Climate Change, Farm Efficiency and Food Security in Punjab, Pakistan: Evidence from Household-Level Panel Data

Khush Bukhat Zahid
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Supervisor: Dr. Munir Ahmad
Joint Director, PIDE

Co-Supervisor: Dr. Muhammad Iqbal
Controller of Examination, PIDE

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CERTIFICATE

This is to certify that this thesis entitled: **"Climate Change, Farm Efficiency and Food Security in Punjab Pakistan: Evidence from Household-Level Panel Data"** submitted by Ms. Khush Bukhat Zahid is accepted in its present form by the Department of Economics, Pakistan Institute of Development Economics (PIDE), Islamabad as satisfying the requirements for partial fulfillment of the degree of **Doctor of Philosophy in Economics.**

External Examiner:

Dr. Bashir Ahmad
Director
Pakistan Center for Advanced Studies
University of Agriculture
Faisalabad

Supervisor:

Dr. Munir Ahmad
Joint Director
PIDE, Islamabad

Co-Supervisor:

Dr. Muhammad Iqbal
Controller of Examinations
PIDE, Islamabad

Head, Department of Economics:

Dr. Attiya. Y. Javid
Head
Department of Economics
PIDE, Islamabad.

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LIST OF ABBREVIATION

AEZ	Agro-Ecological Zones
ARMS	Agricultural Resource Management Survey
BBS	Bangladesh Bureau of Statistics
CGE	Computable General Equilibrium
CCA	Cost of Calories Approach
CGCM	Canadian Global Coupled Model
CMI	Crop Moisture Index
COLS	Corrected Ordinary Least Squares
DEA	Data Envelopment Analysis
DFA	Distribution Free Approach
FDH	Free Distribution Hull
FAO	Food and Agriculture Organization
FGLS	Feasible Generalized Least Squares
FSI	Food Security Index
GCM	Global Circulation Model
GEMs	General Equilibrium Models
GLS	Generalized Least Square
GDP	Gross Domestic Product
GCMs	Global Climate Models
GCOS	Global Climate Observing System
HADCM	Hadley Center Coupled Model
IPCC	Intergovernmental Panel on Climate Change
IAMs	Integrated Assessment models
IFPRI	International Food Policy Research Institute
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
IMPACT	International Model for Policy Analysis of Commodities and Trade Agricultural
IDRC	International Development Research Center

KMO	Kaiser-Meyer-Olkin
MLE	Maximum Likelihood Estimates
NPV	Net Present Value
NSW	New South Wales
NASA	National Aeronautics and Space Administration
NFDC	National Fertilizer Development Centre
OLS	Ordinary Least Square
PDSI	Palmer Drought Severity Index
PCA	Principle Component Analysis
PSLM	Social and Living Standard Measurement Survey
PERI	Punjab Economic Research Institute
PIDE	Pakistan Institute of Development Economics
PPMC	Pearson Product Moment Correlation
SFA	Stochastic Frontier Approach
TFA	Thick Frontier Approach
TFP	Total Factor Productivity
TTI	Tornqvist-Theil Index
USDA-NASS	USDA-National Agricultural Statistics Services
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

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DEDICATION

"Dedicate to my beloved parents

who are my actual source of inspiration"

ABSTRACT

There is consensus among climate scientists that damages to agriculture from climate change will be disproportionately concentrated in developing countries whose economies are largely farm based. The effects on industrial economies will understandably be modest if long term aggregate global effects are taken into account. It is projected that in another twenty or thirty years global warming will actually benefit farm production in developed countries of higher latitude where temperatures and precipitations have not reached the critically damaging level that lower latitude countries have already attained. Scientists agree that there is no doubt that developing countries are going to feel the impact of climate change on their agriculture much sooner and more severely since they lack the technological knowhow and capacity to adapt. This consensus serves a timely warning to agronomists, breeders and economic managers of the developing world, in particular of South Asia, where local agriculture's proneness to respond to climate change in the shape of falling output, floods and droughts has been evident for some years. It is time for the economic managers in Pakistan to engage them in preparing their farming communities for the challenges posted by climate change. This study attempts to add its bit to emphasizing the urgency of these forecasts.

This dissertation seeks to examine, both theoretically and empirically, the impact of climate change on farm efficiency and household food security status in Rural Punjab Pakistan. These impacts have been examined at the farm level for a representative sample. Current study explores the climate change impact by using Stochastic Production Frontier Model. We also constructed household food security index by incorporating Technical and Profit efficiency as a food security indicator. Logistic regression was used to measure the impact of socioeconomic and weather shocks on household food security status. The outcomes of this study are indicative of a strong impact of climate change on the agriculture of Punjab, Pakistan. Increase in long run normal precipitation and temperature have significant effect on agricultural production and farm profit that fluctuates in direction as well as magnitude across quarters. Agricultural inputs like fertilizer, irrigation, pesticide sprays, labor man-days and tractor hours positively contributed to farm production. The incidence of weather shocks and socioeconomic characteristics of the farming households are important factors of technical efficiency at farm level.

Results are suggestive that the mean technical efficiency score of sampled farm households stands at 0.82 indicating that the average farm production could be increased by about 18 percent by using the existing technology more efficiently in the presence of climate change. The results of profit frontier also show that climate change has a substantial impact on farm profit. The quasi fixed inputs are positively and significantly related to farm profits while input prices contribute negatively to farm profitability. The average profit efficiency score turned out to be 0.72, suggesting that the average farm, by improving their efficiency can increase the profit up to 28 percent. Food Security Index (FSI) is also constructed using different indicators like per capita cereal production, cultivated area, number of food crop grown, animal adult units owned, assets value, health expenditures, technical and profit efficiencies which represent all three aspects for food security including availability, accessibility and utilization. The overall results show that 50 percent of the households were food insecure during the study period, while the remaining 50 percent were found food secure.

We also attempted to find out the effects of socio-economic factors and climatic shocks that effect the status of household food security. The results revealed high incidence of food insecurity in the sampled districts that varies across cropping zones, cotton-wheat the least and rice-wheat crops zone the most food secure. Tenants and households headed by aged members were found more food insecure. Households having access to irrigation (from tube-well) were found more food secure than those who do not have this facility. Climatic shocks —precipitation and temperature deviations from the respective long run norms do play a significant role in determining the household food security status. The findings of present study are evocative of huge impact of climate change on the rain-fed areas of Punjab since these are water scarce areas depending on rain fall for cropping. Arguably, it is vital for the better performance of the agriculture sector to combat the impact of climate change more effectively through implementation of adaptation strategies.

Chapter 1

INTRODUCTION

Climate change is one of the biggest threats the earth faces in the form of turbulent weather. The addition of greenhouse gases in the environment is causing global warming which has emerged as an important issue in the recent past for the changes it is bringing about in climate patterns and its potential future impact on the wellbeing of the earth's inhabitants. According to the Intergovernmental Panel on Climate Change (IPCC), "…*climate change refers to a change in the state of the climate that can be identified by changes in the mean or variability of its properties and that persists for extended periods, typically decades or longer*" (Lee, Nadolnyak and Hartarska 2012:1). The increase in volume of "greenhouse gases[1]" raises the temperature of the earth and changes the precipitation pattern. The rise in earth's temperature is causing frequent occurrence of extreme weather events having devastating effects on crops' performance as well as livelihoods and food security of the people, especially the vulnerable among them (UN 2015). Achieving food security is dependent on predictable weather conditions, extent of measures taken and developed, and climate change resilient cropping system (Dilley and Boudreau 2001). Climate change affects the agricultural sector dramatically as has been seen during the past four decades. It is predicted to get even worse over the next 25 years (IPCC 2013). These outcomes will disturb everyone on the planet[2].

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[1]Pakistan's total GHGs emission in the year 2008 were 309 million tons (mt) comprising of CO2 (54%), methane (36%), nitrous oxide (9%) and one percent of other gases (TFCC 2010) which is due to emission of methane from rice paddies (Cicerone and Shetter 1981) carbon dioxide and greenhouse gases (GHG) from industrial production and burning of crop residues (Rehan and Nehdi 2005) and atmospheric brown clouds (ABC) from sea salt and mineral dust (Ramanathan,*et al.* 2007).
[2]http://thehill.com/opinion/op-ed/218562-food-security-is-in-jeopardy

Climate change is a universal phenomenon and its impact is now being felt and acknowledged globally. It is characterized by increasing average temperature, uneven precipitation and its distribution, rise in incidence of extreme events, melting glaciers and snow, and rise in the sea level. These patterns have threatened the natural ecosystems with serious consequences for the weather sensitive sectors of the economies such as agriculture, forestry, water resources and coasts. In turn people's livelihoods, food security, health, and human settlements are likely to be seriously affected. Agricultural production is directly influenced by the changes in climate and is thus the most vulnerable to vagaries of the climate and global warming (Parry, *et al*. 1999). The current trend in global warming is projected to reduce the world's overall farm productivity by as much as 3 to 16 percent by 2080 (Cline 2007). According to Mendelsohn, *et al.* (2000 and 2004), the high-latitude countries currently benefit from warming since these are cool. On other side, hot regions like low-latitude countries, are vulnerable to impacts of climate change. Therefore, the change in temperature will have negative impact on warm countries especially agriculture based economies in Southern Asia.

South Asia is extremely susceptible to the quirks of Nature mainly because of the size of its population and high prevalence of poverty. This region is home to over 20 percent of the global population, containing more than 40 percent of poor and over 45 percent of malnourished children. About 80 percent of the total affected population by natural disasters lives in this region. Over 86 percent of the total damages caused by droughts in the world are borne by the people of South Asian countries (Spijkers 2011 and UNEP 2003).

The region can experience a widespread variations in climate resulting in 2.3 to 4.5^{o} C rise in temperature by the end of the 21^{st} century that might adversely affect agricultural production (Ruosteenoja, *et al.* 2003; Christensen, *et al*. 2007 and IPCC 2007). The cereal crops in South Asia are already being grown under heat stress (Kelkar and Bhadwal 2007) and thus with the expected rise in temperature[3] the yields could decline up to 30 percent by the end of this century (IPCC 2007). In the region most of the countries are low income and agriculture-based economies where droughts and floods are becoming weather norms. Consequently, the supplies and prices of agricultural commodities fluctuate quite a lot affecting the general wellbeing of the small farmers and the low income consumers. They devote a large chunk of their income on essential necessities, food in particular. For them, food security is already a daily concern which will become a major issue, and would add to their sufferings in the days to come if the current trend in climate change continues.

Available studies are supportive of the evidence that changes in climatic conditions have threatened food and livelihood security of a large chunk of the world population in general and of developing countries in particular, since economies of the latter largely depend on the agriculture sector (Finger and Schmidt 2007; Nelson, *et al*. 2009; Crosson, 1997 and Schipper, 2004). Furthermore, developing countries lack the capacity to adapt to climate changes (Eriksen, *et al.* 2008). Therefore, climate change can wreak havoc in these countries. Though there are several other factors which contribute to agricultural productivity such as technological advancements, policy environment and optimal utilization of physical inputs (Cabas, *et al.* 2010), but these factors cannot contribute effectively to the performance of agriculture unless the

[3]The global mean atmospheric temperature has risen by 0.6˚C in twentieth century and expected rise in the range of 1.1-2.9˚C in the twenty-first century under low emission of greenhouse gases, and by 2.4˚C to 6.4˚C increase under high emission (Islam *et al.,* 2011), depending upon the scenario of future innovations (Aggarwal and Sivakumar, 2011).

climatic and weather[4] conditions are favorable for plant growth and animal rearing. Even the day to day variations in weather conditions constrain the agricultural practices resulting in low productivity (White 1985). Any abnormal variation in the climate or weather influences the factors of production resulting in wide range of losses in proportion to the severity of climatic shocks. Various studies have empirically estimated the impact of climate change on agriculture and shown diverse results, the empirical literature in general concludes that agricultural production is affected both negatively and positively.[5] In short these impacts change over time which depends on the magnitude and rate of the climate change (Steffen, *et al*. 2004; O'Brien and Leichenko 2003 and Leichenko and O'Brien 2006).

Pakistan is not an exception and is the most vulnerable[6] country in the South Asian region because of its overwhelming dependence on agriculture which is sustained by the Indus Basin River System. The farm lands of Pakistan are mostly categorized as arid to semiarid, where rainfall is not enough to grow agricultural crops adequately (Waraich and Mohsin 2005). About 11 percent of the area receives 250-500 mm annual rainfall, one half of the area has an annual rainfall of 150-250 mm and about one-third receives less than 150 mm annually. The country on the whole is classified as arid (Iqbal, *et al*. 2008) with the added susceptibility of the sector to the climatic condition. The Task Force on Climate Change (TFCC) indicated that the temperature increases in Pakistan are predicted to be higher than the worldwide average resulting in significant reduction in agricultural production (TFCC 2010).

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[4] "*The distinction between weather and climate is a measure of time. Weather is conditions of the atmosphere prevailing over a short period of time while climate is over a relatively long periods of time" (NASA).*

[5]The studies like Adams, *et al.* 1988; Cline 1996; Parry, *et al.*2004; Lobell, et al. 2007; and Cabas, *et al.*2010 among others found negative relation, while some others found positive association between increase in temperature and agricultural production such as Gbetibouo and Hassan 2005.

[6]Maplecroft Climate Change Vulnerability Index (CCVI) ranked Pakistan 24th in the list of countries most vulnerable to climate change.

The intensity and frequency of extreme climate events has increased during the recent decades causing production losses worth billions of dollars. From droughts and floods to snow storms, Pakistan is increasingly battered by extreme weather events. The longest drought from 1997 to 2001 and floods during 2010 and 2014 are recent examples of this calamitous behavior.

The province of Punjab is agriculturally the most productive part of Pakistan having total land of over 205 thousand square kilometers. Its cultivated area is approximately 57.2 percent of the total cultivated area of the country (Punjab Development Statistics 2009). Punjab holds a unique position among provinces of Pakistan as the major contributor in agricultural production (Malik, Aftab and Sultana 1994). It shares about 26 percent of the total land area in the country and accounts for over 55 percent of the country's total population. The continuous population growth in Punjab and in rest of the country is posing a serious threat in the shape of food, fiber and fodder shortages. This is largely due to low level of technological development and inability to adapt to the changing climate. There is a severe dearth of resources which stands in the way of meeting the challenges posed by climate change. It calls for uplifting the living standard of the people of rural areas by reducing poverty and income disparity. It would require revitalization of the rural economy by boosting the agricultural sector. Increases in agricultural productivity will not only contribute to farm income, but will also stimulate the progress of the rural non-agricultural sector, which has significant role in reducing rural insecurity and instability. Towards this end, increase in cereal production is a key determinant of the poor farmer's good life and the wider issue of his food security. This cannot be ensured without creating and sustaining an efficient farm production level (USAID

2009) which in its ultimate turn would once again depend on and demand some stability in the climatic behavior (Nasir and Hyder 1987).

