presents us with a more concise idea of how institutions impact climate change. Here, the positive sign reflects that good institutions have a direct impact on the carbon emission while the bad institutions have a negative impact. This is contradictory to our hypothesis. Therefore, the interaction time 'Yield*Institutional Quality' is added to study the impacts of good and bad institutions on climate change. The negative sign of the interaction term indicates that bad institutions result in more emissions of carbon while good institutions are able to reduce their levels of emissions.

A one unit increase in the agricultural land use would lead to a 0.129 unit decrease in the level of carbon emissions. Forests also have a negative impact on the emissions of Carbon Di oxide. A unit increase in the forest area would decrease the carbon levels by 0.180 units. The interpretation of the institutional variables is interesting. A one unit increase in the institutional quality would lead to a 35.22 unit increase in the carbon emission. However, this study is more concerned about the interaction term. A one unit increase in the interaction term would lead to a 0.017 unit decrease in the interaction term.

$$\textbf{Institutional} \quad \textbf{quality} = \frac{0.008}{0.017} = \textbf{0.470}. \tag{5.5}$$

Therefore, the states with institutional quality greater than 0.47 manage to outdo their compatriots in mitigating climate change. Haryana, Punjab etc. possess great institutions and therefore a knowledge of the advanced agricultural management practices coupled with good institutional finance. This has helped them to perform outstandingly in the agricultural sector while states like Maharashtra, Andhra Pradesh, and Karnataka owing to their bad institutional quality have failed to deal with the problems of agricultural sector resulting in large scale migration and farmer suicides.

Two tests are performed to check for validity of the instruments. Firstly, the Durbin Wu-Hausman test is performed for endogeneity (see table 5.16). The null hypothesis for the DWH test is that variables are exogenous.

Table 5.16: Durbin Wu-Hausman Test - IV
(see in B.9)

Test	Statistic	Prob >F
Durbin Score	3.39616	0.00
Wu-Hausman	3.12778	0.00

The probability score is 0% in all the tests and is less than 5% at the 95% level of confidence. Therefore, we can reject the null hypothesis of exogenous variable and say the endogenous variable is valid.

Table 5.17: Sargan Test of Overidentification - IV
(see in B.9)

Test	Statistic	Prob >F
Score chisquare (3)	3.54403	0.1700
Basmann chi2 (2)	3.36137	0.1862

The probability score is 17% and 18% which is greater than 5% at the 95% level of confidence. Therefore, we cannot reject the null hypothesis of over identifying restrictions are valid (in table 5.17).

5.3.2 Fixed Effects Regression

The fixed effects regression model is applied to test for differences in the intercepts. This method is used whenever the variables studied are expected to vary over time. Each state of India is peculiar in its own way and therefore to test for the relationship between the explanatory variable, agricultural productivity and the dependent variable, carbon emission renders important as the fixed effects model tries to study their relationship within the entity or group. One of the most important assumption of this model is that the time-invariant variables do not correlate with other individual characteristics as they are absorbed by the intercepts.Here, the intuition of agricultural productivity having a direct impact on carbon emissions holds true. Further, agricultural land use has a negative impact on carbon emissions as stated in the hypothesis earlier while forest area has a positive impact. The interaction term 'yqi' holds a negative sign (see table 5.18).

Table 5.18: Fixed Effects Regression
(see in B.10)

Dependent Variable – Carbon Emissions	
Yield	0.002
	(1.76)
Forest Area	0.346
	(0.93)
Agricultural Land	-0.242
	(8.39)**
Institutional Quality	7.503
	(2.22)*
Interaction Term [Yield*Institutional Quality]	-0.004
	(1.71)
_cons	15.871
	(3.13)**
N	90
R^2 : Within	0.4731
Between	0.3695
Overall	0.2911
prob>F	0.0000
Rho	0.99823

* p <0.05 ; ** p <0.01

F Test that all u_i are 0: F (8, 76) = 18.11 ; $Prob$ >F = 0.00

To better interpret this value, the optimum value of Institutional Quality is estimated.

$$\textbf{Institutional Quality} = \frac{0.002}{0.004} = \textbf{0.50} \tag{5.6}$$

Again here, we can see that the states with institutional quality greater than 0.50 manage to perform better than their competitors. The R^2 within value stands at 0.47 explaining a 47% variation in the model. The F-test examines the null hypothesis that all the dummy variables are zero. This is rightly rejected by the high F-value of 93031.46 with a $prob > F = 0.000$ which is less than 5%.

5.3.3 Random Effects Regression

The random effects model differs with the fixed effects model in that it assumes randomness in the variables across groups. The panel dataset considered is only for a short time period. Moreover, the variables considered are both time variant (Yield, Forest Area, Agricultural land) and time invariant (Institutional Quality). Therefore, it is advantageous to use random effects model since it permits for the use of time invariant variables. The random effects model assumes that the entity's error term is not correlated with the explanatory variables thereby allowing for the use of time-invariant variables.

Table 5.19: Random Effects Regression
(see in B.11)

Dependent Variable – Carbon Emissions	
Yield	0.009
	(2.66)**
Forest Area	-0.265
	(2.39)*
Agricultural Land	-0.229
	(2.31)*
Institutional Quality	35.041
	(2.42)*
Interaction Term (Yield*Instituional Quality)	-0.019
	(2.50)*
_cons	10.317
	(2.09)*
R^2:Within	0.0571
Between	0.3605
Overall	0.2820
N	90
Rho	0.17795

* $p < 0.05$; ** $p < 0.01$

Here, the intuition of agricultural productivity having a direct impact on carbon emissions holds true. Further, agricultural land use and forest area, unlike the fixed effects model, have a negative impact on carbon emissions as stated in the hypothesis earlier (see table 5.19).

The interaction term 'yqi' holds a negative sign. To better interpret this value, the optimum value of QI is calculated.

$$\textbf{Institutional} \quad \textbf{Quality} = \frac{0.009}{0.019} = \mathbf{0.47} \tag{5.7}$$

Again here, we can see that the states with institutional quality greater than 0.47 manage to perform better than their competitors.

The R-square value stands at 0.28 explaining a 28% variation in the model. The F-test examines the null hypothesis that all the dummy variables are zero. This is rightly rejected by the high F-value of 93031.46 with a $prob >$F = 0.0005 which is less than 5%.

The next important step after performing the fixed effects and random effects model is to check for the best model. This is done using the Hausman Test. The Hausman specification test examines for the individual effects. If the individual effects are correlated with the explanatory variable, the random effect model violates the Gauss-Markov assumption. It is because individual effects are parts of the error term in a random effect model. However, in the fixed effects model, the individual effects form a part of the intercept and therefore fail to violate the Gauss-Markov assumption. In other words, when using random effects model, the estimator are not the best linear unbiased estimator (BLUE) while in the fixed effects model, they are BLUE. The null hypothesis of the Hausman test is to prefer the Random Effects Model. In case, the null hypothesis is rejected, the fixed effects model is preferred over the random effects model.

Which Model to Choose?

The above analysis has been performed in three most common methods. Firstly, the pooled OLS regression was performed. Then the panel IV regression for fixed effects and random effects model was done. The question pertains – which out of the three is the best model? Before doing a quick comparison of the results obtained by the three models, we perform the Hausman test.

Table 5.20: Hausman Test for Fixed Effects vs Random Effects
(see in B.12)

Coefficients \Variable	Re	Fe	Difference	S.E
Yield	0.0091776	0.0020386	0.007139	0.0032471
Forest Area	-0.2653077	0.3461686	-0.6114763	.
Agricultural Land	-0.2287733	-0.2421272	0.0133539	0.09494264
Institutional Quality	35.04063	7.50346	27.53717	14.08925
Interaction Term	-0.187951	-0.0035205	-0.0152745	0.00724727

b = consistent under Ho and Ha

B = inconsistent under Ha, efficient under Ho

Test: Ho: difference in coefficients not systematic

chi-square(3) = $(b-B)'[(V_b-V_B)^{-1}](b-B)$ = 9.13

$Prob >$chi(2) = 0.0276

The Hausman test assumes the null hypothesis to be no systematic difference in coefficients. In other words, the random effect model is preferred in case the null hypothesis is failed to be rejected. However, in this case the fixed effect model is to be preferred since the null hypothesis is rejected as the P-value is less than 5%. Therefore according to the Hausman test (see table 5.20) the fixed effects model should be fitted to analyse the panel dataset.

The hausman test clearly suggests to proceed with the Fixed Effects model for this panel dataset. However, it is important to realize that the general intuition that higher the forest area, lower is the carbon emissions is proved wrong in the fixed effects model. Another problem that arises in panel data regression is the number of entities. A panel of 9 variables and 10 years is too small for a fixed effects estimation and therefore the results are not very efficient. The general rule of thumb is to have atleast 30 entities. Thus, it is reasonable to proceed with the Pooled IV OLS regression (see table 5.21). The model fits well with the given dataset and the general hypotheses is validated. Further, and importantly, the Institutional Quality calculated comes out to be very much similar in all the three cases. Therefore, we can assert that the states with an institutional quality of 0.47 or above manage to perform better than their counterparts in mitigating climate change.

Table 5.21: Comparision of Panel Data Regressions - OLS vs RE vs FE

Dependent Variable – Carbon Emissions	OLS	RE	FE
Yield	0.00814	0.009	0.002
	(0.00339) **	(2.66)**	(1.76)
Agricultural Land	-0.129	-0.265	0.346
	(0.0819)	(2.39)*	(0.93)
Forest Area	-0.180	-0.229	-0.242
	(0.101) *	(2.31)*	(8.39)**
Institutional Quality	35.22	35.041	7.503
	(16.07) **	(2.42)*	(2.22)*
Interaction Term	-0.0173	-0.019	-0.004
(Yield*Institutional Quality)	(0.00774) **	(2.50)*	(1.71)
Constant	2.796	10.317	15.871
	(4.295)**	(2.09)*	(3.13)**
R^2		0.28203	0.29344
F, Wald Tests	42.98	21.93	93031.46
Observations	90	90	90

Robust Standard Errors in Parentheses

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Chapter 6

Maharashtra - A Peculiar Case

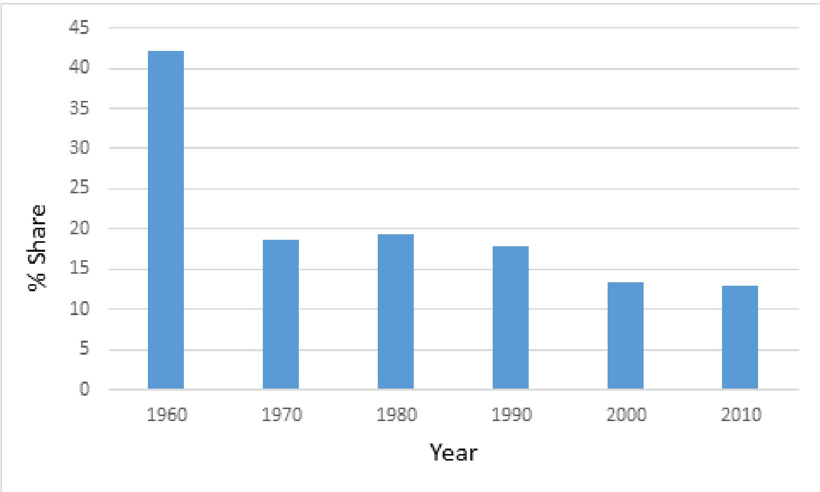
The state of Maharashtra is the third largest state of India in terms of geographical area and second largest in terms of population. Agriculture is the main occupation in the state despite the strong influx of industrialization. The state is blessed with quality soil which renders most of the land cultivable. It is highly dependent on the south-west monsoon and therefore any fluctuations in the rain cycle has an adverse impact on productivity. Further, the state's food needs are primarily met by its production of Rice, Jowar and Bajra – the three principal crops of the state. One intriguing fact about the state is the economy's dependency on cash crops. Sugarcane, Cotton and Turmeric are the main cash crops produced in the state. As we'll see in the next sections, the dependency on cash crops has resulted in a fatal condition of the agricultural economy in turn leading to farmer suicides and migration. Some of the major drought prone regions in India happen to be in Maharashtra especially the western regions of Ahmednagar, Latur and the Vidharbha Region consisting of Nagpur and Amaravati. The former districts fall under the 'Marathwada' region. This comes as a surprise because irrigation facilities in these regions have received a big boost since the formulation of 'New Economic Policy' in 1991 of which Maharashtra was a key member. This also resulted in the state constructing dams to foster irrigation. Moreover, Maharashtra has the largest number of dams in India. Hence, the state's poor agrarian economy is amusing and presents an intriguing study.