The climate of Punjab is semi-arid with hot summers and cold winters. The summer mean daily temperature registers around 38^{0}C while the winter mean ranges from 3–6^{0} C. The mean monthly rainfall is approximately 200 mm in summer and 36–50 mm in winter (FAO 2006). The crop production in the province heavily depends on farming under semi-arid conditions which makes it highly vulnerable to climate change (TFCC 2010).

Agriculture is a pivotal sector in agrarian economies. The growing concern is that the potential of Green Revolution (GR) is over and now the agriculture productivity has either stagnated or growth has slowed down[7] (Byerlee and Siddiq 1994; Ali 1995 and Khan 1998). There is no remarkable improvement in sustaining the output performance and thus stability in food security condition in Asia in general and South Asia in particular (Lal 2011). On the other hand, the susceptibility of agriculture sector to climate change has gained general consensus worldwide (Cline 2007), while the old GR technologies do not withstand the changing patterns of climate. Agriculture growth rate still remained considerably low in recent years[8]. The

[7] Khan (1998) estimated annual growth in TFP during green revolution period (1966-1976) which was 3.45 and decreased to 2.2 percent during 1977-1986 and 0.75 percent between 1987-90.Byerlee and Siddiq (1994) reported that wheat production only increase by 1.4 percent per annum during 1977-1990 as compared to 5.1 percent during 1966-1976.The decline in productivity and crop yield raises serious concern about the sustainability of agriculture in Pakistan.

[8] Annual growth during FY 2015 was 2.53 percent that decreased to -0.19 percent during FY 2016. The growth of crops declined by 6.25 percent. Wheat and sugarcane production increased only by 1.58 percent and 4.22 percent, respectively as compared to last year. The growth of subsector of crops included important crops, other crops and cotton ginning also remained negative. Important crops witnessed growth of -7.18 percent per annum during FY 2016 as compared to -0.52 percent during FY 2015. That accounts large decline in cotton production (-27.83 percent), rice production (-2.74 percent) and maize production (-0.35 percent). Other crops witnessed a decline of 0.31 percent during FY 2016 against positive growth of 3.09 percent during FY 2015 due to decline in the production of pulses, fruits and oilseeds posting growth of -12.49 percent, -2.48 percent and -9.56 percent, respectively. Cotton ginning remained negative posted a growth rate of -21.26 percent (Economic Survey of Pakistan 2016).

agriculture sector growth is contingent on favorable weather condition. There is a strong relationship between agriculture and climate -temperature, precipitation, floods and other aspects of weather that finally affect economic performance including agriculture production, commodity prices and finally economic growth. The emerging challenges of national food security and climate change have shifted the policy focus globally towards the development of agriculture sector during past few years.

Climatic variables such as precipitation, temperature, humidity and others affect production through different stages of plant growth. Climate change affects the timing and application of inputs resulting in inefficiency and low yields. An unfavorable climate influences productivity of factor inputs causing production losses and affecting profit efficiency. Therefore, agricultural production can be increased by efficient utilization of inputs (Ahmad, *et al.* 2002) and adapting to changing climate which result in improvement in efficiency of the farmer and his household food security status (Robert 2009).

The changing climatic patterns and their impacts on agricultural productivity attracted the attention of the researchers to quantify the impacts of climate change and to suggest possible remedial measures (e.g. Adams, *et al.* 1999; Rosenzweig, *et al.* 2001; Olesen and Bindi 2002; Izaurralde, *et al*. 2003; Parry, *et al.* 2004; Fischer, *et al.* 2005; Schmidhuber and Tubiello 2007; Nelson, *et al.* 2009 and Codjoe and Owusu 2011 among many). However, most of the previous work ignored the role of management practices/farmers efficiency while quantifying the impacts of climate change. The present study intends to fill this gap.

The empirical literature shows that farmers using same level of technology and facing the same environment significantly differ in realized output per unit of land (Binswanger and Von Braun 1991; Brada and King 1993 and Foster and Rosenzweig 1995). This suggests that there are certain other variables that also affect output in addition to physical inputs and the climatic factors. Therefore, it requires examining the climate change impacts on agriculture by accommodating this missing link—the management factors on the part of the farmers. To disentangle the impacts of climate change and weather shocks from the management efficiency of the farmers (Technical Efficiency), the stochastic frontier analysis technique is used.

Growth rate in agriculture sector is twice more effective in reducing poverty as compared to growth rates in other sectors of the economy (FAO 2014).The adverse impacts of climatic changes on the performance of agriculture especially that on the production of food crops influence the food security situation of the country at the national and household levels. There are three important components embedded in definition of food security[9]. The leading one deals with the availability of food in a given country or household through any means. The second concerns the accessibility of food by people or households. The third component relates to the nutritional value of the food consumed. Climate change is therefore both directly and indirectly related to household food security status. Any change in temperature and precipitation pattern affects production efficiency through its effect on crop directly and increases the yield gap[10]. Climate change in the form of episodic events like floods and droughts that leave large tracts of arable land unfit for cultivation and cause huge crop losses that threaten not only household food security but also impact the agricultural economy as a whole (Anita and Aggarwal 2007). Combating food insecurity has become a major

[9] "*When all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 2007).*
[10] "*The ratio of actual output to maximum attainable output is called yield gap"*

task in developing countries and much attention has been given to this issue since the food crisis of 1972-73 (Ahmed and Farooq 2010).

The present study uses stochastic frontier approach as a primary method of analysis. Farm specific inputs and climate are explicitly incorporated in the model. The study also investigates the effects of various farmer characteristics, such as age, education, tenurial status and farm size on the farmer's efficiency. '*Technical Inefficiency Effect Model'* includes the function in which technical efficiency is made explicitly dependent on farm specific characteristics in line with Battese and Coelli (1995). The efficiency scores generated from the estimated models are included along with other components in construction of Food Security Index (FSI). The other variables used in construction of FSI are per capita cereal production, health expenditure, variety of food crops planted, present value of farm assets, livestock owned and cultivated area. Climatic factors along with other socio-economic variables are considered as the determinants of FSI—while investigating the impact of climatic variables on household food security status overtime.

1.1 Scope of the Study

Climate change is a worldwide issue and its effects must be addressed urgently because of frequent food insecurity phases and the substandard livelihoods of the poorest people in developing countries. There are very few comprehensive studies to evaluate the influence of climate change in developing countries (IPCC 2013). Historical data reveals that at the end of the last century the average temperature of the earth increased by 0.6 °C and is going to increase further by 1.4 ºC to 5.8 ºC through the current century (IPCC 2013). Having said this, it is important to investigate the impact of climatic variables on agriculture and suggest policy recommendations which are based on the findings of the studies that are contextual and aligned with the development preferences of the country.

High rates of population growth with incidence of food insecurity and scarcity make South Asia most susceptible to impact of climate change. Historical data points to occurrence of hazardous events in South Asia due to expected increases in temperature. The rise in temperature and variability in precipitation will negatively affect crop production alongside their indirect impacts in the form of water shortages, change in soil moisture status as well as incidence of pests and diseases (Sivakumar and Stefanski 2011).

Pakistan is located in an arid and semi-arid region of South Asia and rainfall is not sufficient to grow agricultural crops. About 68 percent of the area lies under annual rainfall of 250 mm whereas about 24 percent of its area gets yearly rainfall between 250-500 mm. This leaves only 8 percent of geographical area where the annual rainfall exceeds 500 mm. Thus, water is one of the most limiting constraints for agricultural production in Pakistan (Alam 2000). Agriculture being one of the major contributors to the national GDP makes Pakistan's economy highly vulnerable to climate change. It is reported that due to its high susceptibility to variability in monsoon rainfall, agriculture in Pakistan remains under serious threat making the country vulnerable in respect of food security (TFCC 2010).

Small land holders who constitute the majority of the farming community also have low financial and technical capacity to adapt to the effects of climate variability and change (Morton 2007). There is no comprehensive research available in the country about the influence of climate change on agriculture production and food security. There are snags in the availability, accuracy and reliability of data in the country. In order to address these statistical weaknesses it would be helpful to downscale global research to local settings.

1.2 Objectives of the Study

The general goal of the study is to measure the impact of climate change on agricultural production, farm profits, and household level food security. The more specific objectives of this research are to:

- assess the effect of climate change on farm production and technical efficiency;
- analyze the impact of climate change on farm profits and profit efficiency;
- estimate the relationship between household food security and climate change as well as farm level efficiencies; and
- suggest recommendations based on the findings of this study.

1.3 Research Contribution

This study will make the following contribution in the empirical literature:

- *Empirical analysis*: this would involve the study of impact of climatic factors along with socio-economic variables on farmers' production efficiency. The available studies relating the subject have used national level data or district level data for the analysis due to non-availability of household level data such as Javed, *et al.* (2014),Siddiqui, *et al.* (2012) and Ahmad, *et al.* (2014) among many. The study in hand would thus be a first attempt to study the impact of climate change at the household level in Pakistan. It uses farm survey data collected by Punjab Economic Research Institute (PERI) and matches this data with climatic data of respective households based on village level latitude and longitude.
- The existing studies on technical efficiency of Pakistan's agriculture do not give a clear picture of farmers' production efficiency because they use farm level data on a single crop, mostly wheat and rice, and few categories of inputs while climate change is not factored in the analysis (Battese, *et al.* 1993 and Ali, Parikh and

Shah 1996). The present study extends this analysis to all the crops together with all measureable inputs and includes climatic variables. Its outcomes are therefore more reliable.

- Available efficiency studies have mostly been focusing on farm and farm operators' attributes to evaluate the sources of measured efficiencies. Against this backdrop, the present study, assesses the impact of weather shocks (climatic deviation) in addition to these variables, extends the previous work in coverage and scope.
- Moreover the analysis is extended by analyzing the effect of climate change on profit efficiency. This area had previously been ignored by researchers, who focused merely on farm productivity. Indeed, profit efficiency is a broader concept since it incorporates both input and output oriented efficiencies.
- This study links technical inefficiency and profit efficiency in crop production directly with food security status of rural households. Technical and profit efficiencies scores generated from stochastic frontier models are used as indicators respectively for availability and accessibility components in constructing food security index. On the basis of this index, households are classified into two groups namely food secure and insecure.
- This dissertation also assesses the influence of climate change on household food security status using the Logit Model Approach. Socioeconomic and climatic variables are used as determinants to assess their impact on household food security status.
- The study suggests policy options to improve farm level technical and profit efficiencies and hence enhance household food security. This would further be

instrumental for addressing the farm level impacts while designing the national climate change policy.

1.4 Methodology and Data

The study covers three aspects of the farm households. First, we evaluate the impact of climate change on farm efficiency through using stochastic production frontier. Second, farm efficiency is also measured using profit frontier efficiency of the sample households. This examination is based on the assumption that if production inefficiency exists then the farmer is not operating on maximum profit frontier but below it and hence the profit efficiency is less than one. Both production and profit efficiencies are measured by stochastic frontier approach with the help of R-Frontier software package. Third, we assess the impact of climate change directly on the food security status. FSI is used as a dependent variable and various socioeconomic and climatic variables are used as explanatory variables—and the Logit model is applied to estimate the relationships.

The study uses data from the PERI farm households' surveys for three years (2005-08) and Meteorological department's monthly climatic data for 1961-2010 employing 20 years' moving averages for climatic variables for the survey period.

1.5 Organization of the Study

Explaining the background of the study, delineating the major objectives, highlighting the research contribution and the structure of the thesis in the first chapter, the remaining study is organized into 5 chapters. Chapter 2 provides a detailed survey of the literature on efficiency and food security from different countries of the world including Pakistan, historical review of methodologies used in different studies, and definition and concept of efficiency. Various approaches used for efficiency measurement using panel data have also been discussed in this chapter.

The studies dealing with impact of climate change on efficiency and food security are also discussed in the same chapter. Chapter 3 explains the methodology of the study, which includes empirical models for estimating efficiency and food security. Different functional forms used for model specification in various studies are discussed. The empirical models and particular functional forms used for the analysis are also explained. Chapter 4 provides information about data sources and explains the construction of various variables. The analytical procedures of estimating profit and production efficiencies and household food security status are also discussed.

Chapter 5 presents the results and discussion of technical and profit efficiencies and their relationship. It also discusses the results of the model dealing with climate change and food security status. The last Chapter 6 provides conclusions and suggests some policy recommendations based on the findings of the study. This chapter also pinpoints the limitations of the study.

Chapter 2

SURVEY OF LITERATURE

2.1 Introduction

This chapter elaborates on the relationships between climate change, agricultural production, farm efficiency and food security through appraising the relevant literature both theoretical and empirical. A large body of literature is available on these issues. However, the literature reviewed in this chapter has been chosen for its relevance to the proposed research issues.

The rest of the chapter is divided into 9 sections. Section 2.2 deals with climate change and agriculture. Section 2.3 discusses the choice of methodology specific to the study. Section 2.4 discusses the production theory. Section 2.5 reviews the frontier methodology literature. Section 2.6 provides the discussion on efficiency literature in agriculture and discusses different approaches used in efficiency measurement. Section 2.7 deals with climate efficiency framework, profit maximization theory under climate change and profit frontier. Section 2.8 examines food security and its linkage with climate change. Section 2.9 reviews the empirical literature using the above concepts and Section 2.10 concludes the chapter.

2.2 Climate Change and Agriculture

All economic sectors are susceptible to the global warming to some degree, but agriculture is the most vulnerable sector to its adverse effects (Cline 2007). This is so because agriculture activity is highly dependent on climate such as temperature and rainfall, a fixed season—sowing and harvesting, evapo-transpiration, water availability, and concentration of CO2, pests and diseases infestation and land suitability. Changes in these resources affect plant and animal livings (Alexandrov and Hoogenboom 2000). For all these reasons, climate change effects represent a '*challenge*' that agriculture sector has to face, not in the distant future, but NOW.

Many studies[11] have been conducted to evaluate the climate change impact on agricultural sector in various parts of the world. The literature mostly attempts to quantify its potential effects on crop yields, land values and farm revenues. These include Production Function Model, Ricardian Model, Agronomic-Economic Model, Agro-Ecological Zone Model, Integrated Assessment Model and the Computable General Equilibrium Model (CGE) (Mendelsohn, *et al*. 1994; and Downes and Pemberton 2009).

To estimate the climate change impact on agricultural production, one of the most widely used technique is the Production Function Approach. An empirical model linking soil, water, economical inputs and climate for specific crops has been used to estimate yield's sensitivity to climate. The climate change impact is evaluated by considering yield variations under different circumstances. The economic dimension is of secondary importance when production function approach is adopted and therefore, it considered in a partial and simplified way (Bosello and Zhang 2005). Amongst the critique on this approach, is its intrinsic inability to handle adaptive capacity of the farmers against climate change. This deficiency can lead to overstating the yield reduction (Mendelsohn, *et al.* 1994). Ramirez, et al. (2013) however argues that despite its weakness of not capturing the adaptation strategies followed by the farmers in response to climate change, the use of production function approach has two major advantages: firstly, it provides the results in terms of the relationship between yields and climatic variables; and secondly, this relationship is directly

[11] Easterling, *et al*. 1993; Peiris, *et al*. 1996; Brown and Rosenberg 1999; Craigon, *et al*. 2002; Chang 2002; Jones and Thornton 2003; Deschenes and Greenstone 2006; Elbakidze 2006; Simar and Wilson 2007; Schlenker and Roberts 2006; and Shrestha, *et al*. 2013 among many.

estimated since the model is based on observed variables, while controlling the results for physical and biological variables (containing fertilizers, pesticides, etc.). Furthermore, these models produce significant information for larger model frameworks that consider the economy wide sectors.

The Ricardian Model is a cross-sectional analysis to examine the influence of economic, climatic, and environmental factors on land value or farm revenue (Mendelsohn, Nordhaus and Shaw 1994). In countries with a large proportion of small farmers and undeveloped land markets farm revenue is used for analysis in place of land value (Jain 2007). The Ricardian approach is based on correlating agricultural practices and land values with climatic variables. If the land is optimally utilized in the production of agricultural commodity then the annual net profit from the production will be equal to observed land rent. The influence of climate change is evaluated in terms of farm outcome variations, comparing the current situation to simulated scenarios (Mendelsohn and Nordhaus 1999). They are easy to estimate by considering spatial correlations and through panel data analysis (Salvo, *et al*. 2013). The main characteristic of the Ricardian Model is that it does not adopt the 'dumb-farmer' hypothesis[12]. It treats adaptation to climate change as a 'black box'. (Salvo, *et al*. 2013). As such, it implicitly considers farmer adaptation strategies without the need to implement them as explicit exploratory variables (Mendelsohn and Dinar 2009).There are also some other limitations in the Ricardian approach for instance, it assumes a Partial Equilibrium Model and does not consider relationships with other sectors (Salvo, *et al*. 2013 and Massetti and Mendelsohn 2011). It also assumes the output and input prices constancy as a result of global change in climate that undervalues damages and overvalues benefits by holding prices constant and does not

[12] The hypothesis is that farmers and other actors would not react to a change in climate.

measure adjustment costs (Cline 1996). Also, another drawback of the Ricardian Model is the assumption that farmers can observe all changes in climate and will adjust to them and it will be relatively cheap. Nevertheless, research has shown that farmers are slow to make adjustment to climate change and therefore, their adjustment would be costly (Quiggin and Horowitz 1999 and Adams 1999). Moreover, it does not incorporate variables, such as unobservable farmer and farm characteristics, which could lead to biased estimation of results. Its main focus is on economic dimension of agriculture and little on other dimensions such as social and biological (Seo and Mendelsohn 2008).There are some land value studies that argue that net present value (NPV) of revenue is not a good indicator of land values. Clark, *et al.* (1993) suggested that application of NPV is not suitable to determine land prices and land values. Just and Miranowski (1993) and Falk (1991) also reject NPV model to decide farm land value.

Agro-economic Models used simulation technique to evaluate the relationship between crop productivity and environmental factors. The results are retrieved from simulation models and then used in economic models with the help of specific computer software in order to predict its impact. The basic notion of Agronomic Models is to consider only controlled changes in crop physiology. It restrict the analysis to change in production of a specific crop, simulate and match crop productivity for diverse climatic conditions (Eitzinger, *et al*. 2003 and Torriani, *et al*. 2007). Future climate scenarios are usually simulated using a General Circulation Model (GCM). It belongs to computer-built generation of models based on mathematical dynamic equations. There are certain limits in operating GCM that depends on the capacity of computing program. Notably, results accuracy depends on the precision of responses and the process uploaded in the analysis (Barron 1995).It endorses the so-called 'dumb-farmer' hypothesis that excludes the aspects of plausible adoption strategies by the farmers for coping with the effects of climate change (Rosenzweig, *et al.* 1993 and Reilly, *et al.* 1994). Main focus of these models is on ecological and biological outcomes of climate change on soil and crops, owing to this reason these models are 'agriculture oriented'. Original models however do not endogenise farmer behavior and ignore economic dimensions. Agronomic-Simulation Models have few limitations such as uncertainty about functional forms and ignoring the linkages with other sectors in the economy (Salvo, *et al*. 2013).

To reflect the economic dimensions these models can be coupled with other models. In the traditional formulation, farmer's management practice is kept fixed and adaptation is not considered. Some researchers are of the opinion that controlled experiment could be ruined by incorporating exogenous adaptation into the plant simulation models (Mendelsohn 2009) and can cause inaccurate estimates of farm benefits of climate change (Reinsborough 2003).

In the Agro-ecological Zone Model (AEZ) yields of crops located in different agro-ecological zones[13] are measured under specific climatic conditions. Different methodologies such as the Ricardian analysis (Seo and Mendelsohn 2008) and Multinomial Logit Model (Mendelsohn 2008) are used with the (AEZ) framework to examine the consequence of climate change on agricultural production.

Researchers developed Integrated Assessment Models (IAMs) based on the combined use of General Circulation Model (GCM), crop growing, soil usage, and economic models (Prinn, *et al*. 1999 and Kainuma and Matsuoka 2003). To generate useful information for policymakers the IAMs describe the causes and effects of

[13] On the basis of similar characteristics such as climate, soil, and constraints to crop production, environmental impact and potential productivity, land is divided into smaller units called Agro-ecological zones (Fischer 2006).

climate change by simultaneous analysis of all agricultural aspects and knowledge from various academic disciplines into a single framework (Dinar and Mendelsohn 2011). These models are very complex and difficult to estimate. The accuracy of the model depends on the handling of complicated interaction between different elements. Due to unavailability of the required data, in several cases the interaction between land use and agriculture with climate can be treated only partially (Salvo, *et al.* 2013).

The General Equilibrium Models (GEMs) inspect the economy as a complex system of inter-reliant components such as industry, institutions, factors of production and international economic conditions (Darwin, *et al.* 1995; Bosello and Zhang 2005 and Calzadilla, *et al*. 2010). GEMs have the advantage to capture changes throughout the economy and provide information on the effects of climate change on different regions and on other economic sectors. Climate is taken as exogenous and its effects on different endogenous variables like commodity prices, output, employment and welfare are determined.

Advantages of these models include the inter-sectoral linkages and endogenous market prices, but they are highly aggregated and also represented by a single firm (Bosello and Zhang 2005). Various integrated models of climate change have been developed (Nordhaus 1994, 2007, 2008; Darwin, *et al*. 1995; Calzadilla, *et al*. 2010 and Trnka, *et al*. 2010 and 2011). These models are difficult to estimate the aggregates of different sectors that differ in their economic and spatial characteristics. The factors of production, including irrigation water are considered in these model as differential inputs (Mendelsohn and Dinar 2009).

2.3 Choice of Methodology

To estimate the effects on agriculture produced by climate change numerous methodological issues are involved such as types and availability of data used for analysis, adopted functional forms, various policy and geographical variables used, complexity of their relation and inter-spatial and inter-temporal heterogeneities (Salvo, *et al*. 2013). Empirical literature employs different methods of empirical estimation that depend on the nature and scope of the particular study. The present study employs a production function approach because of some obvious reasons. Firstly, countries like Pakistan have underdeveloped property markets making the land prices difficult to ascertain that makes the original Ricardian Model inapplicable in its true spirit (Jain 2007) and it also requires farmers to have a perception about climate change and the adaptive strategies they have undertaken (Mendelsohn and Reinsborough 2007). Ricardian Model does not incorporate some variables like unobservable farmer characteristics as it can lead to biased results (Salvo, *et al*. 2013). Secondly, a panel-data technique was selected for this study based on data availability, which lacks data on climate change perception and the farmers' relevant adaptive strategies. The production function approach is more suitable to study climate change impact on the individual farm level by incorporating biological and social aspects of agricultural production with large units of cross-sectional data set dealing with farm productivity. Thirdly, other models like the Agronomic-economic Model were deemed as not the most suitable models because they require daily crop management and input data (Eitzinger, *et al*. 2003 and Torriani, *et al*. 2007). Neither daily input nor daily crop management data were available and also the non-availability of daily data on temperature over the full period of study did not permit us to use Agronomic-simulation Model. There is also uncertainty about the functional form of the model. The Agro-ecological Zones model was inapplicable because of high data demands in order to conduct studies at farm level (Fischer, *et al.* 2006) but we modified the production function by incorporating dummies for crop zones comprising different sample districts. The Integrated Impact Assessment Models are supposed to be inapplicable because they deal with economy-wide focus that combines the macro economy with structural details that permits analysis of the impact at the sector or household level (Prinn, *et al.* 1999 and Kainuma and Matsuoka 2003). In the present study, farm efficiency and food security is measured by considering household crop production as a principal channel of impact. The production function approach, specifically the stochastic production frontier approach therefore seems to be the best fitted.

The profit function analysis is another approach which characterizes the production structure and technology (Kumbhakar and Lovell 2000). This approach produces "profit efficiency" measures, which can be defined as the ability of a farm to achieve the highest possible profit given the prices of outputs and inputs and the levels of fixed inputs (Ali and Flinn 1989). The objective of the producer is to maximize profit either by maximizing output by using a given level of inputs or by minimizing the use of inputs to produce a same level of output. A production frontier represents the maximum possible amount of output that can be produced with a given level of inputs. Therefore, technical efficiency is measured first by using stochastic production frontier, and then we consider the profit frontier for measuring the profit efficiency in the presence of exogenous climatic variables i.e. temperature and rainfall.

The profit function approach assumes perfect markets. Its applications therefore to analyze performance of agriculture in developing countries' has been criticized by Junankar (1980) because of non-existence of perfect markets and so the farmers face different prices. However, agricultural markets in Pakistan are fairly developed and are integrated reasonably well (Qureshi 1974; Kurosaki 1996; Ghafoor and Aslam 2012). Therefore, we prefer application of profit frontier to achieve the objectives of the present study. The other advantages of using the profit frontier approach are as follows. Firstly, since the inefficiencies come from output side due to technical mismanagement or factors related to physical reduction in output quantity and thus technical and allocative efficiencies can be best understood through profit function that how the optimal use of inputs affects profitability of the farm. Secondly, the profit function captures both the input and output sides because it is measured as revenue minus cost—that helps make optimal decisions. Higher revenues offset the increase in cost to produce goods and services (Kumbhakar and Lovell 2000). Thirdly, the profit function provides the way to estimate output efficiency by capturing the revenue side of the firm (Berger, *et al*. 1993).

Next, there is a need to understand how the impacts of climatic conditions—climate change and weather shocks, are captured in stochastic frontier approach, since they modify farmers' behavior and influence their production decisions. Climate change is a long-term phenomenon and the farmers usually have fair knowledge of local historical climatic conditions and take into consideration while deciding on the output-input mix (Demir and Mahmud 2002; Kumar 2009; Hughes, *et al.* 2011; Pereda and Alves 2012; Pereda, *et al.*2013; Dell, *et al*. 2013and Key and Sneeringer 2014). Therefore, the local level climatic conditions cannot be treated as random and it is reasonable to consider long-term climate conditions (average) as key input in production since they directly influence crop development (Ramirez, et al. (2013); Pereda and Alves 2012; Pereda, et al.2013 and Key and Sneeringer 2014).

The traditional production function studies have also been criticized on the ground that they estimate only the short-run impact in panel data specification (Dell, *et al*. 2013). In comparison, climate change is a long-run phenomenon which takes time in years to have impact on crop production (IPCC 2007).Therefore, in order to examine the impact of climate change on crop yields more effectively, twenty (20) years moving averages of temperature and precipitation have been introduced in the production function (Segerson and Dixon 1999; Chang 2002 and Cabas, *et al.* 2010).

The other feature of the climatic conditions is year-to-year variations in climate which are called weather shocks/extreme events—the short-run weather conditions including droughts, floods, frosts, hailstorms, sudden rise and fall in temperature, unexpected rains etc. Once the farmers decided what and how much to produce incorporating the average climatic conditions of the locality (long-term), the extreme weather events occurring during the crop growing and harvesting season which are not known to farmers in advance might trigger production losses by moving away from production frontier or deviating from the profit frontier influencing the technical efficiency (Demir and Mahmud 2002; Kumar 2009; Pereda and Alves 2012; and Key and Sneeringer 2014). The researchers usually assume that environmental conditions are captured by the two sided random error in stochastic frontiers (Demir and Mahmud (2002).Depending upon the management abilities, skills, physical and financial resources, the producers can also respond to expected short-term changes in weather[14]. For example, stop watering crop in response to expected rainfall—avoid over watering, covering plants/watering crops or using other means in case of frost and vice versa. Therefore, the weather anomalies—deviations from the historical trends, are considered as one of the foremost determinants of the inefficiency model

[14]Exogenous variables that characterize the environment in which production takes place, affects the capability of a manager to convert inputs into outputs (Coelli *et al.* (2005, p. 281).

(Demir and Mahmud (2002)[15] and their exclusion from frontier equation might lead to biased estimates (Sherlund, Barret and Adesina 2002; and Mukherjee, *et al.* 2013).

This dissertation is aimed to address the effects of both long and short term climate change in Pakistan agriculture. Following Segerson and Dixon (1999), Chang (2002) and Cabas, *et al.* 2010), this study considers the 20 years moving average of climatic indicators[16]—temperature and precipitation, to capture the long-term effects and are taken as direct input for crop production. The short-term weather conditions are thought to be constraining factors in realizing the technology potential optimal. To capture short-term meteorological phenomena that move production away from the production frontier, deviations of current climatic indicators from historical trends are considered as determinants of technical efficiency.

2.4 Production Theory

Production is defined as "the process of producing output using a given set of inputs or the process of transforming inputs into output in the form of either inputs for another production process or final consumer goods" (Beattie, Bruce and Griffin 1980:153-155). A production function is defined as "the maximum output attainable by given level of inputs and technology" (Beattie and Taylor 1985:3-6). It describes

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[15]There are mixed opinions regarding inclusion of weather or climatic variables in the inefficiency effects. Key and Sneeringer (2014) argue that farmers respond to both short term and long term changes in weather and make investments in durable assets based on long run or expectations about future weather (i.e. the climate). They also respond, in a particular year, to deviations from the expected long run climate change that are called weather shocks and make adjustments. Therefore, inclusion of both long run and deviations from long run climate in inefficiency effects model as separate regressors allows us to isolate the effects of expected climate on efficiency. Other studies which incorporated climatic variables in inefficiency model include Pereda and Alves (2012), Igliori (2005) and Imori (2012)—the latter two studies are cited in Pereda and Alves (2012).