This part of the chapter presents an overview of the agricultural economy of Maharashtra since Independence. The state has always been at the forefront of the Indian agricultural scenario. It was one of the first states to integrate the primary sector into the industrial and tertiary sector and also played a major role in opening up its rural economy to foreign investments. The New Economic Policy (NEP) of 1991 had Maharashtra's strong backup as it helped open the rural economy to the global world. In the next sections, seven key areas are discussed. Firstly, the contribution of agricultural economy to the state's livelihood and gross domestic product is discussed. In the second section, the land use statistics and irrigation pattern is discussed. Thirdly, the cropping pattern is analysed. Cropping pattern in Maharashtra has witnessed tremendous change and it presents a challenging case study. Fourthly, the rainfall pattern and energy inputs are discussed. The fifth section attempts to dissect the institutional credit and its implications on the rural livelihoods. The sixth section investigates the growth and the rapid decline of cotton farming while also throwing light on the state farm suicides. The seventh and the final last section focusses on the sugarcane industry.

6.1 Agricultural Economy of Maharashtra

The contribution of agricultural sector to the net state domestic product has increased over the last decade. In the year 2004 it contributed around 10% to the state GDP which has increased to 12% in 2013. However, compared to the early 1960s, this growth is minimal. In the year 1960, agriculture contributed around 40% to the net state domestic product, which has declined tremendously to 12% in 2013 (see figure 6.1). This is largely due to the shift in the state's economic policy. During the 1980s and 1990s, the government's policy favoured industrialization which led to the installation of many power plants and heavy industries. Further, tertiary sector received a boost as well owing to the IT boom. The technological and service industry led to large scale migration from the rural sector to the big cities such as Pune, Mumbai and Nagpur. Naturally, agricultural sector received a massive setback. The substitution of labour with capital didn't help its cause either.

Figure 6.1: Share of Agriculture to State GDP



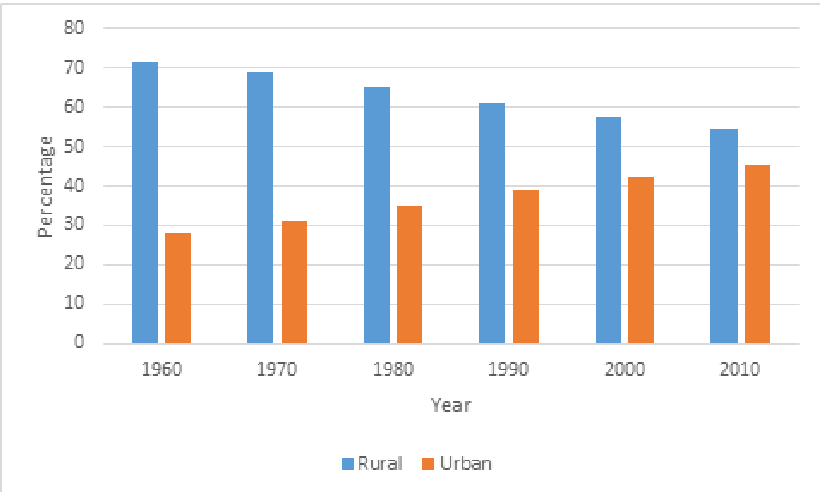
Source: Government of Maharashtra (2015)

The sector wise contribution of the agricultural sector to the total GDP gives a further insight into the changing pattern of the economy since independence. In 1960, agriculture was the engine of the state's economy. It contributed over 40% while manufacturing and tertiary sector had an 8% and 50% share respectively (see figure 6.2). However, over the past four decades, things have taken a drastic change. As seen from the graph below, manufacturing sector has gradually replaced agricultural sector while tertiary sector has witnessed almost very little change. The reason for this is the introduction of new industries especially sugarcane and automobile. Currently, agriculture only contributes to around 12% of the total GDP while manufacturing sector has a much greater contribution at 29%.

Figure 6.2: Sector Wise Contribution to State GDP

Source: Government of Maharashtra (2015)

Figure 6.3: Trends in Rural and Urban Population



Source: Government of Maharashtra (2015)

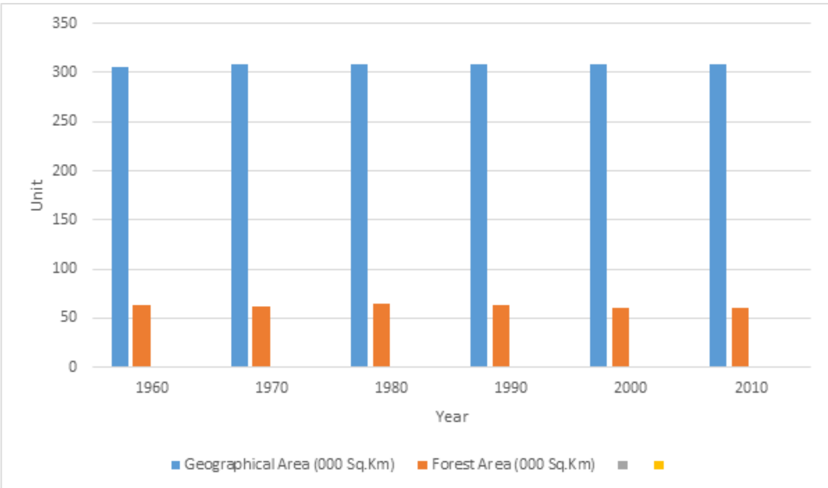
The rural and urban population pattern (see figure 6.3) clearly depicts the increase in migration from the rural to urban areas. This is also a consequence of the industrialization and boom of the Information Technology sector in big cities like Mumbai, Pune, Nasik and Nagpur. It is interesting to see that all these cities are the capital of their respective regions – Konkan, Western Maharashtra, Marathawada and Vidharbha respectively.

As seen from the figure 6.3, rural population contained more than two-thirds of the total population while the urban setup was just around 30% mark in the 1960. Four decades later, the population distribution is 50% each in the urban and rural districts. This is equivalent to a 3.86% CAGR in the urban areas.

6.2 Land Use and Irrigation Pattern

Maharashtra is the third largest state in India in terms of area with a total geographical area of 308 Square Kilometres. The forest area on the other hand accounts for 20% of the total geographical area. This has remained constant over the last five decades although the last two decades have witnessed a slight increase in the forest area from 62,500 Sq.Km to 65,654 Sq.Km.

Figure 6.4: Land Use Pattern - Maharashtra



Source: Government of Maharashtra (2015)

Irrigation facilities have acquired central stage since the implementation of new agricultural policy at the national level and later in the new economic policy of 1991. Table 6.2 presents the irrigation statistics of Maharashtra as a percentage of the gross cropped area. Irrigation area has increased at a CAGR of 3%. The percentage of irrigated area in 1960 was 6.5% which has increased to 18.2% in the late 2000s. However, this is still less than the national average of 20% (see table 6.1). Water scarcity poses a big challenge to the government. Recently, the state high court had ordered for the influx of water in the drought affected region from other states. However, this only presents a short term solution. In the next paragraphs, the uneven distribution of irrigation will be discussed. Irrigation statistics from the four major regions of the state are collected and then plotted region-wise as well as crop-wise.

Table 6.1: Irrigation Trends - Maharashtra

Year	Gross Cropped Area (000 Hectares)	Gross Irrigated Area (000 Hectares)	% Irrigated Area
1960	18823	1220	6.5
1970	18737	1570	8.4
1980	19642	2415	12.3
1990	21859	3319	15.2
2000	21504	3550	17.8
2010	23175	4050	18.2

Source: Government of Maharashtra (2015)

Further, the region-wise share of irrigation by source is analysed. This seems important because only a few parts of the state are drought affected while the other agricultural areas are not. Despite this, the performance of these regions is abysmal. It is noteworthy that these regions have been receiving decent rainfall in the last decade.

Table 6.2: Region-Wise Percentage Irrigation share by sources for 1961-2010

Region	Surface Irrigation	Well Irrigation	Net Irrigation	Gross Irrigation
Konkan	2.9	1.0	1.8	1.6
Western Maharashtra	45.8	58.6	54.3	55
Marathawada	13	28.9	21.5	22
Vidharbha	38.3	11.4	22.4	21.4
Maharashtra	100	100	100	100

Source: Government of Maharashtra (2015)

The Konkan region comprises of the western districts including Mumbai, Raigard, and Thane These regions are blessed with enormous rainfall every year and often the precipitation level rises more than the forecasted value. In other words, the deviation from the normal is large. Western Maharashtra comprises of the industrial and soil-rich lands. This includes Pune, Satara, Kolhapur, and Solapur which fortunately receive decent rainfall. Moreover, these regions are situated closer to the administration and commercial capital Mumbai. Hence, the argument of trickle-down effect occurring cannot be ruled out. But the regions that are of prime importance in this study are the two drought prone and worst growing regions of Vidharbha and Marathawada. As evident from the table 6.2, Marathawada and Vidharbha lack good irrigation facilities accounting for 22% and 21% respectively of the total gross irrigation. Western Maharashtra, on the other hand, does exceptionally well accounting for more than half of the state's total share. So, where does the main issue arise? Are really the drought prone regions regressive owing to the lack of rainfall? Or is there a hidden agenda? This is made clear from the following table which focusses on the crop-wise irrigated area.

6.3 Cropping Pattern

The most striking statistics from the table 6.3 is of Sugarcane. The irrigated area to total crop area is the most for Western Maharashtra. Moreover, it is clear that western Maharashtra gained more form the state's irrigation schemes as it constantly had more than 50% of its total crop area irrigated. In case of sugarcane, it was 75% which is quite an astounding figure. The policy of the government to focus on just one crop in sugarcane and also on one region of Western Maharashtra demands investigation. Vidharbha is home to two major crops. The cash crop Cotton and the traditional crop of Rice. Both these crops require high amount of water and fertilizer use respectively. However, since the region is located in the Deccan plateau the temperatures tend to be much higher than the rest of the state often peaking at 50 degrees Celsius. Add to this the sad state of rainfall. Productivity in this region is bound to be affected and the consequences of this are being felt in the form of farmer suicides and large scale migration.