[16] Empirical models with both 20 and 30 years moving averages of climate variables were estimated. However, in our case 20 years moving average better captured the impact of climate change, performed well in terms of yielding magnitudes and significance of the estimated parameters of climatic variables.

the technical relationship that transform inputs into output, and can be represented in terms of an input-output relationship as (Debertin 1986:14-15).

$Y = f(x) \dots \dots$ (2.1)

where Y is output and x is a vector of inputs.The inputs can be classified into two main categories, variable and fixed factors. The quantity of variable inputs used may change during a specified production period. The fixed factors do not change during this period.The classification of inputs leads to the concept of long-run and short-run production processes.The former refers to a production situation where all inputs are considered variable.The latter refers to a situation where at least one input is fixed.This can be expressed as:

$Y = f(x_1/x_2) \dots \dots$(2.2)

Where x_1 and x_2 are vectors of variable and fixed inputs, respectively.

The production frontier reflects "the maximum output that can be produced from a given level of inputs or alternatively it represents the minimum input used to produce a given level of output" (Fare 1988). It represents a present state of technology in a specific industry.

A classic production function is based on the following assumptions (Doll and Orazem 1984:21).

- Monoperiodicity: that implies that the production in a given year is independent of production in the previous and succeeding years.
- Homogeneity: it implies that the inputs and outputs of the farm are homogeneous.
- The production function is a single and at least twice differentiable function.
- The function shows no uncertainty related to physical production, transformation process and input and output prices.

- There is no boundary to input availability.
- The firm is usually characterized as profit maximizing or cost minimizing subject to technical and economic constraints and forces.

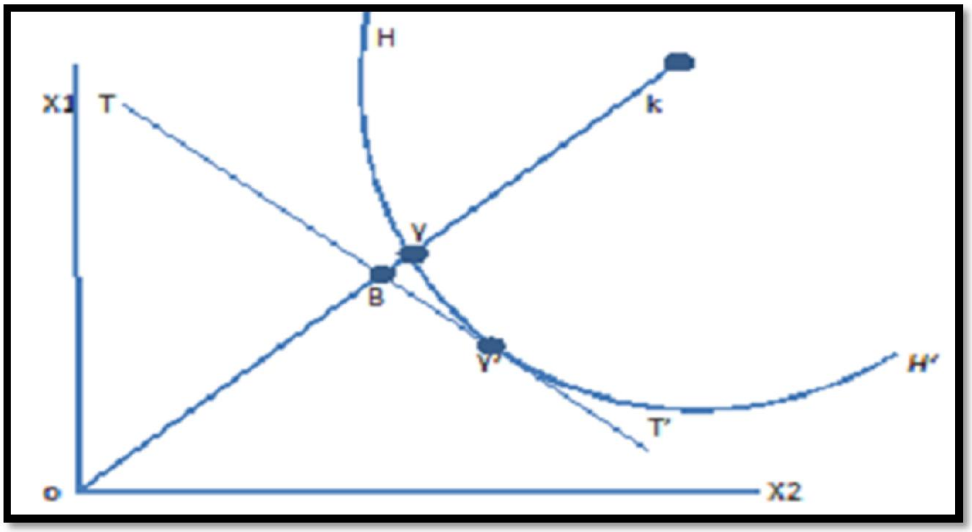
2.5 Definition of Efficiency

Koopmans (1951) defined efficiency as "*a producer is considered technically efficient if and only if, it is impossible to produce more of any output without producing less of some other output or using more of some inputs*." Efficiency measures the economic or productive performance of a firm, farm or any organization. It indicates whether it is effective to produce output as much as attainable from a given level of inputs. Farrell (1957) introduced the concept of relative efficiency, which is a deviation from the efficient firm in a typical group within the sample. He explained the concept of efficiency using an efficient unit isoquant. Following Debreu (1951) and Farrel (1957) decomposed technical efficiency into two components, which is known as 'Farrell and Debreu decomposition of technical efficiency'. An output and input vector is considered to be technically efficient, if it does not require any change in output quantity or change in inputs and is also not feasible for further increase in output. They decompose the efficiency into allocative and technical efficiency. Allocative efficiency is also known as input oriented efficiency while technical efficiency is concerned more with output. An allocatively efficient firm is one which uses input and output vector in an optimal way. In other words, firms use their factor inputs more efficiently to produce a given level of output, given the input prices and technology. In technical efficiency, "the firm produces optimal level of output by using the given quantity of inputs".

By using input/output oriented approaches the concept of efficiency can be described more easily. The input-oriented measure is based on the question "how much can input quantities be proportionally decreased without changing the production of output quantities?" The output-oriented approach deals with the question "how much can the output be increased without increasing the amount of input use by utilizing the given inputs more efficiently?" (Coelli, *et al.* 1998).

Input oriented approach for the measurement of efficiency is illustrated in the figure below. Firm faces the factor input price and tries to minimize expenditures to produce certain output level Y'. TT' is the factor input price line. Two factors of production say X_1 and X_2 are assumed here. This price ratio line shows that any combination of the two inputs can be chosen to produce given level of output with same expenditures. The isoquant, HH', shows the combination of factor inputs to produce optimal level of output. All points on this isoquant reflect technically efficient production.The firm attains the equilibrium at point Y', it is technically and allocatively feasible level of output. At Y', price line is tangent with isoquant curve. In other words, at equilibrium point price ratio is equal to the marginal rate of technical substitution. A line connecting the origin to the point K, crosses the isoquant at the point Y. If the firm produces the same output by using factor inputs at point K, then given level of output is produced with inputs which are out of range of the firm.

Figure 2.1: Input-Oriented Technical Efficiency



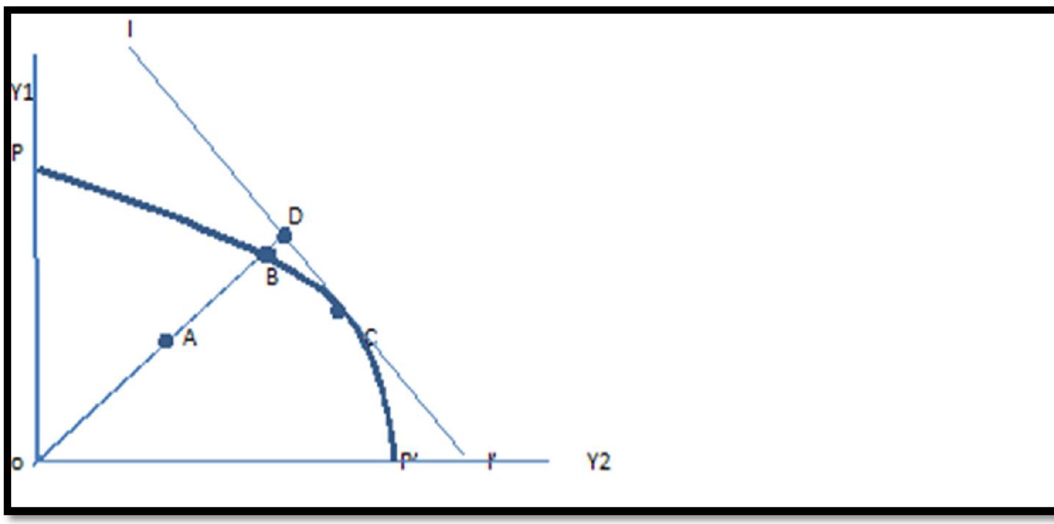
Source:Reproduced from Kumbhakar and Lovell (2000)

Two types of inefficiencies will arise; if the firm cuts down its expenditure to Y, then it will produce same output with small amount of factor inputs. Technical inefficiency can be measured by ratio $(\frac{Oy}{Ok})$, hence the point Y is not an optimum point because of the reason that the distance BY can be reduced without any drop in output and allocative inefficiency is measured as $(\frac{OB}{OY})$. Product of technical efficiency and allocative efficiency is called Economic efficiency and can be written as $\mathrm{EE} = (\mathrm{OY}/\mathrm{OK})(\mathrm{OB}/\mathrm{OY}) = (\frac{\mathrm{OB}}{\mathrm{OK}})$.

The output oriented measures emphasis on the changes in output of the firm that may be attained when using the same level of inputs.The isorevenue line and production possibility curves describe economic efficiency in Figure 2.2. Two outputs Y_1 and Y_2 are assumed here with PP' production possibilty curve (PPC). The PPC shows different combinations of outputs (Y_1 and Y_2) that can be produced using a given level of inputs (X).The PPC reflects a technically efficient practice. An isorevenue line II' is drawn tangential to the PPC at point C and a ray from origin

OB meets it at point D. If firm produces output at point C, then it is an equilibrium point where marginal revenue is equal to price ratio. A line from origin to point D, after joining point A crosses the production possibility curve at point B. If firm produces output inside the production possibility frontier at point ‘A’ then it is a technically and allocatively inefficient level of output. If firm produces the output at point ‘B’, then firm will obtain higher revenues than at point ‘A’. The obserbed firm uses the same quantity of inputs as that used by the efficient firm. A is the level of output for an observed firm whereas the output level of an efficient firm is at B.

Figure 2.2: Output-Oriented Technical Efficiency



Source:Reproduced from Kumbhakar and Lovell (2000)

The technical inefficiency of the observed firm is define as ($\frac{OA}{OB}$), but for the given input use the best proportional combination of the outputs is at point C. So output produced at point B is not optimal. Because income may be increased (BD) without any addition to input use. Allocative inefficiency is define as AE = ($\frac{OB}{OD}$). Economic efficiency is the product of technical and allocative efficiency can be written as EE = $\left(\frac{OA}{OB}\right)\left(\frac{OB}{OD}\right) = (\frac{OA}{OD})$.

According to Fare and Lovell (1978) if there is constant return to scale then output and input oriented technical efficiency measures will be equal, but in case of increasing and decreasing return to scale they differ in dimensions. There are many reasons for which measuring efficiency is important but according to Lovell (1993) the two principal reasons are: " *success units indicators, performance measured by which production units are evaluated, secondly only by measuring efficiency and productivity, splitting their effects from the effects of the production environment, we can explore hypotheses concerning the source of efficiency or productivity differentials*."

2.6 Approaches Used for Efficiency Measurement

Most commonly used approaches for the measurement of efficiency are non-parametric and parametric. The parametric approach is different from the non-parametric approach due to the presence of white noise error term and also because of some assumptions of the efficiency term. The non-parametric approach does not measure the parameters of selected variables, while parametric does. The parametric approach comprises of Stochastic Frontier Approach (SFA), Distribution Free Approach (DFA) and Thick Frontier Approach (TFA) whereas the non-parametric approach is comprised of the Free Distribution Hull Approach (FDH) and Data Envelopment Analysis (DEA). If the parametric approach is used for efficiency estimation, then the specific functional form is chosen for model specification. In the non-parametric approach, the functional form of the model is not assumed (Aigner, *et al*. 1977 and Meusen, *et al.* 1977).

These approaches have widely been applied in measuring productive efficiencies at farm level and the concept of frontier is consistent with the fundamental economic theory of optimization behaviour (Porcelli 2009). The economic unit operating on the frontier is considered to be efficient pursuing technical and behavioral objectives and any deviation from the frontier is interpretted as a measure of inefficiency (Drysdale, Kalirajan and Zhao 1995). The evalaution of information regarding the distance of an economic unit from the frontier and about the relative efficiency has many policy implications (Bauer 1990).

2.6.1. Non-Parametric Approach

The nonparametric approach for efficiency estimation is not based on any frontier model and does not have any parameter to estimate. Farrell (1957) proposed to use the convex hull approach for the measurement of the efficiency frontier. This is a piecewise linear programming technique and was applied by Shephard (1970) and Afriat (1972) for the estimation of the frontier. In 1978, Charnes, Cooper and Rhodes (CCR) proposed and applied Data Envelopment Analysis (DEA) for efficiency measurement. This method was originally developed for nonprofit making institutions and organizations. The reason is that accounting of profit measures was difficult to calculate at that time. DEA is an approach used by researchers and academicians to estimate the efficiency of the firms or decision making units in terms of optimal utilization of inputs to produce the given amount of output when production function is not known to the firm (Green 2011). However, DEA does not separate white noise term from the data. It is a linear programming methodology to envelope the data by constructing piece-wise frontier under constant and variable return to scale conditions (Forsund, Lovell and Schmidt 1980). The major drawback of DEA is that it does not assume white noise term and all outliers in the data which leads to biased results of efficiency. DEA assigns the upper bound to the efficiency; therefore, comparison of efficiency among the firms is very difficult (Molyneux, *et al*. 1996). Consequently, the present study would apply the parametric approach to evaluate the farm efficiency.

2.6.2 Parametric Approach

Parametric methods are mostly categorized into deterministic frontier and stochastic frontier. In the of deterministic production frontier the deviation of the observed output from the frontier output is represented by technical inefficiency without considering the effect of statistical noise based on the implicit assumptions that all random variations are attributed as technical inefficiency (Battese, Malik and Gill 1996). It ignores the possibility that performance of the firm might be affected by factors which are not under the control of the operator. Observation and measurement errors in data are an additional source of variation in the frontier (Battese and Coelli 1993). This resulted in the development of the stochastic production frontier.

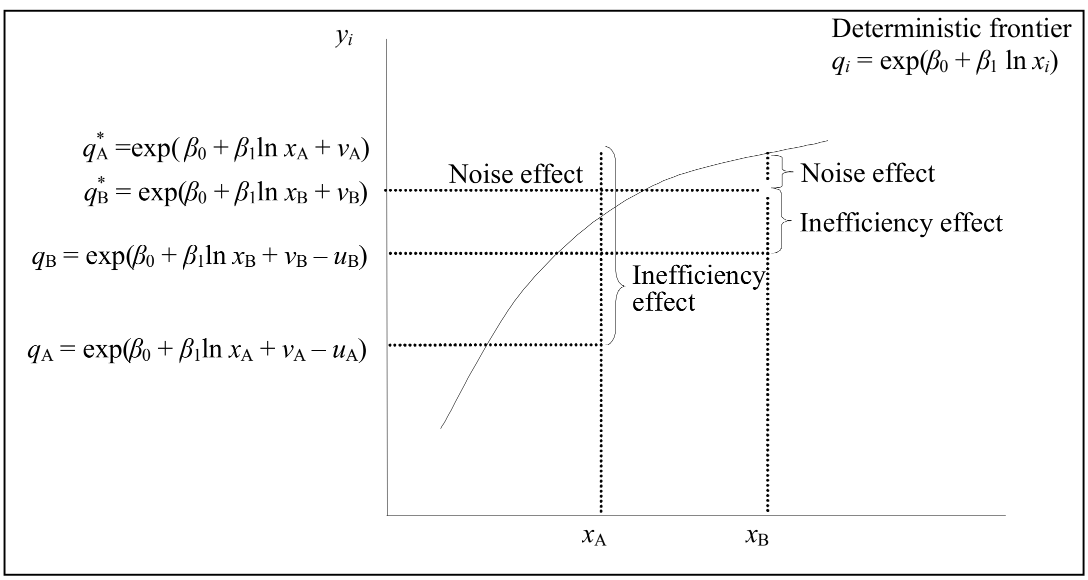
The Stochastic Frontier Approach (SFA) was developed independently by Aigner, Lovel and Schimdt (1977) and Meeusen and Van den Broeck (1977). The first application on farm level data was done by Battese and Corra (1997). The SFA approach allows technical inefficiency in cost, revenue and profit functions. They separate out the technical inefficiency from the white noise. The random error term in this case is composed of two terms and can be expressed as

$$\varepsilon_i = v_i - u_i.$$

Where v_i is a two sided white noise component which has normal distribution i.e. $v_i \sim iid(0, \delta_v^2)$ with constant variance and zero mean, and u_i is technical inefficiency term which has either half normal distribution, gamma distribution exponential distribution or truncated normal distribution and $u_i \geq 0$. It is assumed that both inefficiency and white noise terms are independent of explanatory variables (Green 2008).

The basic properties of SFA have been explained through Figure 2.3. The deterministic model draws the efficient frontier, but stochastic shocks and other random variations cause deviation from the deterministic frontier (Battese 1992). The two firms A and B use x_A and x_B levels of inputs and produce output levels of q_A and q_B, respectively. Firm B is more efficient than firm A because it lies near the efficient frontier. The frontier output may be above or below the deterministic frontier depending upon the stochastic errors, either positive or negative, respectively and the distance between the frontier outputs q^* and observed output q represents the technical inefficiency (Coelli 1998).

Figure 2.3: The Stochastic Production Frontier Model



Source: Reproduced from Battese (1992)

Berger and Humphrey (1991) has introduced another approach called Thick Frontier Approach (TFA) and Distribution Free Approach (DFA) was proposed by Berger, *et al.* (1993). Each approach has its own merits and demerits. For example, TFA has certain shortcomings such as ‘it is less structured than SFA’, and thus it disseminates less information being sensitive to the assumptions made for error and inefficiency terms (Berger, *et al*., 1993). The TFA discards half of the data resulting in enormous loss of degrees of freedom. Efficiency calculating by using TFA is not for each of the producer or firm as it estimates the function for firms that lie in upper and lower average quartile. It estimates efficiency for the hypothetical average producer in the upper quartile region relative to the hypothetical average producer in the lower quartile region (Green 1995). The results are based on average quartile not very useful for policy makers and managers (Kumbhakar and Lovell 2000).

If panel data is available for efficiency analysis, then the restrictive assumptions need not to be imposed on inefficiency term (Schimdt and Sickless 1984). Berger, *et al*. (1993) introduces Distribution Free Approach for the estimation of inefficiency of the firms using panel data. DFA is like the application of GLS on random effects model. In this approach, composite error term is decomposed into white noise term and inefficiency term as $\hat{\varepsilon}_i = \hat{v}_i - \hat{u}_i$. It is assumed that random error tends to average zero over the time period. Remaining residual depicts the inefficiency of the firms (Schimdt and Sickle 1984 and Kumbhakar and Lovell 2003:176-179). If panel data is available, then separate regression is run for each firm and residuals are saved for each firm, and then the average of residuals of each firm is calculated.

$$\hat{\varepsilon}_i = \frac{1}{T}\hat{\varepsilon}_{it} = \hat{u}_i \dots\dots (2.3)$$

In case of cost efficiency estimation, minimum value of the average residual is calculated. To calculate efficiency, difference between average residual of each firm and minimum residual is taken. Then exponential is applied on the difference. Cost efficiency is calculated as

$$\hat{C}_{eff} = \exp\{-(\hat{\varepsilon}_i - \hat{\varepsilon}_{min})\} \ldots \ldots (2.4)$$

The maximum value of average of residuals are calculated in case of profit efficiency as

$$\hat{\pi}_{eff} = \exp\{-(\hat{\varepsilon}_i - \hat{\varepsilon}_{max})\} \ldots \ldots (2.5)$$

Berger (1993) argued that the random error v_{it} does not cancel out completely for each firm; it contains the element of luck as well as inefficiency. If the residuals have extreme values, then it is truncated at q^{th} quintile and $(1\text{-}q)^{th}$ quintiles.

Also, DFA has some limitations, like it assumes time invariant efficiency. It does not impose any assumption on efficiency term, in other words, it relaxes the assumption of SFA in the panel data. Secondly, it requires a separate regression run for each firm and allows the firms to change production technology over the time period (Green 2011).

Following the above review of the approaches, it may be concluded that the selection of a particular approach depends on many criteria such as data availability, objective of the study and its relative advantages over the other methods used in a given situations. From the viewpoint of the present study a parametric approach Stochastic Frontier Approach (SFA) is important and more relevant because it has a particular advantage over other approaches specifically if the objective is the measurement of agriculture sector efficiency (Battese and Corra 1997).

In deterministic estimation, technical inefficiency includes all deviations from the average function. Nonetheless, the deviations can be disentangled in the Stochastic Frontier Approach. By separating the technical inefficiency term from the noise, one can easily find out the factors affecting the firm/farm efficiency. Its other benefits include the possibility of conducting conventional statistical tests, accommodating specific functional form based on the technology as well as the distribution assumption for the inefficiency term. Therefore, the stochastic frontier estimation technique is considered to be the most suitable instrument to evaluate the performance of a production unit/farm (Ozkan, *et al.* 2009). The literature also heights the fact that the stochastic frontier technique shows strong association between the farm inefficiency and farmer- and farm-specific characteristics, environment and other socio-economic factors influencing the production process.

2.7 Climate Change and Efficiency Framework

The overall productivity growth rate of agriculture in Pakistan has been historically slow; this trend has attracted considerable research attention in recent times to identify potential contributing factors of the slowdown, and to explore possible remedial measures (Economic Survey of Pakistan 2011). Only a few studies pay attention to the impact of climatic factors in measuring agricultural productivity and efficiency and suggest remedial measures and strategies (Olesen and Bindi 2002). However, the climatic effects on productivity and efficiency were not fully reflected in the research. For this reason, the production function estimation technique was chosen, specifically the Stochastic Frontier Analysis. These techniques use individual farm-level survey and climatic data adequately in examining their impact on farm productivity. It is necessary to discuss the Maximum Likelihood estimates of the stochastic frontier production function and the technical inefficiency determinants. The stochastic frontier production function has been extensively used to measure the technical efficiency of agriculture production in recent years (Sharma and leung 2000; Chiang, *et al.* 2004 and Yusuf and Malomo 2007).

2.7.1 Profit Maximization and Climate Change

In agriculture sector, a large number of climatic and non-climatic variables affect crops production. We may assume a production function for agriculture which is strictly quasi concave, continuously differentiable with a positive derivative (Lafrance and Pope 2010). The function links climatic and non- climatic inputs into output of a farm at a certain location. A general production function is written as

$$Y_i = f(X_i^c, X_i^{nc}) \quad \text{i} = 1 \ldots. \text{N} \quad \ldots \ldots (2.6)$$

$$X_i^c = (X_{i1}^c, X_{i2}^c, \ldots \ldots, X_{iK}^c), \quad k = 1 \ldots \ldots .. K$$

$$X_i^{nc} = (X_{i1}^{nc}, X_{i2}^{nc,}, \ldots \ldots, X_{iJ}^{nc}), j = 1 \ldots \ldots J$$

In this set of equations, Y_i denotes output from crops production at the i[th] farm, $X_i^{nc}$are the vectors of J inputs used to produce Y_i and X_i^c defines a vector of K exogenous climatic factors. Climatic variables include farm level temperature and precipitation and non-climatic variables include fertilizers, seeds, irrigation and other farm inputs. This production function is non-negative in output and concave in inputs as more of inputs are used eventually the extra output generated by the extra input begins to decrease (Beattie and Taylor 1985, pp: 9-16). In production function, a single output is function of one or more inputs.[17] Maximum profit is attainable from production activities, given the prices of inputs used and the prices of outputs produced using a given level of technology (Kumbhakar and Lovell 2000). The profit function is written as

$$\pi_i = f(P_i, W_i) \ldots \ldots . \text{i} = 1 \ldots \text{N} \qquad \ldots \ldots (2.7)$$

where π_i is profit, W_i is vector of input prices and P_i is vector of output prices and $f(.)$ is a general functional form. To estimate the relationship between the profit and input and output prices, it is essential to specify the functional form of the

[17] The cost is a function of input prices and output quantity, while revenue is function of quantities of inputs and output prices.

function. The profit function is characterized as increasing in *P*, decreasing in W and homogenous of degree one in input and output prices, continuous and convex in *P* and W.

Literature shows that an adverse climatic condition increases the cost of production through several mechanisms such as delivery and effectiveness of irrigation (Kundzewicz, *et al*. 2007) and land degradation (Sivakumar and Ndiang 2007) that results in excess use of inputs by the farmers in order to increase production. Factors such as climate change which effects the agricultural productivity influence the price of agricultural land (Hanif, *et al.* 2010). Not only that, there is growing evidence that climate variability influences the distribution and incidence of crop pests and diseases (Gregory, *et al*. 2009).

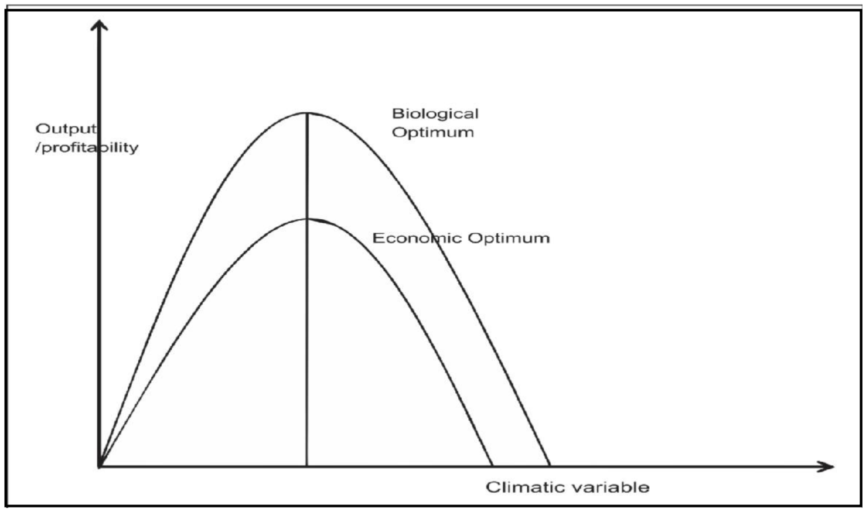
Assuming that the objective function of farmer is to maximize the profit, a cost function is required to be introduced here to solve the problem of profit maximization for a farmer—which is a function of input prices and output quantity. Climate change as input variable is needed to be introduced in order to solve the profit maximization problem in the presence of climate change phenomena. Given the set of factor prices, climate and output—W_j , X_i^c and Y_i. The cost function can be written as

$$\mathrm{C_i} = f(Y_i, W, X_i^c)\ \mathrm{i} = 1,2, \dots .\mathrm{N} \quad \dots \dots (2.8)$$

$$W = (W_1, W_2, \dots \dots W_J)$$

where $\mathrm{C_i}$ is cost of production at the i[th] farm, and W_i is a vector of factor prices. Y_i is aggregate output. In Figure 2.4, we assume that up to a certain level $\frac{\partial C}{\partial X^C} < 0$, derivative of cost function w.r.t climate change, decreases which means that change in cost of production is negatively influenced by change in climate condition but after a certain limit, climate change exhibits positive impact on cost of production (hence, $\frac{\partial C}{\partial X^C} > 0$). The same condition holds for Y if a climatic variable increases to a certain limit, then $\frac{\partial Y}{\partial X^C} > 0$ — the derivative of production function, increases correspondingly with rise in climatic variables i.e. temperature and precipitation. After a certain limit the production may decline, i.e. $\frac{\partial Y}{\partial X^C} < 0$ (Amiraslany 2010).

Figure 2.4: Profit Maximization and Climate Change



Source: Reproduced from Amiraslany (2010)

By using the above concepts of cost function $C_i(.)$ at given market prices, climatic factors and production function $Y_i(.)$ at the given level of inputs, it is possible to measure the economic effects of climate change on farm profitability. Profit maximization problem in reduced form at a given location can be specified as

$$Max_{y_i}(\pi_i) = [P_i Y_i - C_i(Y_i, W, X_i^c)] \quad i = 1 \ldots.. N \ldots \ldots (2.9)$$

The profit, π_i, for ith farm is defined as farm revenue less variable costs. Where P is the price of output, Y represents the output; W is vector of input prices and X_i^c is the vector of climatic variable. Under perfect competition at the optimum point all profits in excess of normal returns to all factors are driven to zero. The first order condition of profit maximization function (Equation 2.9) with respect to output can be expressed as

$$\frac{\partial \pi_i}{\partial Y_i} = 0$$

This would yield the following equation

$$P_i - C_i'(Y_i, w, X_i^c) = 0$$

Rearranging the terms in above equation would yield Equation 2.10

$$P_i = C_i'(Y_i, w, X_i^c) \dots \dots (2.10)$$

Equation 2.10 shows that price is equal to marginal cost. It results in optimal output valueY_i^*. The Y_i^* is the optimal level of output that can be produced on the frontier curve involving the optimum use of given inputs. After plugging Y^* back in Equation 2.9, the optimal profit function is written as

$$\pi_i^* = P_i Y_i^* - C_i^*(Y_i^*, w, X_i^c) \dots \dots (2.11)$$

If we relax the assumption of constant market prices and assume that prices are the function of climatic changes and production function is a function of climate variations and output price, it can be rewritten as

$$\pi_i^* = [P_i(X_i^c) Y_i^*(P_i, X_i^c) - \mathrm{C_i}(Y_i^*, w, X_i^c)\ ]$$

It implicitly implies farmers' behavior and short term and long term decision they make on production and input employment are guided by the market prices of inputs and output which in turn depend on climatic phenomena which can be expressed in reduced form.

$$\pi_i^* = \pi_i^*[P_i(X_i^c), Y_i^*(X_i^c), W(X_i^c), X_i^c] \dots \dots (2.12)$$

Thus net profit is a function of variation in climatic variable only (Amiraslany 2010) and can be written as

$$\pi_i^* = f(X_i^c) \dots \dots (2.13)$$

Equation 2.12 captures both direct and indirect impacts of climate change on farm profits. Indirect impact is through change in prices and direct is through its impact on production. However, we are interested in measuring the impact of climate change directly on farm profitability and productivity rather than indirectly through its impact on change in prices. In addition to this we also consider the weather shocks through which it is not possible for the farmer to operate on efficient frontier curve in order to maximize its profit. However, this analytical framework only works when we expect prices are constant and producers are price taker in all the market and there is no influence of prices on farmer production decision (Molua and Lambi 2007). Farmer's production decision depends only on long term phenomena of climate change that is considered as given (Demir and Mahmud 2002). If this assumption is violated the estimates of the functions are meaningless from the economic point of view.