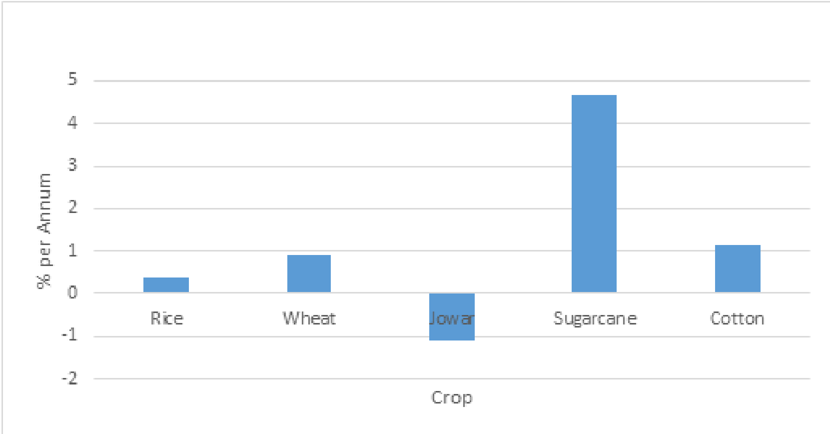
Table 6.3: Crop-wise Irrigated Area as a Percentage of total crop irrigation 1961-2010

Region	Rice	Wheat	Groundnut	Cotton	Jowar	Sugarcane
Konkan	3.4	0.0	4.4	0	0.0	0.2
Western Maharashtra	10.5	54.1	63.2	57.1	73.3	75.8
Marathawada	4.0	26.4	23.0	32.7	25.5	21.3
Vidharbha	83.0	19.5	9.3	16.3	1.1	2.7
Maharashtra	100	100	100	100	100	100

Source: Government of Maharashtra (2015)

The next paragraphs focus on analysing the cropping pattern in the state. Maharashtra is home to three major crops – Rice, Sugarcane and Cotton. Wheat is dominant in the western part of Maharashtra although the country gets its larger share of the crop produce from the northern states of Punjab and Haryana. The cropping pattern in the state has experienced drastic changes since the 1960s. The most common crops in the state during the early part of independence were rice, jowar and wheat. However, post green revolution period, the state has experienced a sudden surge in the plantation of two crops that have acquired prime importance – Sugarcane and Cotton. The figure 6.5 shows the cumulative annual growth rates for the major crops from 1961-2010.

Figure 6.5: CAGR of Major Crops 1961-2010



Source: Government of Maharashtra (2015)

The case of sugarcane again signals out the abstruse policy of the governments over the last decades. Jowar is the staple food of the state. The traditional dish of Maharashtra - 'Jowar ki roti' is extremely popular all over the country. Hence, it is difficult to understand the negative growth rate of one of the traditional crops and widely grown crop of the state. Further, sugarcane plantation has been rising at an alarming rate. The problem with sugarcane plantation is the amount of water it requires to fruition. This has already been discussed in the previous pages where the crop has been shown to receive a large proportion of the irrigation facilities.

The table 6.4 presents the cumulative growth rate of area, production and yield of the major crops.

Table 6.4: Cumulative Growth of Area, Production and Yield of Major Crops 1961-2010

	Area	**Production**	**Yield**
Rice	0.30	1.61	1.23
Wheat	0.92	2.74	3.04
Jowar	-1.20	0.42	1.36
Sugarcane	4.30	3.00	1.78
Cotton	1.22	2.05	2.42

Source: Crop Report of Maharashtra, Agricultural Statistics information, epitome II, Government of Maharashtra

The cumulative growth rate of area, production and yield is highest for sugarcane. This is again intriguing but not surprising. Jowar has witnessed a decrease in its area by 1.2% per annum while cotton on the other hand has gained at a similar level. Around 4% of the farmed land in Maharashtra is under sugarcane but it consumes well over 70% of well and surface irrigated water (see in 6.3). Another interesting case study is offered by the cash crop, Cotton. During the colonial rule, India was one of the main centres for cotton and jute production. Today, it ranks behind china in terms of global cotton production. Vidharbha, the northeast region of the state is rich in soil ideal for growing cotton and soybeans. What used to be a thriving industry once upon a time has become a nightmare of one for the government and the country. Cotton prices have reduced by more than 50% putting additional pressure on the farmers. Unfortunately, the soil quality is such that it is difficult for the farmers to change to new types of crop. The cases of sugarcane and cotton will be studied further in the next sections.

6.4 Energy Inputs and Rainfall Distribution

Energy inputs especially fertilizer consumption and electricity consumption have been dealt with extensively in this thesis. Indeed they have an important role to play in mitigating climate change. Fertilizer consumption in Maharashtra has witnessed a dramatic increase since the green revolution on par with the country. The table 6.5 showcases the fertilizer consumption statistics from 1961-2010.

Table 6.5: Fertilizer Consumption in Maharashtra 1961-2010

Region	N		P		K		Total NPK	
	% Share	*% of total fertilizers*	*% Share*	*% of total Fertilizers*	*% Share*	*% of total Fertilizers*	*% Share*	*% of total Fertilizers*
Konkan	4.0	73.2	1.9	15.5	2.5	11.4	3.2	100.0
Western Maharashtra	51.1	58.3	48.1	24.5	61.1	17.2	51.8	100.0
Marathawada	21.5	58.3	23.7	28.6	19.7	13.1	21.8	100.0
Vidharbha	23.3	59.4	26.4	30.0	16.8	10.6	23.2	100.0
Maharashtra	**100.0**	**59.0**	**100.0**	**26.4**	**100.0**	**14.6**	**100.0**	**100.0**

Source: Crop Report of Maharashtra, Agricultural Statistics information, epitome II, Government of Maharashtra

Western Maharashtra once again assumes the central role. Its share is more than half among all the four regions suggesting the region's strong position in the state. More interestingly, Vidharbha and Marathawada despite consuming only one-fifth of the total fertilizers posit a strong case. This paradox is made clear through the table 6.6 which focusses on the cumulative growth rate of fertilizers over the last four decades.

Table 6.6: Cumulative Growth Rate of fertilizers in Maharashtra 1961-2010

Region	N	P	K	Total NPK
Konkan	4.4	2.6	2.8	3.8
Western Maharashtra	4.8	5.9	4.9	5.1
Marathawada	7.5	8.7	7.3	7.8
Vidharbha	5.2	7.4	3.8	5.6
Maharashtra	5.4	6.7	5.1	5.7

Source: Crop Report of Maharashtra, Agricultural Statistics information, epitome II, Government of Maharashtra

A quick look at the growth rate of fertilizers in the region of Marathawada and Vidharbha explains the growing challenges the region is facing. Over the last five decades, their consumption of fertilizers is greater than the state average, which is of significant concern. Marathwada, in particular, has consumed fertilizers at a growth rate of 7.8% per annum despite its relatively low share in the total consumption. Vidharbha, on the parallel, has consumed fertilizers at a cumulative growth rate of 5.6% which coincides with the state average, and is greater than the growth rate of Konkan and Western Maharashtra. This increase in consumption of fertilizers can be attributed to the type of soil and cropping pattern in these regions. There has been a dramatic rise in the cultivated area under cotton, sugarcane and soybean. This is due to the fact that farmers are looking for short term crops that could fetch them high returns. It is to be noted that all these crops require high consumption of fertilizers and water. In the following pages, the special case of sugarcane and cotton farming will be looked at. These two crops have been at the heart of the state's agricultural economy for the last three decades. Sugarcane, in particular, has been given unconditional preference and support by the governments. Cotton farming, on the other hand, has been exploited by the foreign investors following the opening up of the economy. Before delving deep into these crops, a quick statistical inference into the electrical consumption and rainfall distribution is presented. The distribution of rainfall is uneven in the state as Western Maharashtra and Konkan regions gain the most from it while Marathawada and Vidharbha hardly have adequate rainfall.

Table 6.7: Electricity Consumption in Maharashtra 1961-2010

Year	Agricultural Consumption (Million Kwh)	% of Total Consumption
1960-61	15	0.55
1970-71	356	4.65
1980-81	1723	12.2
1990-91	6604	22
2000-01	9940	21
2010-11	16527	18

Source: Government of Maharashtra (2015)

Agricultural electricity consumption has increased at a cumulative growth rate of 19% per annum. However, its share in the total consumption of the state has declined in the last two decades. It was highest during the post green and white revolution where it accounted for 22% of the total electricity consumption in the state. However, in the last three decades, its share has remained almost the same despite an increase in the overall electricity consumption (see table 6.7). This is because the share of domestic consumption has achieved a cumulative growth rate of 18% per annum.

The rainfall distribution has been uneven especially favouring the western side of the state. Konkan and Western Maharashtra constantly receive adequate and even excess rainfall in some period. On the other hand, the two drought prone regions Marathawada and Vidharba have been lacking sufficient rainfall (see table 6.8). This is a greater cause of concern because sugarcane is the major crop grown in these regions. What is astonishing is the fact that a crop that consumes 1200mm of water every year is grown in two of the most drought prone regions of the country. Therefore, these crops and the two regions as a whole demand further investigation.

Table 6.8: Annual CGR of Rainfall in Maharashtra

Region	**1961-2010**
Konkan	0.5
Western Maharashtra	0.5
Marathawada	0.05
Vidharba	-0.1
Maharashtra	0.4

Source: Crop Report of Maharashtra, Agricultural Statistics information, epitome II, Government of Maharashtra

6.5 Institutional Credit

The pathetic condition of the farmers and agricultural sector in general has demanded constant attention and scrutiny by the government both at the central and state level. In the past years, the state government has increased its expenditure on the agricultural sector in several ways. One of them is by raising the minimum support price of the traditional and cash crops. Secondly, it has also increased the area under irrigation while also providing compensation to the farmers' families in case of tragic occurrences. However, it would be safe to say that the corruption level and poor choice of agricultural policy by the past governments has resulted in the state's agricultural crises.

Table 6.9: Distribution of Credit by Sources

Type	Institutional			Non-Institutional			
Sources of Loan	*Govt.*	*Co-Op*	*Bank*	*Moneylenders*	*Traders*	*Others*	*Total*
Percentage	1.2	48.5	34.1	6.8	0.8	8.6	100

Source: NSSO Situation Assessment Survey of Farmers: Indebtedness of Farmer Household, 2003 Report No. 98, 59th round

It is clear from the table 6.9 that the majority of credit comes from the cooperatives and Bank loans. However, the case is quite different from what it is as shown by the statistics. The institutional credit is obtained by only a certain sect of the farmer population given the bad state of bureaucracy. Due to the high amount of paperwork and intermediaries involved in the process of obtaining credits, most of the low-income farmers reach out to the moneylenders and traders for loans. Unfortunately, this only worsens the problem rather than mitigating it. This is due to the fact that these moneylenders and traders charge high rates of interests. This causes the farmers to pay more than what they would have with the normal institutional credit thereby indebting them for life. One of the consequences of the non-institutional credit situation is the emergence of bonded labour. As the farmers are unable to repay the loans, they submit their whole life to the landlords as a way to repay the loan. However, bonded labour is slowly being abolished from various parts of the country with the reforming of the agricultural laws. Lastly, the institutional credit system comprising of the government, cooperatives and bank isn't free from problems either. Various studies have shown that the value of loan on paper is not reflective of the loan acquired by the farmer. The increase in the total loan disbursement to the agriculture remains only on paper but in real terms there is no increase in loan amount to agriculture particularly to the small farmers (Mahendradev, 1987).