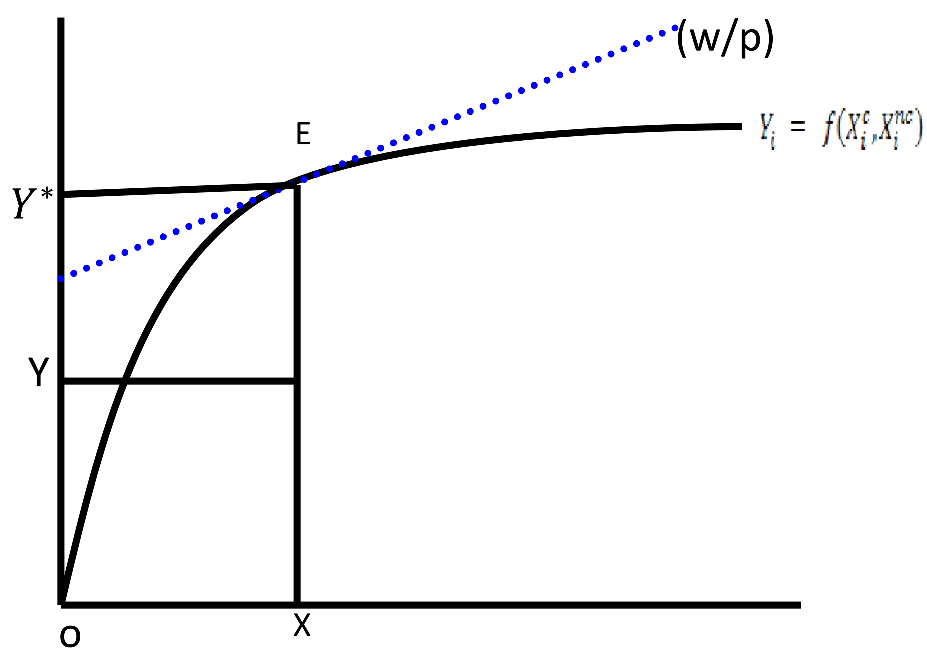
2.7.2 Profit Efficiency Frontier

Efficiency is measured using production, cost, revenue and profit frontiers.[18] The production frontier reflects " the maximum output that can be produced from a given level of inputs", a technically efficient farmer is one who produces the maximum output from a given level of inputs (Fare 1988). A cost efficient producer is one who produces the given level of output at a minimum cost and a revenue efficient producer is one who produces the maximum achievable quantity of output with given inputs. The farmer is profit efficient, if it maximizes the allocative and technical efficiencies (Kumbhakar and Lovell 2000). A profit maximizing firm/farm either minimizes cost of producing a given level of output or maximizes its output given the input prices. We assume that given the output and input prices, the producer seeks maximum profit by using the given level of inputs to produce the maximum quantity of output. As profit is the difference between total revenues and total cost, the farmer

[18]The concept of frontier is applied to production, cost, revenue and profit frontiers. The difference lies in restricting the observations to below the production, revenue and profit frontiers, and above in case of cost frontier. These concepts are extensively reviewed in various studies including Schmidt (1985 and 1986), Lovell and Schmidt (1988), Bauer (1990), Lovell (1993), Bravo-Ureta and Pinherio (1993), Green (1995), Cornwell and Schmidt and Sickles (1990) and Bravo-Ureta, *et al.* (2007) among others.

will attempt to produce maximum output at the minimum cost. To evaluate the performance of the farm, we used the profit frontier in the presence of climate change. Profit efficiency is provided by the ratio of observed profit to maximum profit. It requires both allocative and technical efficiencies. This can be described with the help of Figure 2.5.

Figure 2.5: Profit Efficiency Frontier



Source: Reproduced from Kumbhakar and Lovell 2000

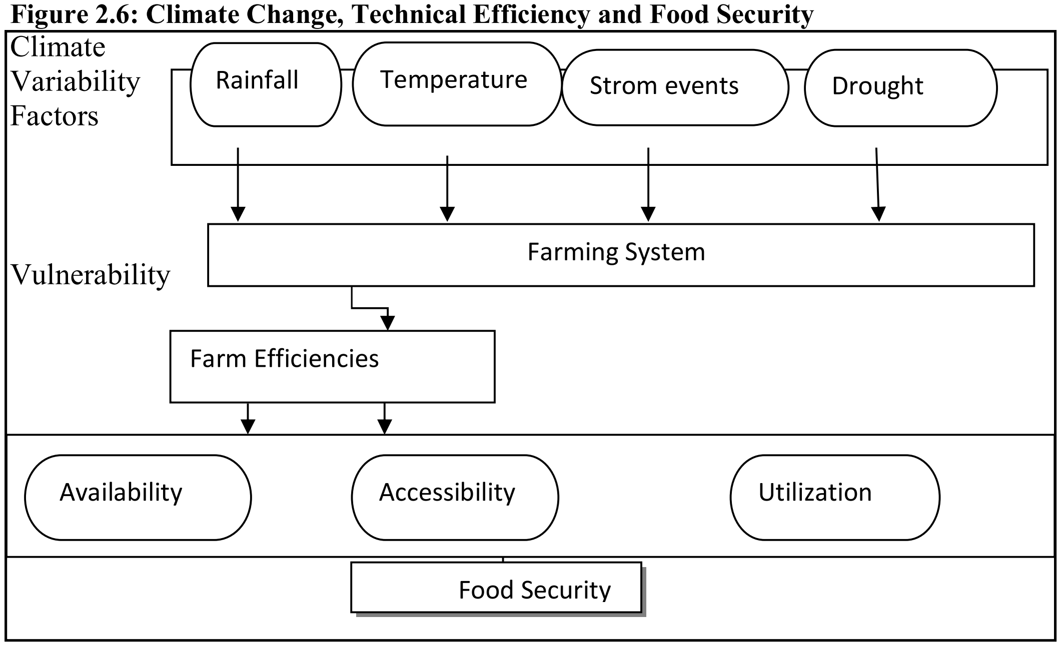
Where $Y_{it} = f(X_{it}^{c}, X_{it}^{nc})$ and which represents the production function. It touches the price ratio line at point E and the maximum level of output Y^* is produced by the firm. Thereby the profit is maximized and profit efficiency becomes equal to 1. For all other input-output combinations, profit efficiency is less than 1. We assume that output is produced by one factor input 'X' given the measured technology. If the firm produces another level of output, say Y, then it will be a technically inefficient level of output, which will reduce the revenue of the firm.

The difference between Y and Y^* is referred to as technical inefficiency. If the firm produces an output below Y^*, then profit of the firm will decline and profit inefficiency will increase due to technical and allocative inefficiency. But if the firm produces output Y^* then the profit of the firm will increase leading to profit efficient. The measure of profit efficiency would be equal to one.

2.8 Climate Change, Technical Efficiency and Food Security: A Conceptual Framework

According to IPCC (2014), developing countries are affected more as a result of climate change as compared to the developed ones. This would be more correct if we disintegrated the global level impact to community level. This fact is supported in case of smallholding farmers.

Figure 2.6: Climate Change, Technical Efficiency and Food Security



Source: Composed by Author

The poor are the ones who face the consequences more severely in case of any climatic irregularity due to shortage of resources and lack of relevant information (Ansari 2002) that influence food security at the individual and household level. Figure 2.6 conceptualizes this link.

Climate change can affect food systems in different ways both directly and indirectly. Its direct effects include reduction in crop production through changes in pattern of rainfall and warmer temperatures, increased heat stress and changes in the length of the growing season (Easterling, *et al.* 2007; and Schmidhuber and Shetty 2005). Besides climate change, other socioeconomic factors play an important role in food security (Funk and Brown 2009; Hodges 2005 and Tubellio, *et al.* 2007). Food security in Pakistan is likely to deteriorate as a result of change in climate. There exists a high degree of diversity in climate change effects across different climate scenarios, regions and sectors. Likewise, diversity in outcome also exists across households, both by region and income groups (Parry, *et al.* 2004 and Ahmed, *et al*. 2009). Food security studies reveal that poor and food insecure households are more vulnerable to climate change effects, considering that they have limited options to absorb the effects of climate change. Substantial improvement in technical efficiency of food production can be achieved by significant changes in cropping patterns, farming practices and other adapting strategies (Millennium Assessment of Ecosystems 2005). The relationship between climate change and food security status has been taken more seriously by the researchers since the early 1990s (Kane, *et al.* 1992) and these studies generally focused on regional or domestic agricultural impact (Arthur 1990; Downing 1992; Darwin 1997 and Adam, *et al*. 2005).

The effects of climate change on food security not only involve direct impact on local food production but also set off consequences on the whole food system (Ericksen 2009; Ingram 2009; Tubiello, *et al*. 2007; and Liverman and Kapadia 2010). According to Nelson, *et al.* (2009) climate changes cause rise in prices of most cereal crops due to fall in production resulting in reduced purchasing power of food and calorie intake leading to malnutrition. There are many reports that indicate that the quality as well as dietary value of food crops, especially cereals, may also be affected by climate change (Ziska, *et al.* 1997; Hesman 2002 and Nagarajan, *et al*. 2010).

2.9 Empirical Evidence

2.9.1 Climate Change Impact Studies in Agriculture

Climate change is a complex phenomenon and it requires integrated thinking and conceptual frameworks to straighten out depraved planning issues such as sustainability (IPCC 2007). It can be illustrated as "*the dynamics between the biological and human ecosystems integrating social, biological, physical, and built components interacting with one another"* (Cadenasso and Pickett 2013).

Climate change can cause many impacts on agriculture, some of these effects can be biophysical, ecological and economic (Khanal 2009). Literature review selected in this section provides the biophysical and socio-economic impacts of climate change on agriculture by focusing on crop productivity. In total 13 climate impact studies briefly reviewed in this section are from different countries including Pakistan. These studies are also summarized in Table 2.1. The aim is to identify how these researches connect the aspects of climate change with agriculture productivity. The purpose is to provide a literature background for the study, different concepts and methodologies used, and to identify variables, their expected results in this specific field and to highlight some of the gaps that are required.

The first study is by Deschenes and Greenstone (2000) that estimated the economic impact of climate change on agriculture sector of the United States caused by year to year fluctuation in weather. They tried to establish the relationship between profits per acre and temperature by using cross-sectional hedonic equation for country level agricultural profit as dependant variable instead of land values. The data on agricultural production was acquired from i.e. 1987, 1992, 1997, and 2002 Agriculture Census relating to all farms and ranches. The climate variables included in the analysis were daily precipitation and daily temperature calculated in growing season for most of the crops, except winter wheat. Fixed Effect Model was used as technique for analysis. The estimated results indicated that climate change would lead to 4 percent increase in agricultural sector profits annually. The analysis also indicated that rise in temperature will have no significant impact on yield of important crops like maize and soybeans.

Schlenker and Roberts (2006) is the second study reviewed here, which concludes that there existed a nonlinear relationship between weather variables and corn, soybean and cotton yields for the United States for the period 1950 to 2004. The weather variables included in the study were minimum and maximum temperature and total precipitation of each day of the growing season. The corn and soybean yields increased linearly with temperature until 29°C and for cotton up to 33°C. This relationship remained stable over time and location and was used to predict the effects of the latest warming episodes on crop yield. It was predicted that the crop yield might decrease by 72 to 80 percent in such conditions.

The third study is by Lobell, et al. (2007), which analyzed the impact of climatic variables on 12 major crops[19] for the period of 1980–2003 in California. Climatic variables like minimum and maximum temperature, and precipitation were used as predictors. The yield of these crops was used as the response variable. They concluded that for most crops these climatic variables cause two third of observed yield variance. The results revealed that current climatic trends affected crop yields that differ in magnitude and direction; some were less affected than others. It was

[19] "These crops were table grapes, wine grapes, tomatoes, lettuce, almonds, strawberries, avocados, hay, oranges, cotton, walnuts, and pistachios".

expected that unexplained variance may occur with climatic variables because of the choice of spatial scale, cultivar selection, irrigation water use, monthly average conditions and various other operational aspects.

The fourth study that evaluated the impact of climate change on agriculture was Guiteras (2007) that used Indian district panel data for the period 1956-1986 and predicted medium and long-run effects on farm productivity. To convert daily records to yearly weather matrices for analysis two methods are used. The first, degree-days, reflect the significance of total heat over the growing season, but it fails to measure the nonlinear effects on crops. The second method, counts the number of growing-season days in each one-degree Celsius temperature bin. The average monthly precipitation of each growing season was used for analysis. The prediction of climate change was made for three scenarios 1990-1999, 2010-2039 and 2070-2099. Semi Ricardian approach was used to capture the impact of district characteristics' vector and climatic variables. The predicted medium-run impact was negative and statistically significant. The study predicted that the impact of climate change over the period 2010-2039 would reduce major crop yields from 4.5 to 9 percent. In the absence of long-run adaptations a 25 percent decrease in yields is indicated by long run impact. The medium term impact on yields was estimated to be negative 4.5-9 percent because farmers were late in recognizing and adapting quickly to climate change. The total losses were 1-1.8 percent of output per year. The study further concluded that the consequences of long-term climate change could be more severe than just 25 percent loss in yields if adaptation strategies were not applied rapidly.

The fifth study that analyzed the impact of climate change on country level agricultural productivity in Cameroon was by Molua (2008). The data period was from 1961 to 2001. Translog production function was applied to analyze the impact.

The data consisted of three components for analysis: climatic, agronomic and economic. Output was used as the quantity index of permanent and arable crops, while inputs included in the model were rainfall, temperature, cultivated area, labor, fertilizer, pesticides, capital, and irrigation. Rainfall and temperature data was computed by departure from the monthly mean divided by the standard deviation. The estimation and prediction were based on three hypotheses, one with both climatic and input variables and the other with only climatic or input variables. The projection of future climate change based on global warming rates was divided into three scenarios based on the restriction under consideration. Scenario A: temperature and precipitation rise by 1.5°C and 15 percent. In Scenario B, it is 2.5°C and 8.5 percent and in Scenario C it will be 3.5°C and 4.5 percent. The years under consideration were limited to 2010, 2020, 2030, 2040 and 2050 because of uncertainties involved. The projected result indicated that the economic value of the predicted output in 2050, based at 1998 prices, will range from US$ 3.5 billion to US$ 7.1 billion, which was 41 percent less and 18.5 percent greater than the 1961–2001 mean respectively.

Hanif, et al. (2010) is the sixth study that quantified the impact of climate change for sustainable development of agriculture sector at the regional level using data from Pakistan. The fixed effects model for eleven districts of Punjab was estimated with feasible generalized panel regression for the time horizon of 1970-2009. They applied hedonic price approach by taking agriculture land prices per acre as dependent variable whereas the explanatory variables were categorized into two groups' climate and non-climatic variables. The climatic variables used were the mean minimum and maximum temperatures and the mean precipitation of both *kharif* and *rabi* seasons. The non-climatic variables included area under cultivation, population density and per capita income. The study found that the *kharif* minimum temperature and precipitation had important positive relationship with land prices and maximum temperature was not significantly related to land prices while *rabi's* precipitation and minimum temperature had negative relation with land prices and maximum *rabi* temperature exhibited a positive relationship. In *kharif* season, it was found that an increase of one mm in precipitation would result in Rs.166.57 per acre rise in land price on average, while in *rabi* season, a fall of Rs.860 per acre was expected. An increase in maximum temperature by 1^0C caused the agricultural land price to increase by Rs. 25208.66 per acre. The study however did not have data for variables such as soil fertility, land characteristics, and irrigation data though at district level these factors could have had significant impact on land prices.

Ahmed and Schmitz (2011) is the seventh study. This employed production function technique to examine the effects of climate change on agriculture production in selected districts covering the four provinces of Pakistan. The dataset covers the period from 1987 to 2004. The yield per hectare of major food crops such as wheat, rice and maize served as dependent variables. The panel data methodology was used to capture the fixed and random effects by using fertilizer, credit, number of tube wells, and labor per hectare, the number of tractors, average *rabi* season rainfall and temperature and drought which are measured as the deviation of rainfall from long-term normal values as an independent variable. The study found that fertilizer use per hectare and agricultural credits have a significant positive effect on food crop yields. Crop yields increases by 1100 kg per hectare if increase in agricultural credits per hectare is one percent. The model portrays a substantial positive effect of privately owned and operated tube wells on farm output but non-significant impact of public tube well because of their poor quality and mismanagement. The study found negative impact of temperature on crop yields as food crop yield reduces by 44 kilos per hectare for an increase in temperature of one degree. Precipitation deviations from long term normal also found negative and significantly affecting food crop yields. In the case of farm mechanization results are not significant but labor force variable has significant impact on productivity growth.The study suggests that these non-climatic variables can be used to cope with yield reduction induced by climate change to improve the access of food crops in these provinces.

Auffhammer, et al. (2012) is the eighth study that examined the impact of climate change on agriculture. In this study simulation as well as statistical methods were employed to investigate the impact of monsoon rainfall on yield of rice in rain-fed area of India. The statistical analysis revealed that episodic drought and extreme rainfall events negatively affected rice yield during 1966–2002. Using Monte Carlo simulation it was predicted that in the absence of episodic climatic events the yield would have been 1.7 percent higher on average, particularly in the absence of warmer nights and lower rainfall the yield would be higher by 4 percent during the growing season. The result implies that the monsoon effect was nonlinear. Scenarios of with and without climate change were simulated and results revealed that if climate change is not present the yield would have been 5.67 percent higher.

The ninth study is by Lee and Nadolnyak (2012). This study examined the impact of climate change on U.S. agriculture by using the pooled cross-section farm profit model for the period of 2000 and 2009. Two moisture indices, the Palmer Drought Severity Index (PDSI) that ranged from -4 to 4 and the Crop Moisture Index (CMI) that ranged from -3 to 3 indicating extreme drought to extreme moisture, were used in the analysis. Both indices have a negative relationship with temperature and positive with precipitation. The outcome variable was farm profits. The net farm income computed as total farm revenues net of total production costs was used for farm profits and the remaining control variables were farm structures and operator characteristics like non-family farm, age and education of the primary operator used in the analysis. Regression was run separately for all farms combined, the crop and for livestock farms. The elasticities of profits with respect to input and output prices at the mean of the data were found to be -1.85 and 3.41, respectively. The study concluded that the total operated land area of a farm does not significantly influence the farm profits. The coefficient of livestock farm indicated that on an average livestock farms earned about $14,484 less in profits as compared to a crop farm. Similarly, nonfamily farms earned about $347,000 more profit as compared to the farms that were owned and operated by families. It was also found that one unit increase in PDSI leads to 5.5, 4 and 5 percent increase in farm profits for all farms, crop farms, and livestock farms and CMI increased these by 13.9, 9 and 14 percent, respectively.

Siddiqui, et al. (2012) is the tenth study reviewed in this section which intended to explore the influence of climate change on the most important agricultural crops in Punjab, Pakistan. This study disaggregates data according to different development stages of each crop using panel data at district level for the period from 1980 to 2008. The explanatory variables were the monthly average temperature and precipitation and deviation from maximum temperature in case of cotton crop. The dependent variable was production. The Fixed Effect Model was estimated and in the end simulations analysis carried out for the period 2008 to 2030.The study implies that climate change had positive impact on wheat productivity, while the impact was negative for cotton, sugarcane and rice beyond a certain optimal level. The simulations results indicated that if the temperature increased by 1°C the cumulative loss up to 2030 would be 0.02 percent for wheat, 13.29 percent for cotton, and 13.56 percent for sugarcane respectively while the gain to rice crop would be 1.85 percent.

There are certain drawbacks of this study as it uses current values of climatic variables which is contrary to the standard definition of climate change, a long run phenomenon. This study also did not capture the impacts of non-climatic variables which have significant impact on crop productivity. Furthermore, the selected districts and phonological stages for different crops were also unfitting.

The eleventh study was done by Ahmad, et al. (2014) that analyzed the effects of climate change on Basmati and Coarse rice from selected districts of the province of Punjab and Sindh in Pakistan. A panel data at district level was used for the period of 1987- 2010. Fixed Effect Model was employed using 20 years moving averages data of precipitation and temperature as well as climatic deviation across different growth stages. The interaction terms of climatic variables were also introduced along with quadratic form to capture the non-linearity and joint impacts of climate under different model specifications. The non-climatic variables were fertilizers and area under rice, a dummy variable for flood was also introduced in the model. The results point out that temperature and precipitation has significant impact on both types of crop yield. However, these impacts vary across the growth stages both in magnitude and direction. The weather shocks were insignificant in case of coarse rice. The result implies that there exists a nonlinear relationship between precipitation normal and rice productivity. It was also found that for Basmati rice the combined effect of climatic variables was important. The study found that the fertilizer had a statistically significant effect on the performance of Basmati rice yield.

Javed, et al. (2014) is the twelfth study. This study analyzed the impact of climate change on agriculture in Pakistan. Fixed Effect Model and Instrumental Variable method was used to alternative specifications using both production and revenue as a dependent variable. Estimation was made on panel data at the district level during the period of 1980-2010 covering 67 districts. The analysis was carried out for 33 crops using Laspeyres quantity index as an output. Twenty years moving average of temperature and precipitation and deviation from long run normal served as climatic variables, while non-climatic variables were number of tractors and tube wells, fertilizers and cultivated area. Last year's agriculture production was also introduced in the model. The results showed that agricultural production significantly positively affected by increased precipitation while temperature rise negatively affected especially in dry areas. However, these impacts vary in magnitude and direction across regions and seasons. The study showed that agricultural production in the preceding year is an important determinant of the output in current year. The study also found significant positive impact of fertilizers in agricultural production.

The last study reviewed in this section is done by Ahmad, *et al.* (2014), which examined the impact of climate change on wheat productivity in 19 major wheat producing districts of Pakistan for the period from 1981 to 2010. Data was divided into three[20] growth stages. The Fixed Effect Model (FEM) is used for estimations. Along with climatic variables, the non-climatic variables area under wheat crop, tractor and fertilizer were used. The study reflects significant effect of climate change on productivity of wheat and this impact varies across the growth stages. The results indicated that during sowing time a rise of 1 ℃ in the mean temperature would decrease crop yield by 7.4 percent and would increases productivity by 6.2 percent during the vegetative stage. However, crop yield found to be almost unaffected by rise in temperature normal during the maturity stage. Precipitation normal and their deviations form exert a positive impact on the wheat yield. The results expressed that

[20]Germination/tillering, vegetative growth/flowering, and grain formation/maturing normally covering November-December, January-February, and March to April, respectively.

independent variables present in model has explained almost 79 percent of the variation in the dependent variables.

The parameter estimates of non-climatic variables were all statistically significant and carry positive signs. The study concluded that improvement in production technologies has played a significant role in enhancing wheat yield in Pakistan.

The empirical literature reviewed in this section indicates that the estimation techniques commonly employed in climate literature are the hedonic price approach, average production function, semi Ricardian approach and simulation modeling. The simulation and forecasting studies in general focus on country level, few on district level while a negligible of them focus at micro or household level. The literature on measuring the climate change impact on farm performance by using stochastic production frontier approach is inadequate. However, it is discussed in the next section. Climatic variables included relate to temperature and precipitation moving averages of 20 years and their deviations, mean minimum and maximum temperatures and the mean precipitation, growing degree days and indices of climatic indicators, while the control variables are agriculture inputs, soil characteristics, socioeconomic and locational attributes. The present study adds to the literature by factoring technical efficiency. Most of the climate literature focuses on climate relevant variables irrespective of other variables, such as those that are farm and household specific. This study fills this gap by incorporating all these variables along with the climatic factors.

2.9.2 Agriculture and Efficiencies Studies

This section reviews the literature on efficiency measurements in agriculture sector. The frontier methodology applied in the context of this research persuaded us for the selection of these studies. The purpose is to understand efficiency components and procedures adopted, different variables used and their outcomes. More importantly, the relevant review also identifies the gaps in research under study. This section comprises of two parts: the first part deals with the efficiency literature related to various countries' agriculture (excluding Pakistan); and the other part is reserved for empirical work that uses agriculture data from Pakistan.

2.9.2.1 Review of Selected Empirical Studies (Excluding Pakistan)

In total 24 studies are reviewed in this section that belongs both to developing and developed countries (Table 2.2). For review in this section, only those studies are chosen that analyzed the determinants of technical (in)efficiency, since one of main objective of present study is to examine the determinants—socioeconomic as well as the climate related shocks, of (in) efficiency.

The first study reviewed here is by Kalirajan (1991) who measured the technical efficiency of 30 farms which adopted a new rice variety in Coimbatore district of India during 1983 to 1986. Maximum likelihood estimates were obtained by using translog stochastic production frontier function by applying Fletcher and Powell's method with both time variant and time invariant specification of inefficiency terms. In the second step inefficiency score was regressed on various socioeconomic characteristics like education, confidence in technology, extension services and farm size using the ordinary least square estimation technique. The results revealed that there was a wide range in technical efficiency levels across farms, varying from 53 to 95 percent whereas the mean technical efficiency was 69.3 percent. It concluded that inefficiency prevailed in the adoption of technology, which implied that there was a crucial need for the farmers to adopt technology at the micro-level through extension services in order to increase their agricultural production.

The second study is Bravo-Ureta and Pinheiro (1993) which basically deals with review of efficiency studies on agriculture conducted using data from developing countries. However, this study provides a comprehensive analytical appraisal of the work done in less developed countries on farm efficiency and how this is influenced by the farm- and farmer-specific factors. The study included 30 articles related to efficiency analyses from 14 developing countries. The most frequently used variables were farmers' education, experience, extension services, access to agricultural credit, and farm size. The predicted result indicates that the above mentioned variables have a positive relation with technical efficiency. The farm level technical efficiency from all studies ranged from 17 percent to 100 percent with a mean of 72 percent. Analyses have shown that substantial room existed to increase agricultural productivity in developing countries without increasing existing inputs and by introducing new technology. Education, experience, extension services, access to agricultural credit, and farm size were found to be major factors influencing the farm (in) efficiency.

Battese and Coelli (1995) is a third study which is briefly reviewed here. This study used 10 years (1975-76 to 1984-85) panel data of 14 Indian paddy farmers for measuring efficiency by using Cobb-Douglas production function. Data was acquired from (ICRISAT). The technical inefficiency measures were generated by developing a technical inefficiency effects model in which technical inefficiency is a function of a number of farm related variables. The results of the study have shown that the technical inefficiency measures are influenced by farm specific socioeconomic characteristics as well as time. The estimated result revealed that all parameter estimates carried expected signs except that of the bullock hours. A negative sign for education indicated that more educated farmers were less inefficient.

The fourth study chosen for review is by Yao, et al. (2001) that used a panel data set from 30 provinces of China, for the time period 1987–92 and estimated the grain production efficiencies. In order to derive the technical efficiencies across the regions, Cobb Douglas and translog stochastic frontier production function were estimated. The dependent variable was total grain output while independent variables were total grain sown area, total labor input, total fertilizer input, total machinery input and the irrigation ratio. The inefficiency affecting variables were the number of research and development personnel per 1000 hectares of grain sown area, the disaster index, cropping index, rural population share in total population and crop labor share in the total rural labor force. The level of production efficiency was less than 65 percent at the beginning of the data period but declined by over 10 percentage points over the sample period. The efficiency level in the eastern zone is higher than the western because of the massive increases in the use of fertilizers and irrigation. As a result the marginal product of all the non-land inputs in these areas was much lower than in the central and western zones indicating there was large potential for increasing grain output in these areas. The decomposition of TFP growth revealed that technical change had a positive and significant effect on productivity, but the gain in TFP growth was cancelled out by decrease in efficiency levels. Therefore, development efforts were needed in areas where there was the highest potential for growth.

O'Neil and Matthews (2001) is fifth study which is briefly reviewed in this section. This paper examined the farm level technical efficiency using unbalanced panel data of 2,603 farms collected by Irish National Farm Survey for the period 1984 to 1998.The approaches used for the estimation included translog stochastic production frontier with time invariant and time variant technical efficiency specification incorporating the possibility of non-neutral technical change with two step procedure. Output and inputs were first aggregated by Tornqvist-Theil (TT) value indices taking 1996 as base period. Gross farm output was used as a dependent variable and the list of explanatory variables included farm labor, capital and variable inputs. Factors responsible for inefficiency were the farmer's age, the debt ratio of total farm borrowing to total value of farm assets, a dummy for having an off-farm job, a dummy for the location (West of Ireland), household size and farm size. The average level of technical efficiencies varied between 65 to 70 percent while a slightly increasing trend over time was observed. The rate of technical progress was found to be 2.1 percent per annum. It was considerably higher on farms in the east than those in the west. The efficiency of individual farms was positively associated with the household size, type of farming in case of dairy farms, the ratio of debt to assets and the farmer's age, and negatively related to the location (Western Ireland), off-farm job and larger farm size. They suggested that increase in the scale of production and uplifting the financial status of the farmers could improve farm efficiencies.