6.6 Cotton Industry

Maharashtra is one of the major Cotton producing states in the country. The state has around 30 lakh Cotton growers and it accounts for 15 to 20 per cent of the total Cotton output in India. The total area under Cotton (2001-02) was 31.04 lakh hectares, which is about 37 per cent of the total area under Cotton in the country (Mishra et al., 2006).

The area, production and yield of cotton in Maharashtra since the 1960s is presented in the table 6.10. As seen from the table, the area and production of cotton has increased tremendously since the 1960s. Last two decades has witnessed the introduction of a new variety of cotton seed – the BT cotton. However, the low yield statistics for the last two decades are a cause for concern and rightly depict the bad state of the industry and farmers.

Table 6.10: Area, Production and Yield of Cotton

Year	Area (000 Ha)	Production (000 MT)	Yield (in MT)
1960	2500	1673	114
1970	2750	484	30
1980	2550	1224	82
1990	2721	1875	117
2000	3077	1803	322
2010	3942	7473	278

Source: Government of Maharashtra (2015)

Cotton is widely grown in the north and north east part of the state. The vital regions being Vidharbha and Marathawada. The nature of the crop is such that it is heavily dependent upon monsoon. Maharashtra is situated in the western part of India and therefore is one of the first states to receive the south-west monsoon. This is also the rationale behind the state growing majority of crops during the rabi season. Over 90% of the crop's water demand is provided by the monsoon while the rest is obtained through irrigation. Cotton industry flourished during the colonial rule but then witnessed a great decline during the war years. The colonial rule exploited and ruined the cotton industry. The drive to improve Cotton production in all Cotton producing states started soon after the independence, when development schemes such as Cotton Extension Scheme and Grow More Cotton Campaign were launched by the government of India in the year 1950-51 (Mishra et al., 2006). These schemes however had deficiencies and to overcome them the government launched a new centrally sponsored scheme i.e. Intensive Cotton District Programme in 1970-71 which was renamed as Intensive Cotton Development Programme (ICDP) in 1979-80. The main objectives of the scheme were to increase the production of Cotton by adopting improved farm practices and advanced production technology. In the year 2000 the fresh thrust to Cotton research and development has been given by the launching of a Technology Mission on Cotton (TMC). The purpose of the mission is to bring the entire gamut of research, technology transfer, marketing and processing of Cotton under one roof. Despite these efforts Cotton yield in India is lowest in the world because of severe pest attack and its predominant cultivation under rain fed conditions (Narayanamoorthy & Kalamkar, 2006).

There has been wide research done with respect to the cotton industry's situation in India. Many economists and scientists have specifically studied the state of Maharashtra and the current situation of the farmers. A prominent scientist among them is Vandana Shiva, an environmental activist. She specifically focusses on the entry of Monsanto in India. Until 1990, India's economy was not liberal and there were very less private players. In 1991, India opened up through the new economic reforms which liberalized and globalized the economy. Five things changed with Monsanto's entry: First, Indian companies were locked into joint-ventures and licensing arrangements, and concentration over the seed sector increased. Second, seed which had been the farmers' common resource became the "intellectual property" of Monsanto, for which it started collecting royalties, thus raising the costs of seed. Third, open pollinated cotton seeds were displaced by hybrids, including GMO hybrids. A renewable resource became a non-renewable, patented commodity. Fourth, cotton which had earlier been grown as a mixture with food crops now had to be grown as a monoculture, with higher vulnerability to pests, disease, drought and crop failure. Fifth, Monsanto started to subvert India's regulatory processes and, in fact, started to use public resources to push its non-renewable hybrids and GMOs through so-called public-private partnerships (Vandana Shiva, 2013). However, in the late 2000s Monsanto started to provide GMO and hybrid variety of seeds which experienced drastic failure. The crop's failure added to the indebtedness of farmers who upon seeing no hope took to killing themselves. The suicide statistics of farmers in Maharashtra are shocking. Further, their case is not helped by the institution. A vicious cycle is created by the foreign investors, governmental institutions, non-governmental institutions. While the farmers rely on the foreign investors such as Monsanto for the cotton seeds, they are indebted because of the non-institutional credit loans acquired from private money lenders and traders. The crop insurance scheme does not apply to these farmers as well because they fail to complete the bureaucratic procedure hence completing this vicious cycle. The suicide statistics are investigated in the next pages. The table 6.11 is presented underneath and analysed briefly.

Table 6.11: Farmer Suicides in Maharashtra 1997-2006

Year	Number of Farm Suicides	% of total state suicides	% of Country Farm Suicides	Male Farmer Suicides	Female Farmer Suicides
1997	1917	15.2	14.1	1600	317
1998	2409	17.6	15.0	1938	471
1999	2423	17.8	15.1	2050	373
2000	3044	21.6	18.2	2492	530
2001	3536	24.2	21.5	2945	591
2002	3695	25.4	20.6	3155	540
2003	3836	26.0	22.3	3381	455
2004	4147	28.2	22.7	3799	348
2005	3926	27.2	22.9	3638	288
2006	4453	28.7	26.1	4111	342
Gross Total	**33364**	**26.3**	**20.1**	**29109**	**4255**

Source: Nagraj (2008)

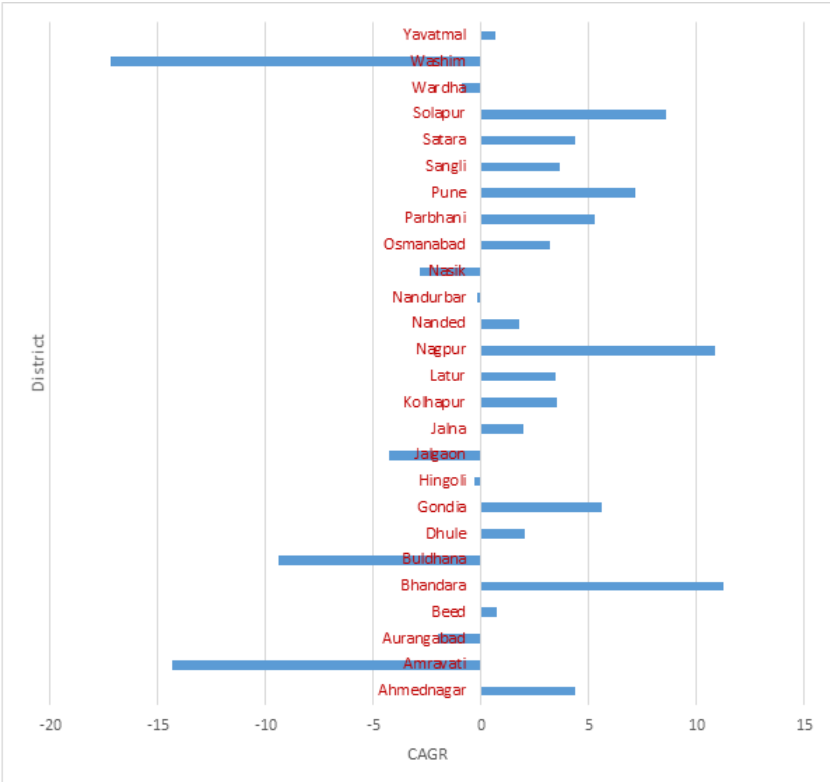
The table 6.11 provides gruelling statistics with respect to the suicide situation prevalent in the state. The number of farm suicides has more than doubled since 1997 from 1917 to 4453. Further, the farm suicides comprise almost one-third of the total suicide cases which is astonishing. Also, every 5th farmer in the country commits suicide. Moreover, over 90% of the total farm suicides are committed by men revealing that the pressure is more on the male farmer than the female. However, it is unknown whether the reasons for farm suicides are unknown. The causes for suicides are manifold. Firstly, the rising seed and fertilizer prices put the farmer in debt. Add to this the fact that the moneylenders charge unreasonable interest rates on loans means that the farmers are unable to repay the loans on time. In case of crop failure, they have no choice but to kill themselves. Secondly, the cash crops' value is witnessing a decreasing trend. This causes huge losses to the farmers. Thirdly, most of the seeds come with patent implying the farmers have to plant a new seed every season. Fourthly, the non-renewable nature of the seeds mean that not only are they harmful to the environment but they also have a big risk factor associated with them. Moreover, these genetically modified seeds do not often undergo the required tests. Lastly, the poor institutional support in terms of subsidies and irrigation facilities further worsen the situation.

6.7 Sugarcane Industry

While the cotton farming in Maharashtra is in a crises due to lack of institutional support to the farmers, sugarcane industry poses a challenge only because of the massive institutional support it attracts from the government. Sugarcane is an annual crop that is grown both in the rabi and kharif seasons. However, the crop is a water-guzzler for it requires atleast 1500-2000 mm of water over the growing season. This is twice of what the state receives in annual rainfall. So, why is such a high water capacity crop being grown in a drought-prone state?

Sugarcane plantation in Maharashtra dates back to as early as 1950. The first sugar factory was setup in Ahmednagar, Marathawada district of Maharashtra. Incidentally, the founder of the factory, Mr. Vikhe-Patil also happened to be a politician from the same district. In the next five decades, the politicians' career (most prominent among them being Sharad Pawar) were shaped by the amount of sugarcane plants and emergence of sugar factories. These men flexed their muscles to provide everything possible for the growth of the crop. Paradoxically, this was much earlier to the emergence of water crisis. On the other hand, it could be argued that the water crisis emerged because of the overdue attention given to Sugarcane plantation by the politicians to serve their vested interests. We have already seen in the previous sections the dramatic increase in sugarcane's cultivated and irrigated area. The figure 6.6 depicts the district wise growth of sugarcane production from 2001-2015. Only five districts namely, Amaravati, Nasik, Jalgaon, Washim and Buldhana have experienced a negative growth rate. On the contrary, the region of Marathawada comprising eight districts namely Aurangabad, Nanded, Latur, Parbhani, Jalna, Beed, Hingoli and Osmanabad has witnessed a huge rise in Sugarcane plantation area. Surprisingly, this region is one of the most drought prone regions in the country receiving around 800mm annual average normal rainfall while Konkan region received an average annual rainfall of 3000 mm in 2015. This shocking of an agricultural policy by the government has resulted in a man-made calamity that is adversely affecting human lives. This leads us to the question – why is so much attention and institutional support given to just one crop? Why is agriculture in Rajasthan, an extremely dry state situated in the north-west India, able to perform better? The reasons are quite straightforward but at the same time appalling.

Figure 6.6: District-Wise CAGR of Sugarcane 2001-2015



Source: Department of Agriculture (2015)

Three core reasons can be cited. Firstly, the profitable nature of the crop attracts the farmers. Further, it is a crop grown all over the year and is less prone to pests and weeds. Moreover, sugarcane does not require a special type of soil (FAO). Secondly, sugarcane production increased in line with the sugar factories during the late 20th century. These factories had modern technology and the necessary research to process sugar. Introduction of private sugar firms resulted in an increased investment in the sugar industry. Thirdly, the role played by the government in developing the sugarcane industry. The favourable policy of the government with respect to sugarcane and sugar prices further incentivized low-income farmers to switch to sugarcane farming. This has resulted in an excessive supply of sugarcane in the state. Further, sugarcane is an important raw material for one of the most consumed goods in the state – Jaggery. This has led to accumulation of stocks and thereby an increase in the price of sugar.

Chapter 7

Conclusion

This thesis began with an analysis of the agricultural growth in India post-independence with special emphasis on energy consumption and carbon emissions. The study then proceeded to explore the impact of productivity and energy intensity on climate change. It also sought to investigate the role of institutions in the development of the primary sector and its impact on climate. Past literature has failed or partly succeeded in establishing a compact relationships between energy intensity, agricultural productivity and climate change. Further, the exact role of institutions in mitigating climate change is inconclusive. The thesis aimed at addressing the following two questions:

1) What is the impact of agricultural productivity on climate change?

2) Does the impact of agricultural productivity on climate change differ from region to region? If yes, why? In other words, do institutions have a role to play in mitigating climate change? How?

Before summarizing the empirical findings, an overview of the agricultural economy was presented. The study found that growth in the agricultural sector was low during the first decade after independence. However, the introduction of the 5-year plan coupled with the Green and White revolution accelerated productivity during the 1960s and 1970s. The next decade again experienced a slow growth of the sector. The new economic policy of 1991 liberalized the economy which introduced the private players into the primary sector for the first time. This policy boosted the agricultural market. Agricultural sector post 1991 reform was driven mostly by the foreign investors. However, the sector witnessed a slow growth rate largely owing to the decline in input use and farm machinery. Climate change had a significant impact too and it continues to do so. Despite the numerous steps taken by the government post-independence to ameliorate the primary sector, agriculture's share in the gross domestic product has experienced a steep decline. At the time of independence, agriculture contribute more than 60% to the country's GDP. In 2014, its share had come down to a mere 14%. Nevertheless, the energy inputs especially fertilizer and electricity consumption increased manifold. With the prioritization of agriculture in the 5-year plans, irrigation systems gained due importance. This is reflected in the steady increase of area under irrigation over the last five decades. The study also incorporated a new methodology to calculate carbon emissions arising from the energy consumption. The analysis revealed that there has been a 50% increase in the carbon di oxide gases from 1995.

This study embraced rigorous econometric analysis of the micro and macro level data obtained from various official sources to empirically prove the questions posed above. To estimate the impact of energy inputs and agricultural productivity on climate change, two approaches were identified. Firstly, the ordinary least squares regression and then the instrumental variables regression where the energy inputs were taken to be the instrument variables. The first technique of ordinary least squares regression predicted a strong positive relationship between productivity and climate change. Further, it also emphasized on the importance of carbon sinks. Forests in India comprise almost 23% of the total geographical area hence serving as a huge carbon sink. The OLS regressions showed the existence of negative relationship of forest area on the level of carbon emissions. Same proved to be the case between land use area and productivity. One of the striking features of this methodology was the introduction of climatic variables normal and excess rainfall. These variables were particularly introduced in the model so as to obtain an insight into the role of climate, herein rainfall, in affecting the level of carbon emissions. The OLS regressions show a negative impact of normal rainfall on level of CO_2 emissions while the excessive rainfall conditions were shown to have a positive influence on it. Rainfall helps a country to expand its carbon sink which in turn would lead to increase in carbon sequestration. However, this purely depends on the level of precipitation. If the rainfall is normal, then it has a positive effect on the country's carbon sink. On the other side, if there is scanty or excess rainfall, it could decrease rather than increase the carbon sink. This is because less rainfall often leads to deforestation and soil erosion. Even if we assume that the carbon emissions arising from the erosion are negligible, the decrease in quality of soil would require further use of fertilizers and other chemicals to strengthen the crop yield. The same reasoning could be applied to excessive rainfall for it leads to situations of flood and destroys crop productivity.

The second methodology incorporated was the instrumental variables regression. Unlike the multiple regression, this methodology assumed agricultural productivity to be an endogenous variable while the energy inputs and capital formation were taken as instruments. The findings from the regressions were consistent with the results of OLS regressions. However, the coefficients and standard errors proved to be better in the Instrumental Variable regressions than in the multiple regression model. In sum, the two approaches were successful in presenting satisfactory results to answer our first research question. There exists a positive relationship between agricultural productivity and climate change. This finding is further strengthened with the use of instruments which rightly state that increase in energy inputs has resulted in the increase in the level of carbon di oxide emissions.

The second aim of the thesis was to provide an insight into the role institutions can play in agricultural growth and mitigating climate change. To test this, state level data was taken. While the previous methodology relied on a multiple regression and instrumental variable approach, this empirical analysis incorporated a panel data regression since we had a balanced panel dataset on hand. Unlike the previous methodology, here precipitation statistics for the nine Indian states considered were partially available. Two very important variables were introduced. Firstly, the index of institutional quality for each state for the said period. The second variable was the interaction term – yield*institutional quality. The intuition behind the introduction of these two variables was to see the impact of institutions on mitigating climate change and in the development of the agricultural sector. The empirical findings revealed that institutional quality has a direct impact on the level of carbon emissions. However, the interaction term provides with the best inference. Presence of good (bad) institutions has a positive (negative) impact on the development of agricultural economy and a negative (positive) impact on the level of carbon emissions. Moreover, the inference from the land and agricultural productivity were similar to the results of OLS and IV-2SLS regressions.

The last chapter of the study offers an evaluative perspective on the curious case of Maharashtra. The state has experienced dramatic changes in weather over the last two decades and its agricultural economy is on the decline. This problem is further worsened by the numerous farmer suicides and migration of rural population to the urban. The case of Maharashtra presents an accurate reality check of the empirical findings. Firstly, the state's climate change crisis is a result of their poor management of agricultural practices and high energy input use. Secondly, the political institutions over the years have focussed on developing the western part of the region while being oblivious to the north east and northern parts. Thirdly, the state's love affair with sugarcane has resulted in the creation of a powerful sugar industry which virtually rules the agricultural sector. On the other hand, the negligence of the cotton farming and opening up of the economy to private players has resulted in the exploitation of cotton farmers in the market coupled with low price of cotton. This has had a severely adverse impact on the livelihoods of the cotton farmers. A majority of them have lost their lives while the others see no future in growing the cash crop. The other consequence of this has been the imbalance in the climatic cycles, of which droughts are a result.

The case of Maharashtra also throws light on the flawed agricultural policy followed by the state government for a number of years. This thesis seems to point towards this through a sophisticated investigation of the sugar and cotton industries over the last five decades. Among the many flawed policies is the policy program towards the sugarcane industry. Politician's vested interest in the industry coupled with the crop's favourable crop productivity has incentivized many farmers to turn to sugarcane. This has created a huge vacuum in the development of other crops, more importantly cotton. The repercussions of such a flawed policy are realized in the regions of Vidharbha and Marathawada where every day hundred farmers lose their lives. Besides, the effect of it is also being felt in the uneven climatic conditions which are in turn impacting the crop yield while diminishing the irrigation potential of the state. The theoretical arguments therefore suggest for an urgent restructuring of the economy and agricultural policy by the government which would reinvigorate the livelihoods of farmers and the agricultural sector. Moreover, the central government's policy needs a revision as well. India started the growth process from the services side and the results of it are still being awaited in the agricultural sector. Although the new economic reforms in 1991 have liberalized the sector leading to increased private investments in agriculture, they are simply not sufficient and efficient. For India to become globally competitive, it is imperative for the investments to pour in. Moreover, the modern technology of Indian Agriculture is still seen as backward in the western countries. Lastly, the green and white revolutions heavily relied on supply side economics and not on the demand pull. However, the case today is exactly the opposite. It is the demand pull that is the driving force. The agricultural policy in a nutshell is plate to plough and not the other way around. Therefore, the institutions have a greater role to play for it is important for the private and public authorities to collaborate with farmers and not treat them as outliers. Farmers need to attain central importance.

This thesis has stuck to a top to bottom approach beginning with macro level agricultural data and then proceeding to dissect the states' agricultural situation. However, given the complex social system prevailing in India strengthened by the politician's vested interest and crony capitalism, it is extremely difficult to exactly dissect the precise reasons for the current agricultural crises. Lately, India is taking massive strides towards a green and clean economy. This has resulted in a large number of farmers turning to organic farming. Exploring the impact of organic farming on productivity and climate should be a step forward in this research. Further, more case studies of other drought prone states such as Telengana, Madhya Pradesh, Chhattisgarh are required. It would also help to do a case-by-case study of the farming sector in the northern states of Punjab and Haryana, which seem to do exceedingly well.

This thesis offers an evaluative perspective of the various econometric methodologies conducted in understanding the role of agricultural growth and institutions towards the increase in carbon emissions. However, the study encountered a number of limitations while carrying out the empirical analysis which need to be considered. Firstly, the availability of data on important variables such as normal and excess rainfall was not readily available and hence had to be constructed. Moreover, data on carbon emissions was obtained from the official FAO database which considered both anthropogenic and chemical factors while calculating them. This thesis assumes the anthropogenic factors to be minimal in impacting climate change. Further, the thesis also overlooked many small states while carrying out the panel data regressions. It also neglected precipitation statistics due to unavailability of accurate data. Despite these limitations, the study was successful in establishing a positive relationship between productivity and the level of carbon emissions while also predicting the role of institutions in mitigating climate change. Because the institutional quality was a calculated as a weighted index of many factors, the unavailability of rainfall statistics didn't pose much of a problem since it was reflected in some form or the other through the institutional index. However, there definitely is scope for further research on this part of the study especially involving small states and more concise data.

In spite of India progressing in the agricultural sector and the country's potential in becoming a leader in the world agricultural market, it faces a number of challenges in the domestic scenario which need to be paid urgent attention to. The twelfth five year plan's initiative to integrate the agricultural sector with the world economy presents a solid case but there is scope for further improvement. In the first place the agricultural policy as whole needs revision. Farmers need to be made the centre of attention and everything has to revolve around them and not the other way around. In a way it is a déjà vu moment as India looks headed towards another agricultural revolution. However, unlike the previous ones, this revolution also needs to give climate and nature its due importance. It is time the country turned back its history pages and learned to venerate the nature while simultaneously modernizing the agricultural sector. Efficient policies and successful integration of the three core sectors would help India realize its potential of becoming a global leader in the world market while also making a statement in mitigation of climate change.

Appendices

Appendix A

Some Important Calculations

This chapter of the appendix explains briefly the methodology used in calculating three vital tools introduced in the thesis - **Carbon Dioxide Emissions** and **Standard Precipitation Index**.

A.1 Carbon Dioxide Emissions

The data on carbon dioxide emissions for India was procured from the Food and Agriculture Organisation database. However, region-wise and state level data was not available and hence had to be constructed. The methodology to construct the state-level carbon emissions are explained in the following pages. The calculations were performed on a spreadsheet.

Step-1: Three columns are constructed namely $\mathbf{A_i}$ - Nitrogen (N), $\mathbf{B_i}$ - Phosphorous (P) and $\mathbf{C_i}$ - Potash (K) ; for i = 90

Step-2: The energy invested in producing, storing and transporting fertilizers is assumed to be 60,700 KJ per kilogram of Nitrogen, 12,560 KJ per kilogram of phosphate and 6,700 KJ per kilogram of potash. The conversion rates are applied accordingly to obtain energy from N, P and K in GJ.

$$\begin{aligned} Nitrogen = D_i = [A_i]60700 \\ Phosphate = E_i = [B_i]12560 \\ Potassium = F_i = [C_i]6700 \end{aligned} \tag{A.1}$$

Step-3: The breakdown of energy in nitrogen fertilizer is 90 per cent natural gas, 5.2 per cent liquid fuels and 4.8 per cent electricity. The energy embodied in phosphate is 47.4 percent electricity, 26.7 percent liquid fuel and 25.9 percent natural gas. Potash contains 42.1 percent electricity, 31.3 percent liquid fuel and 26.7 percent natural gas

Energy from Nitrogen:

$$\begin{aligned} Natural\ Gas = G_i = [D_i]0.90 \\ Liquid\ Fuel = H_i = [D_i]0.052 \\ Electricity = I_i = [D_i]0.048 \end{aligned} \tag{A.2}$$

Energy from Phosphate:

$$\begin{aligned} Natural\ Gas = J_i = [E_i]0.259 \\ Liquid\ Fuel = K_i = [E_i]0.267 \\ Electricty = L_i = [E_i]0.474 \end{aligned} \tag{A.3}$$

Energy from Potash:

$$\begin{aligned} Natural\ Gas = M_i = [F_i]0.267 \\ Liquid\ Fuel = N_i = [F_i]0.313 \\ Electricity = O_i = [F_i]0.421 \end{aligned} \tag{A.4}$$

Step-4: The total energy from natural gas, liquid fuel and electricity is then calculated.

$$\begin{aligned} Total\ Natural\ Gas = P_i = G_i + J_i + M_i \\ Total\ Liquid\ Fuel = Q_i = H_i + K_i + N_i \\ Total\ Electricity = R_i = I_i + L_i + O_i \end{aligned} \tag{A.5}$$

Step-5: The carbondioxide emissions (in 1000 Tonnes of CO_2) arising from natural gas, liquid fuel and electricity are computed using the following formula.

$$\begin{aligned} Total\ Natural\ Gas = S_i = [P_i]0.000473543145 \\ Total\ Liquid\ Fuel = T_i = [Q_i]0.0000614250614 \\ Total\ Electricity = U_i = [R_i]0.0001944460 \end{aligned} \tag{A.6}$$

Step-6: Suppose V_i is the electricity consumption in Gigawatthours of i observations. Then, the carbondioxide emissions (in 1000 Tonnes of CO_2) arising from Electricity consumption are computed using the following formula

$$Total\ Electricity = W_i = [V_i]0.69 \tag{A.7}$$

Step-7: The total carbondioxide emissions (in 1000 Tonnes of CO_2) for each state is

$$Total\ CO_2\ emissions = X_i = S_i + T_i + U_i + W_i \tag{A.8}$$

A.2 Standard Precipitation Index

The SPI is calculated using the formula

$$\begin{aligned} Long\ term\ Average &= Average\ (Rainfall\ Series) \\ Standard\ Deviation &= StandardDeviation(Rainfall\ Series) \\ SPI &= \tfrac{Actual\ Rainfall - Long\ Term\ Average}{Standard\ Deviation} \end{aligned} \tag{A.9}$$

The spreadsheet calculation proceeds as follows:

Step-1: Consider, the rainfall series is A_i, i = no of years.

Create a new variable B = AVERAGE[Y_i]

Create another variable C = STD.DEV[Y_i]

Step-2: Take the D_i, deviation from the mean for each year i.e

$$D_i = A_i - B_i \tag{A.10}$$

Step-3: Calculate the SPI

$$SPI_i = \frac{D_i}{C_i} \tag{A.11}$$

Appendix B

Stata Output and Commands

The stata output with commands are presented in this section of the appendix. The STATA 12 software package was used to perform all the regressions and subsequent tests.

Since the output depicts the variables as entered in STATA, the short form for each variable is stated here.

OLS and IV Regressions

Dependent variable – *c*, Carbon di oxide emissions (Kg/Ha)

Exogenous Variable 1 – *al*, Agricultural Land use (Percentage of total geographical area)

Exogenous Variable 2 - *foa*, Forest Area (Percentage of total geographical area)

Exogenous Variable 3 – *Norm*, Normal Rainfall (SPI Index)

Exogenous Variable 4 – *Ext*, Extreme Rainfall (SPI Index)

Endogenous Variable – *ap*, Agricultural Productivity (Kg/Ha)

Instrumental Variable 1 – *f*, Fertilizer Consumption (Kg/Ha)

Instrumental Variable 2 – *gcfc*, Capital Formation (Rs Crore)

Instrumental Variable 3 – *el*, Electricity Consumption (KJ/Ha)

Instrumental Variable 4 – *i*, Irrigated area (% of total agricultural area)

B.1 Output of the OLS and IV-2SLS Regressions

Firstly, the Ordinary Least Squares regression was performed to establish a relationship between agricultural productivity and climate change.

Figure B.1: Stata Output of the OLS Regressions (see in 5.2)

```
. regress dc dal dfoa dap norm ext

      Source |       SS           df       MS      Number of obs   =        50
-------------+----------------------------------   F(5, 44)        =      7.73
       Model |  50897.0204         5  10179.4041   Prob > F        =    0.0000
    Residual |  57968.6702        44  1317.46978   R-squared       =    0.4675
-------------+----------------------------------   Adj R-squared   =    0.4070
       Total |  108865.691        49  2221.74879   Root MSE        =    36.297

------------------------------------------------------------------------------
          dc |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         dal |  -130.2757   37.00077    -3.52   0.001    -204.8459   -55.70554
        dfoa |  -32.06597   15.76943    -2.03   0.048    -63.84717   -.2847672
         dap |   .1017485   .0576785     1.76   0.085    -.0144948    .2179919
        norm |  -4.160117   9.346096    -0.45   0.658    -22.99594     14.6757
         ext |   25.54216   6.452896     3.96   0.000      12.5372    38.54711
       _cons |    44.6925   6.021131     7.42   0.000     32.55771     56.8273
------------------------------------------------------------------------------
```

Figure B.2: Stata Output of the Heteroskedasticity Test (see in 5.4)

```
. estat hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of dc

         chi2(1)      =     0.92
         Prob > chi2  =   0.3368
```

Figure B.3: Stata Output of the IV-2SLS Regression (see in 5.7)

```
. ivregress 2sls dc dal dfoa norm ext (dap=d2i d2el df dgc), vce(robust)

Instrumental variables (2SLS) regression          Number of obs =       49
                                                  Wald chi2(5)  =    55.55
                                                  Prob > chi2   =   0.0000
                                                  R-squared     =   0.3368
                                                  Root MSE      =   37.897
```

dc	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
dap	.2843093	.0991102	2.87	0.004	.0900569	.4785618
dal	-156.6526	41.38578	-3.79	0.000	-237.7672	-75.53795
dfoa	-34.73622	6.779462	-5.12	0.000	-48.02372	-21.44871
norm	-3.090414	8.280692	-0.37	0.709	-19.32027	13.13944
ext	24.14865	7.636376	3.16	0.002	9.181631	39.11567
_cons	37.36881	7.344354	5.09	0.000	22.97414	51.76348

```
Instrumented:  dap
Instruments:   dal dfoa norm ext d2i d2el df dgc
```

Figure B.4: Stata Output of the IV-2SLS Regressions

```
. ivregress 2sls dc dal dfoa norm ext (dap=d2i d2el df dgc d2li), vce(robust)

Instrumental variables (2SLS) regression          Number of obs =       49
                                                  Wald chi2(5)  =    53.75
                                                  Prob > chi2   =   0.0000
                                                  R-squared     =   0.2758
                                                  Root MSE      =   39.603
```

dc	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
dap	.3256237	.1055289	3.09	0.002	.1187909	.5324565
dal	-160.6248	45.61296	-3.52	0.000	-250.0245	-71.225
dfoa	-35.30222	7.115268	-4.96	0.000	-49.24789	-21.35655
norm	-2.787109	8.90775	-0.31	0.754	-20.24598	14.67176
ext	23.8956	7.906261	3.02	0.003	8.399614	39.39159
_cons	35.72559	7.998684	4.47	0.000	20.04846	51.40273

```
Instrumented:  dap
Instruments:   dal dfoa norm ext d2i d2el df dgc d2li
```

Figure B.5: Stata Output of the Sargan's Test of Overidentification (see in 5.9)

```
. estat overid

  Test of overidentifying restrictions:

  Score chi2(3)          =  6.31933  (p = 0.0971)

. estat endog

  Tests of endogeneity
  Ho: variables are exogenous

  Robust score chi2(1)          =  2.28876  (p = 0.1303)
  Robust regression F(1,42)     =  4.24846  (p = 0.0455)
```

Figure B.6: Stata Output of the Endogeneity Test (see in 5.8)

```
. estat endog

  Tests of endogeneity
  Ho: variables are exogenous

  Durbin (score) chi2(1)          =  3.39616  (p = 0.0653)
  Wu-Hausman F(1,42)              =  3.12778  (p = 0.0842)
```

Figure B.7: Stata Output of the Shea's Partial R^2 Statistic (see in 5.10)

```
. estat first

  First-stage regression summary statistics
```

Variable	R-sq.	Adjusted R-sq.	Partial R-sq.	F(4,40)	Prob > F
dap	0.2563	0.1076	0.2404	3.16421	0.0238

B.2 Output of the Panel Data Regressions

Panel Data Regressions

Dependent variable – *lc*, Carbon di oxide emissions (Kg/Ha)

Exogenous Variable 1 – *pal*, Agricultural Land use (Percentage of total geographical area)

Exogenous Variable 2 - *pf*, Forest Area (Percentage of total geographical area)

Exogenous Variable 3 – *qi*, Institutional Quality (An index from 0-1)

Exogenous Variable 4 – *yqi*, The interaction term

Endogenous Variable – *yield*, Agricultural Productivity (Kg/Ha)

Instrumental Variable 1 – *f*, Fertilizer Consumption (Kg/Ha)

Instrumental Variable 2 – *el*, Electricity Consumption (KJ/Ha)

Instrumental Variable 3 – *i*, Irrigated area (% of total agricultural area)

Figure B.8: Stata Output of the Pooled OLS Regressions (see in 5.15)

```
. ivregress 2sls lc pal pf qi yqi (yield = f i el)

Instrumental variables (2SLS) regression          Number of obs =        90
                                                   Wald chi2(5)  =     42.98
                                                   Prob > chi2   =    0.0000
                                                   R-squared     =         .
                                                   Root MSE      =    1.0229

------------------------------------------------------------------------------
          lc |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       yield |   .0081414   .0033914     2.40   0.016     .0014945    .0147884
         pal |  -.1287474   .0819254    -1.57   0.116    -.2893182    .0318234
          pf |  -.1801546   .1008654    -1.79   0.074    -.3778472    .0175379
          qi |   35.21888   16.07205     2.19   0.028     3.718234    66.71953
         yqi |  -.0172868   .0077442    -2.23   0.026    -.0324651   -.0021085
       _cons |   2.795986   4.295202     0.65   0.515    -5.622456    11.21443
------------------------------------------------------------------------------
Instrumented:  yield
Instruments:   pal pf qi yqi f i el
```

Figure B.9: Stata Output of the Panel IV Tests(see in 5.16 and 5.17)

```
. estat endog

  Tests of endogeneity
  Ho: variables are exogenous

  Durbin (score) chi2(1)          =  43.6186  (p = 0.0000)
  Wu-Hausman F(1,83)              =  78.0558  (p = 0.0000)

. estat overid

  Tests of overidentifying restrictions:

  Sargan (score) chi2(2) =  3.54403  (p = 0.1700)
  Basmann chi2(2)        =  3.36137  (p = 0.1862)
```

Figure B.10: Stata Output of the Fixed Effects Regression(see in 5.18)

```
Fixed-effects (within) IV regression          Number of obs      =        90
Group variable: statecode                     Number of groups   =         9

R-sq:  within  = 0.4731                       Obs per group: min =        10
       between = 0.3695                                      avg =      10.0
       overall = 0.2911                                      max =        10

                                              Wald chi2(5)       =  93031.46
corr(u_i, Xb)  = -0.9936                      Prob > chi2        =    0.0000

------------------------------------------------------------------------------
          lc |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       yield |   .0020386   .0011598     1.76   0.079    -.0002345    .0043117
         pal |  -.2421272   .0288642    -8.39   0.000       -.2987   -.1855544
          pf |   .3461686   .3734273     0.93   0.354    -.3857356    1.078073
          qi |    7.50346   3.374033     2.22   0.026     .8904767    14.11644
         yqi |  -.0035205   .0020605    -1.71   0.088     -.007559    .0005179
       _cons |   15.87053   5.065254     3.13   0.002     5.942813    25.79824
-------------+----------------------------------------------------------------
     sigma_u |  5.7862571
     sigma_e |  .24304754
         rho |  .99823875   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F  test that all u_i=0:     F(8,76) =    18.11              Prob > F    = 0.0000
------------------------------------------------------------------------------
Instrumented:   yield
Instruments:    pal pf qi yqi f i el
------------------------------------------------------------------------------
```

Figure B.11: Stata Output of the Random Effects Model (see in 5.19)

```
. xtivreg lc pal pf qi yqi (yield = f i el), re

G2SLS random-effects IV regression              Number of obs      =        90
Group variable: statecode                       Number of groups   =         9

R-sq:  within  = 0.0573                         Obs per group: min =        10
       between = 0.3603                                        avg =      10.0
       overall = 0.2820                                        max =        10

                                                Wald chi2(5)       =     21.93
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0005

------------------------------------------------------------------------------
          lc |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       yield |   .0091776    .003448     2.66   0.008     .0024197    .0159356
         pal |  -.2287733   .0992177    -2.31   0.021    -.4232365   -.0343102
          pf |  -.2653077   .1112152    -2.39   0.017    -.4832856   -.0473299
          qi |   35.04063   14.48761     2.42   0.016     6.645426    63.43583
         yqi |  -.0187951   .0075301    -2.50   0.013    -.0335538   -.0040363
       _cons |    10.3172   4.928416     2.09   0.036     .6576842    19.97672
-------------+----------------------------------------------------------------
     sigma_u |  .11308473
     sigma_e |  .24304754
         rho |  .17795866   (fraction of variance due to u_i)
------------------------------------------------------------------------------
Instrumented:   yield
Instruments:    pal pf qi yqi f i el
------------------------------------------------------------------------------
```

Figure B.12: Stata Output of the Hausman Test (see in 5.20)

```
Note: the rank of the differenced variance matrix (3) does not equal the number of coefficients being tested (5); be sure this is
        what you expect, or there may be problems computing the test.  Examine the output of your estimators for anything
        unexpected and possibly consider scaling your variables so that the coefficients are on a similar scale.

                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |      re           fe          Difference          S.E.
-------------+----------------------------------------------------------------
       yield |    .0091776     .0020386         .007139         .0032471
         pal |   -.2287733    -.2421272        .0133539         .0949264
          pf |   -.2653077     .3461686       -.6114763                .
          qi |    35.04063      7.50346        27.53717         14.08925
         yqi |   -.0187951    -.0035205       -.0152745         .0072427
------------------------------------------------------------------------------
                           b = consistent under Ho and Ha; obtained from xtivreg
            B = inconsistent under Ha, efficient under Ho; obtained from xtivreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        9.13
                Prob>chi2 =      0.0276
                (V_b-V_B is not positive definite)

.
```

Bibliography

Adams, R., Flemming, R., McCarl, B., & Rosenzweig, C. (1993). A reassessment of the economic effects of climate change on us agriculture. *Climatic Change*, *30*, 147–167.

Adams, R., Rosenzweig, C., Ritchie, J., Peart, R., Glyer, J., McCarl, B. A., Curry, B., & Jones, J. (1990). Global climate change and agriculture: an economic perspective. *Nature*, *345*, 219–224.

Aggarwal, A. (1981). *Indian Agriculture*. Delhi: Mittal Publications.

Aggarwal, P. (2008). Global climate change and indian agriculture: Impacts, adaptation and mitigation. *Indian Journal of Agricultural Sciences*, *78*, 911–19.

Agricultural Research Databook (2015). Indian agricultural statistics research institute. http://iasri.res.in/agridata/15data/HOME_15.HTML. Online accessed 04 June 2016.

Andersen, J. & Dale, R. (1989). Prediction of county-level yields using an energy-crop growth index. *Journal of Climate*, *2*, 48–56.

Angrist, J. & Krueger, A. (2001). Instrumental variables and the search for identification: From supply and demand to natural experiments. *Journal of Economic Perspectives*, *15*, 69–85.

Bhalla, G. & Singh, G. (2009). Economic liberalization and indian agriculture: A state-wise analysis. *Economic and Political Weekly*, *44*, 34–44.

Bhalla, G. S. (2001). *Indian Agriculture: Four Decades of Development*. New Delhi: Sage Publications.

Bordi, I., Frigio, S., Parenti, P., Speranza, A., & Sutera, A. (2001). The analysis of standard precipitation index in the mediterranean area: large scale patterns. *Annales Geophysicae*, *44*, 965–978.

Bronick, C. & Lal, R. (2005). Manuring and rotation effects on soil organic carbon concentration for different aggregate size fractions on two soils in northeastern ohio, u.s.a. *Soil and Tillage Research*, *81*, 239–252.

Bruce, J., Frome, M., Haites, E., Janzen, H., Lal, R., & Paustian, K. (1998). Carbon sequestration in soils. *Soil Water Conservation*, *54*, 382–389.

Central Electricity Authority (2012). All india electricity statistics: General review. Report, Ministry of Power, Government of India.

Chand, R. (2005). Exploring possiblities of achieving four per cent growth rate in indian agriculture. Working Paper 01/2005, National Centre for Agricultural Economics and Policy Research, New Delhi.

Chand, R. & Chauhan, S. (1999). Are disparities in indian agriculture growing? Policy Brief 8, National Centre for Agricultural Economics and Policy Research, New Delhi.

Chand, R. & Kumar, P. (2004). Determinants of capital formation and agriculture growth - some new explorations. *Economic and Political Weekly*, *25*, 5611–16.

Chand, R., Raju, S., & Paney, L. (2007). Growth crisis in agriculture: Severity and options at national and state levels. *Economic and Political Weekly*, *42*, 2528–2533.

Cline, W. (2007). Global warming and agriculture: Impact estimates by country. Technical report, Washington: Center for Global Development and Peterson Institute for International Economics.

Cline, W. (2008). Global warming and agriculture. *Finance and Development*, *45*.

Cragg, J. & Donald, S. (1993). Testing identifiability and specification in instrumental variable models. *Econometric Theory*, *9*, 222–240.

Dawin, R., Tsigas, M., Lewandrowski, J., & Raneses, A. (1995). World agricultural and climate change: Economic adaptation. Report 709, US Department of Agriculture, Economic Research Service, Washington DC.

De la Rue du Can, S., Mcneil, M., & Sathaye, J. (2009). India energy outlook: End use demand in india to 2020. Report, California: Ernest Orlando Lawrence Berkeley National Laboratory.

Department of Agriculture (2015). Government of maharashtra. http://www.mahaagri.gov.in. Online accessed 04 June 2016.

Desjardins, R., Smith, W., Grant, B., Janzen, H., Gameda, S., & Dumanski, J. (2001). Soil and crop management and the greenhouse gas budget of agrosystems in canada. in: Stott, d.e., mothar, r.h., steinhardt, g.c. (eds.). In *Selected Papers from 10th International Soil Conservation Organization Meeting on Sustaining the Global Farm, USDA-ARS National Soil Erosion Research Laboratory*, (pp. 476–480)., West Lafayette. Purdue University.

Dixon, B., Hollinger, S., P, G., & Tirupattur, V. (1994). Estimating corn yield response models to predict impacts of climate change. *Journal of Agriculture and Resource Economics*, *19*, 58–68.

Easterling III, W., Crosson, P., N.J., R., Mckenney, M., Katz, L., & Lemon, K. (1993). Agricultural impacts of and response to climate change in the missouri-iowa-nebraska-kansa (mink) region. *Climatic Change*, *24*, 23–61.

Esengun, K., Gunduz, O., & Erdal, G. (2007). Input–output energy analysis in dry apricot production of turkey. *Energy Converse Management*, *48*, 592–598.

FAO (2016). Food and agriculture organisation statistics. `http://faostat.fao.org/`. Online accessed 04 June 2016.

Glyfason, T. (2001). Natural resource, education and economic development. *European Economic Review*, *45*, 847–59.

Government of Maharashtra (2015). Economic Survey of Maharashtra, 2014-15. `https://www.maharashtra.gov.in/Site/upload/WhatsNew/Economic%20Survey%20of%20Maharashtra...pdf`. Online; accessed 04 June 2016.

Gowdy, J., Miller, J., & Kherbachi, H. (1987). Energy use in us agriculture. *Southern Journal of Agricultural Economics*, *19*, 33–41.

Green, W. (2008). *Econometric analysis, sixth edition*. Upper Saddle River, New Jersey: Prentice Hall.

Guiteras, R. (2009). The impact of climate change on indian agriculture. Report, University of Maryland.

Hao, Y., Lal, L., Owens, B., Izaurralde, R., Post, W., & Hothen, D. (2002). Effect of cropland management and slope position on soil organic carbon pool at the appalachian experimental watersheds. *Soil and Tillage Research*, *68*, 133–42.

Hatirli, S., Ozkan, B., & Fert, C. (2005). An econometric analysis of energy input-output in turkish agriculture. *Renewable and Sustainable Energy Review*, 608–623.

Jarecki, M., Lal, R., & James, R. (2005). Crop management effects on soil carbon sequestration on selected farmers' fields in northeastern ohio. *Soil and Tillage Research*, *81*, 265–276.

Kaiser, H., Riha, J., Wilks, D., Rossiter, D., & Sampath, R. (1993). A farm-level analysis of economic and agronomic impacts of gradual global warming. *American Journal of Agricultural Economics*, *75*, 387–398.

Kane, S., Reilly, J., & Tobey, J. (1992). An empirical study of the economic effects of climate change on world agriculture. *Climatic Change*, *21*, 17–35.

Kannan, E. (2011). Trends in india's agricultural growth and its determinants. *Asian Journal of Agriculture and Development*, *8*, 79–99.

Kannan, E. & Sundaram, S. (2011). Analysis of india's agricultural growth. Working Paper 276, Institute for Social and Economic Change (ISEC).

Karkacier, O., Goktolga, Z., & Cicek, A. (2005). A regression analysis of the effect of energy use in agriculture. *Energy Policy*, *34*, 3796–3800.

Kaufmann, R. & Snell, S. (1997). A biophysical model of corn yield: integrating climatic and social determinants. *American Journal of Agricultural Economics*, *79*, 178–190.

Kelejian, H. (1971). Two-stage least squares and econometric systems linear in parameters but nonlinear in the endogenous variables. *Journal of the American Statistical Association*, *66*, 373–374.

Key, N. & McBride, W. (2007). Production contracts and farm productivity: Examining the link using instrumental variables. In *2007 Annual Meeting, July 29-August 1, 2007*, Portland, Oregon. American Agricultural Economics Association.

Khan, A. & Bidabadi, F. (2004). Livestock revolution in india: Its impact and policy response. *South Asia Research*, *24*, 99–122.

K.L.Krishna & Kapila, U. (2008). *Readings in Indian Agriculture and Industry*. New Delhi: Academic Foundation.

Kumar Kavi, K. & Parikh, J. (2001). Indian agriculture and climate change sensitivity. *Global Environmental Change*, *11*, 147–154.

Lal, D. (1976). Agricultural growth, real wages and the rural poor in india (review of literature). *Economic and Political Weekly*, *11*, 47–80.

Lal, R. (1999). Soil management and restoration for c sequestration to mitigate the accelerated greenhouse effect. *Progress in Environmental Science*, *1*, 307–326.

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, *123*, 1–22.

Lal, R., Hassan, H., & Dumanski, J. (1999). *Desertification control to sequester C and mitigate the greenhouse effect', in Rosenberg, N. and Izaurralde, R. C. and Malone, E. L. (eds.) and Carbon Sequestration in Soils: Science, Monitoring, and Beyond, Proceedings of the St. Michaels Workshop*. Columbus, Ohio: Batelle Press.

Lal, R., Kimble, J., Follet, R., & Cole, C. (1998). *The potential of the US cropland to sequester carbon and mitigate the greenhouse effect*. Chelsea, MI: Ann Arbor Press.

Lal, R. & Kimble, M. (1997). Conservation tillage for carbon sequestration. *Nutrient Cycling in Agroecosystem*, *49*, 243–253.

Ledigensky, W. (1976). How green is the indian green revolution, (review of literature). *Economic and Political Weekly*, *8*, 133–144.

Lockeretz, W. (1980). *Energy Inputs for Nitrogen, Phosphorous, and Potash Fertilizers. Handbook of Energy Utilization in Agriculture, edited by D. Pimentel. Boca Raton*. Florida: CRC Press.

Long, S. (1991). Modification of the response of photosynthetic productivity to rising temperature by atmospheric co2 concentrations: Has its importance been underestimated? *Plant, Cell and Environment*, *14*, 729–739.

Lovett, R. (2002). Global warming. rain might be leading carbon sink factor. *Science*, *296*, 1787.

Mahendradev, S. (1987). Growth and instability in foodgrains production: An inter-state analysis. *Economic and Political Weekly*, *22*, 82–92.

Man-chi, W. (2013). A brief introduction to Standardized Precipitation Index (SPI). http://www.hko.gov.hk/education/edu01met/wxphe/ele_spi_e.htm. Online; accessed 04 June 2016.

Manaloor, V. (August 12-18, 2005). Co2 emissions from central canadian agriculture: Meting kyoto targets and its implications. Invited poster presentation at the 26th Conference of the International Association of Agricultural Economists, Queensland, Australia.

Manaloor, V. & Sen, C. (August 16-22, 2009). Energy inputs and co2 emissions in the major wheat growing regions in india. Invited Paper Presentation at the International Association of Agricultural Economists Conference, Beijing, China.

Mckee, T., Doesken, N., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In *Proceedings of the Eighth Conference on Applied Climatology*, (pp. 179–184)., Boston. American Meteorological Society.

Mehlum, H., Moene, K., & Torvik, R. (2006). Instituions and the resource curse. *The Economic Journal*, *116*, 1–20.

Mendelsohn, R., Nordhaus, R., & Shaw, D. (1994). The impacts of global warming on agriculture: a ricardian analysis. *American Economic Review*, *84*, 753–771.

Ministry of Agriculture (2015). Agricultural statistics at a glance. http://eands.dacnet.nic.in/Previous_AT_Glance.htm. Online accessed 04 June 2016.

Mishra, S. (2007). Trends in growth of agriculture sector of the indian economy. Working paper, Indira Gandhi Institute of Development Research, Mumbai.

Mishra, S. (2008). Risks, farmers' suicides and agrarian crisis in india: Is there a way out? *Indian Journal of Agricultural Economics*, *63*.

Mishra, S., Shroff, S., Shah, D., Deshpande, V., Kulkarni, A., Deshpande, V., & Bhatkule, P. (2006). Suicide of Farmers in Maharashtra Background Papers . http://www.spandan-india.org/cms/data/Article/A2015327162918_20.pdf. Online accessed 04 June 2016.

Nagraj, K. (2008). Farmers' suicides in india - magnitudes, trends and spatial patterns. http://www.macroscan.org/anl/mar08/pdf/Farmers_Suicides.pdf. Online accessed 04 June 2016.

Nandkarni, M. (1986). Backward crops in indian agriculture-economy of coarse cereals and pulses. *Economic and Political Weekly*, *21*.

Narayanamoorthy, A. & Kalamkar, S. (2006). Is bt cotton cultivation economically viable for indian farmers? an empirical analysis. *Economic and Political Weekly*, *51*, 2716–2724.

Naresh Kumar, M., Murthy, C., Sesha Sai, M., & Roy, P. (2009). On the use of standardized precipitation index(spi) for drought intensity assessment. *Meteorological Application*, *16*, 381–389.

Narrod, C., Pray, C., & Tiongco, M. (10-12 February 2009). Technology transfer, policies and the role of the private sector in the global poultry revolution. Discussion Paper 00841, IFPRI, Washington D.C.

NCAER (1980). *Implication for Farm Employment, Productivity and Income*. New Delhi: National Council of Advanced Economic Research.

Pant, K. (2009). Effects of agriculture on climate change: A cross country study of factors affecting carbon emissions. *Journal of Agricultural Economics and Environment*, *10*, 84–102.

Park, S., Croteau, P., Boering, K., Etheridge, D., Feretti, D., Fraser, K., Kim, K.-R., Krummel, P., Langenfelds, R., van Ommen, T., Steele, L., & Trudinger, C. (2012). Trends and seasonsal cycles in the isotopic composition of nitrous oxides since 1940. *NatGeosci*, *5*, 261–265.

Paroda, R. & Kumar, P. (2000). Food production and demand in south asia. *Agricultural Economics Research Review*, *13*, 1–24.

Pimetel, D. (1980). *Handbook of Energy utilization in Agriculture.* Florida: CRC Press.

Pingali, P. (2007). Westernization of asian diets and the transformation of food systems: Implications for research and policy. *Food Policy*, *32*, 281–298.

Planning Commission (2015). Databook on indian agriculture. http://planningcommission.nic.in/data/datatable/index.php?data=datatab. Online accessed 04 June 2016.

Prasad, C. S. (2009). *Agriculture and Rural Development in India since 1947*. New Delhi, India: New Century Publications.

Raleigh, C., Jordan, L., & Salehyan, I. (2008). Assessing the impact of climate change on migration and conflict. Technical report, World Bank.

Rao, V. (1996). Agricultural development with a human face. *Economic and Political Weekly*, *31*, 52–62.

Rosenzweig, C. & Parry, M. (1994). Potential impacts of climate change on world food supply. *Nature*, *13*, 133–138.

Roy, J., Sathaye, J., Sanstad, A., Mongia, P., & Schumacher, K. (1999). Productivity trends in india's energy intensive industries. *The Energy Journal*, *20*, 33–61.

Sachs, J. & Warner, A. (2009). Natural resource abundance and economic growth. Working Paper 5398, NBER.

Sedjo, R. & Sohngen, B. (2012). Carbon sequestration in forests and soils. *Annual Review of Resource Economics*, *4*, 126–143.

Singh, H. (1979). Population pressure and labour absorbility in agriculture and related activities : Analysis and suggestions based on field studies conducted in punjab. *Economic and Political Weekly*, *24*, 593–597.

Srinivasan, P. (2005). Impact of trade liberalization on india's oilseed and edible oil sector. Technical report, IGIDR.

StataCorp (2013). *Stata 13 Base Reference Manual*. College Station, TX: Stata Press.

Stock, J. & Yogo, M. (2005). Testing for weak instruments in linear iv regression. In *Testing for Weak Instruments in Linear IV Regression. In: Andrews DWK Identification and Inference for Econometric Models*, (pp. 80–108)., New York. Cambridge University Press.

Swain, A. & Chernoz, O. (1981). In pursuit of energy efficiency in india's agriculture: Fighting 'free power' or working with it. Working Paper 126/2012, Agence Francaise de Development, Paris, France.

Tendulkar, S. (1981). Indian development strategy: Compulsions and constraints. Working Paper 2, Delhi School of Economics.

TERI (2003). *Coping with Global Change: Vulnerability and Adaptation in Indian Agriculture*. New Delhi, India: The Energy and Resource Institute.

Torvik, R. (2001). Learning by doing and the dutch disease. *European Economic Review*, *45*, 285–306.

Torvik, R. (2009). Why do some resource-abundant countries succeed while others do not? *Oxford Review of Economic Policy*, *25*, 241–256.

Tripathi, A. & Prasad, A. (2009). Agricultural development in india since independence : A study on progress, performance and determinants. *Journal of emerging knowledge on emerging markets*, *1*, 63–92.

Uhlin, H. (1998). Why energy productivity is increasing: An i-o analysis of swedish agriculture. *Agricultural Systems*, *56*, 443–465.

Vaidyanathan, A. (2010). *Agricultural Growth in India: Role of Technology, Incentives and Institutions*. Oxford, UK: Oxford University Press.

Vandana Shiva (2013). The seeds of suicide: How monsanto destroys farming. http://www.globalresearch.ca/the-seeds-of-suicide-how-monsanto-destroys-farming/5329947. Online accessed 04 June 2016.

World Bank (2007). The little green data book. Handbook, World Bank, Washington.

World Bank (2016). World bank databank. http://data.worldbank.org/country/india. Online accessed 04 June 2016.

Wu, H. (1996). *The impact of climate change on rice yield in Taiwan. In: Mendelsohn, R., Shaw, D. (Eds.),The Economics of Pollution Control in the Asia Pacific*. Cheltenham, UK: Edward Elgar.