The sixth study is by Rahman (2003) which analyzed Bangladeshi farmers' production efficiency of rice, by employing stochastic profit frontier and inefficiency effects model. Primary data was collected for 380 farms from 21 villages that produced modern varieties of rice during 1997 in three agro-ecological regions. The restricted profit normalized by price of output was considered as a dependent variable while explanatory variables included price of fertilizer, seed, pesticide, labor wage, animal power price normalized by output prices; the fixed inputs were area under modern rice varieties and farm capital. The socio-economic characteristics of the farmers that were used to explain inefficiency were farmers' tenure status, their education, experience, and extension services, the index of infrastructure and soil fertility and non-agricultural income share. The mean level of efficiency was 0.77. The result indicated that extension service, soil fertility and the experience of growing modern varieties negatively contributed to inefficiency. The study concluded that improvement in rural infrastructure, extension services, and soil fertility and by injecting required land reforms can be among the significant measures in reducing farm inefficiency.

Wadud (2003) is the seventh study and this investigates and compares the efficiency measures obtained through DEA and SFA applications to farm level data of for the rice crop in Bangladesh. Data for 150 rice farmers from two villages for three growing seasons in 1997 was used in the analysis. The results revealed that the mean technical, allocative and economic efficiencies obtained using SFA technique model were higher in efficiency score than the DEA model. The results also suggested that farm production inefficiency is influenced by land fragmentation, environmental factors, irrigation infrastructure and socio-economic characteristics of the farmer. Production could be increased by 9 to39 percent if the constraints faced by the farmers were removed and they were also helped in improving their infrastructure.

Binam, et al. (2004) is eighth analytical work and this study measured technical efficiency in three[21] cropping systems of Cameroon. Data was collected for 450 farmers from 15 villages during the 2001-02 crop year. The Cobb Douglas stochastic production function was used for efficiency estimation. The study revealed that average technical efficiency of each system was 77percent, 73 percent and 75 percent respectively. It is revealed by using farm-specific variables to explain inefficiencies i.e. schooling years, credit access, fertile areas and farmer membership of organizations positively contributed to efficiency while extension services and

[21] maize monocrop, groundnut monocrop and maize–groundnut

distance from the main road negatively affected technical efficiency in different cropping systems.

Kibaara (2005) is ninth study, which investigated the impact of different socioeconomic and management practices on technical efficiency of maize production in Kenya. Primary data for 2003-04 main harvest cropping season were used. Technical efficiency model and maximum likelihood method was estimated by Limdep for maize production. In addition, marginal value products and input elasticities were also calculated. The socioeconomic characteristics were used as independent variables in order to see their impact on technical efficiency as the dependent variable. The results revealed that the mean value of technical efficiency was 49 percent. However it ranged from 8 to 98 percent due to inter and intra district variability and the cropping patterns.

The tenth study reviewed in this section is by Thiruchelvam (2005), which examined the agricultural productivity and efficiency of two irrigation units in Srilanka. Data was collected from 45 owners and 45 share growers in each irrigation management unit during 2004. A Cobb-Douglas stochastic production frontier was used for estimation, having output index for chilies and onion as a dependent variable. The list of independent variables included landholding, cost of labor, machinery, power, agrochemicals and seeds. However, socioeconomic characteristics were explicitly incorporated in the inefficiency model. These included the dummy for ownership, farming category, debt level, farmer participation score, distance-from-home dummy and age. The overall technical efficiency of owners and share growers was 88 percent and 76 percent respectively. Analysis revealed that there was a significant difference in productivity and technical efficiency among the growers.

The eleventh is by Adam, et al. (2005) which analyzed efficiency of sorghum growers in Gezira scheme of Sudan during the growing season of 2002-03. The Cobb-Douglas stochastic production function specified the relationship between sorghum output of the 100 tenants and their explanatory variables. Data was collected through structured interviews that included information regarding yield of sorghum, credit received, cultivated area, family labor, hired labor, fertilizer, number of irrigations and capital, which was calculated as the total amount of expenditure on production inputs like seeds, fertilizer, sacks and machinery. The socioeconomic characteristics included in the inefficiency model were age, family size, size of land holding, income, level of education, experience, farm location, off-farm income and contact with extension agent. The results revealed that technical efficiency among growers ranged between 30 and 98 percent, and on average technical efficiency it was 67 percent. The result implied that there is considerable room for increasing productivity by better employing existing available resources by the tenant growers. The study recommended to policy makers to analyze the main factors behind the tenant's technical inefficiency and to formulate policies to improve technical efficiency and hence, household food security.

The twelfth analytical work reviewed here in this section is Rios and Shively (2005), which evaluated the efficiency of coffee growers using the DEA approach. Data were collected for 209 farmers in two districts of Daklak province of Vietnam during 2004. Variable inputs such as hired labor, herbicides, pesticides, organic and inorganic fertilizers and family labor were incorporated into efficiency estimation. In the second step, probit regression was run for endogenous credit as a binary dependent variable for formal or informal access to credit. The explanatory variables were the village dummy, non-agricultural assets and house material dummy. The results indicated that the villages of residence and housing material have positive and significant correlation with access to credit while ethnicity, years of residential use and non-housing assets were not strongly correlated with credit. At the end, Tobit models were employed to investigate the sources of inefficiency under a two-model specification. One model was without the interaction term and another with five interaction terms between tenure, credit, and water pump, length of irrigation pipe, farm size and education. Regression was run separately for each farm size category. The results indicated that small farms were less efficient than large farms. Technical and cost efficiency for small farms was 82 and for large farms was 89 and 58 percent. Inefficiencies observed on small farms were highly dependent on irrigation infrastructure investment.

Alemu, et al. (2007) is the thirteenth study, which analyzed the efficiency performance of farmers in Ethiopia during the cropping season of 2007. Ten districts were selected from three agro ecological zones Dega, Woinadega and Kola. The purpose was to examine the differences in the variables of interest as these districts represented different locations with varying population pressures, land degradation, agro climatic conditions, access to markets and other related factors. A stochastic production frontier was estimated with both two-stage procedure in state and with single-stage maximum likelihood procedure in frontier package. Stochastic frontier production results revealed that mean technical efficiency of 75.68 percent, ranging from 32.15 to 92.66 percent. The F-test result indicated that there was a statistically significant difference in technical efficiency among agro-ecological zones. The farms located in highland zones scored the highest value. On the other hand, maximum likelihood estimates indicated that inputs such as land, labor, draft power and fertilizer had positive and significant elasticities. It further concluded that availability to markets and access to credit reduced inefficiency levels significantly, while education, extension visits, farm management trainings negatively contributed to the efficiency level of farmers. The results showed that improved market outlets and reduced liquidity constraints increase farmers' efficiency level.

Kariuki, et al. (2008) is the fourteenth study chosen for brief review. This study applied Cobb Douglas stochastic model to measure the efficiencies of a crop farmer across five agro ecological zones and land tenure systems in Kenya. Two step procedures were used for estimation strategy. The data was acquired from Tegemeo Institute; Egerton University for 22 districts consisting of 1340 farmers. The total value of farm output was used as a dependent variable. The explanatory variables comprised land size; cost of manure in kilograms, inorganic fertilizer, land preparation, seed used, and dummy variables for main source of water. The study concluded that socioeconomic characteristics such as credit availability, tenure status and membership to farming groups were positively associated with farm level efficiency. The study recommended that land registration of the farmers was important in increasing the level of farm efficiency along with other amendments such as improvement in roads access, seed quality, availability of fertilizer, improved education standards, gender and group participation.

The fifteenth study reviewed here is by Solis, et al. (2009). They analyzed technical efficiency of 693 farms operating under two resource management programs, the PAES and CAJON projects in El Salvador and Honduras hillsides of Central America. Primary data was collected during 2002. Household-level technical efficiency estimated was constructed with the help of input-oriented stochastic distance frontier. Households were categorized into three groups: those producing staple crop like maize and beans, those producing cash crops and livestock products and others off-farm income groups. The input variables were land, family labor, hired labor, off farm labor, purchased inputs and slope of the land, which was a dummy variable equal to 1 if the average slope of the farm was greater than 15 percent. The factors associated with inefficiency were age, education, gender, ownership, access to credit, and participation in farm organizations and, to capture the impact of the project, the number of visits made by project extension agent and number of years of association and practice were used as a variable. To define the number of soil conservation practices adopted by the farmers, “a ratio of cultivated land under soil conservation practices to total cultivated land” was used. The model was estimated using generalized least squares and all variables were normalized by their geometric mean. The estimated partial elasticities showed that purchased inputs, family labor and off farm income added the most to household production; the parameters for hired labor were insignificant. However land, education, extension, gender, participation, non-owner and farm practices exhibit positive and significant effects on household efficiency. Credit, age and years with project association were insignificant. The results also revealed a positive relationship between productivity and output diversification. This study concluded that improvements in technical efficiency brought not only financial benefits to farm households but also contributed to environmental sustainability by adoption of soil conservation practices.

Fakayode (2009) is sixteenth empirical work which measured production efficiency of rice growers in Kwara region of Nigeria. It applies Cobb-Douglas stochastic frontier production function. Primary data was collected from 72 major rice-producing villages comprising 264 rice growers by random selection procedure -- 168 from low land and 96 from upland during 2007 and 2008. Data was further analyzed by different econometric techniques such as OLS regression, chow-test, total

Factor productivity analysis and the Likert-type scale tests. Farm budget analysis indicated that in lowland rice farms have higher returns to labor and management. Farm inputs included farm size, labor, seed, credit and fertilizer. The result further indicated that the lowland rice production system had higher level of technical efficiency of 60.08 percent while for the upland farms it was 40.1 percent. Farmer's farming experience; household size, education, extension and type of rice variety planted that were explicitly included in the inefficiency model were found to be significantly affecting technical efficiency of both lowland and highland farms. The Chow-test comparison also showed significant differences between technical efficiency levels of the two rice farms. The analysis of factor productivity revealed that lowland rice farms were operated at a higher total factor productivity level of 4.3 percent on average as compared to upland rice farms at 3.4 percent. The Likert-type scale analysis of farmers' constraints revealed that inadequate funds was the main problem confronting both upland and lowland rice farmers. This was followed by expensive agro-chemicals, pest and diseases and inadequate labor supply respectively. The study recommended more farmers should be put into rice cultivation to improve the efficiency at which rice farmers were already operating by optimal utilization of inputs.

Nganga*,* et al. (2010) is seventeenth study which measured the efficiency of milk producers and the factors responsible for farm level inefficiency using a stochastic profit frontier model. The data was acquired from mixed animal- crops system Meru south district of Kenya of the Meru south district of Kenya. The hypotheses tests confirmed the suitability of Cobb-Douglas over Translog frontier. Four traditional inputs and socio-economic factors affecting production were incorporated. These included feed cost, drug cost, and wage and herd size. The inefficiency variables were age, education, experience of household head and household size while normalized profit was used as a dependent variable. The result showed that age, household size and non-farm income positively contributed to inefficiency. The result indicated that the growers who are more education and experience and having large farm size tend to exhibit higher levels of profit efficiency. The mean value of efficiency estimates was 60 percent. The study found that, there was potential to increase profitability by about 40 per cent by improving economic efficiency.

Theodoridis and Anwar (2011) is eighteenth study which is briefly reviewed in this section. The author measured technical efficiency of six regions of Bangladesh. This study applied both DEA and SFA techniques and compared the results. The data used in this study consisted of 240 farms from six regions of Bangladesh for the period of 2003-04. The study reported the existence of inefficiencies at the farm level. Technical efficiency obtained through SFA techniques was 0.82, while DEA technique provided average efficiencies of 0.77 and 0.82 assuming CRS and VRS, respectively. The results showed that access to agricultural extension and education has significant impact on efficiency, while greater age and land degradation variables reduced farm efficiency. The results imply that younger farmers were more adaptive to modern technologies.

The nineteenth study reviewed in this section is by Kyei, et al. (2011) which analyzed the factors affecting cocoa farming technical efficiency in Ghana. The study examined the basic determinants of technical inefficiency and socio-economic variables that affect the performance. The stochastic frontier model was applied on the data of 100 households collected in 2009-10. The input factors included fertilizer, pesticides, labor, and farm size, modern equipment and the age of trees. The analyses of inefficiency components showed that except for the age of the farmer, most farm specific factors were insignificant and there was a room to adjust the input variables that included labor, capital and the age of farm. The technical inefficiency decreased drastically if educational level, farming experience and farm size variable increased.

The 20th study we preferred to review her in this section is by Dhehibi, et al. (2012), which examined the efficiency of 51 wheat growers covering 2008–2009 in five districts of Beja and Tunisia. Primary data was collected through structured interviews. The Cobb Douglas stochastic frontier production model was used for estimation. The dependent variable was value of production while explanatory variables were value of seed, total fertilizer, machinery and labor. The inefficiency variables were the education level dummy, crop rotation and the livestock dummy variable, proportion of family labor and share of wheat crops in total cereals. The computed average technical efficiency was 76.93 percent. A Timmer and Kopp technical efficiency index was also calculated from the inefficiency term. The mean value of Timmer and Kopp index was 0.80 and 0.83. The potential efficiency gains increased up to 8 hectare of farm size and decreased again with larger farm sizes. The study recommended other measures like profit efficiency, in order to develop more suitable and cost-effective techniques of cereal production in Tunisia.

Hoang Linh (2012) is 21st study that is considered for brief review. This study applied both DEA and stochastic frontier approaches to estimate technical efficiency of Vietnami rice growers. The results showed technical efficiency estimate obtained under SFA was 0.634 and under CRS and VRS it was 0.704 and 0.765. The analysis concluded that significant inefficiency exists in rice farming so a farm can reduce its cost of production on average by 30-69 percent through adopting advanced production practices. In addition to this, scale efficiency estimates revealed that many farms were operating at less than optimal scale of operation. The study also analyzed the factors responsible for technical inefficiency; they were education, farm size, regional factors and the number of cultivation. The study recommended that those policies which aim at improving basic education, landholding and land quality would be favorable for efficiency improvement.

Adedeji, et al. (2013) is 22nd empirical study which examined the technical efficiency and its determining factors using data from egg producers in Oyo state of Nigeria. Data was collected from 60 poultry farmers, 30 poultry farmers from each of the two local government states through random selection procedure. Data was analyzed through Cobb-Douglas stochastic production frontier function. The explanatory variables were number of birds, labor both family and hired, drugs, vaccine, and chemicals and feed. The household specific characteristics that were explicitly incorporated in inefficiency models were credit access, farmer's age, education level, farming experience, stock size, number of extension contact, and membership of farmers' organization. Hence all these variables were found to be positive and significantly associated to technical efficiency. The estimated technical efficiency of the poultry egg producers was found to range from 18.3 percent to 92.7 percent with an average technical efficiency of 66 percent. The variation in the level of technical efficiency indicated that there are more opportunities for poultry egg producers to rise their productivity and income that would contribute to their socio-economic development by increasing the efficiency level.

The 23rd empirical study which was considered for brief review is by Thibbotuwawa, et al. (2013) which examined the differences of technical, allocative, and scale efficiencies of 60 rice farmers from irrigated and 30 from rain-fed groups in Srilanka. Data was taken from survey during 2007 that comprises the information about the quantity and price of the farm inputs and output and other farm variables were source of seed, farm size and ownership type. This study employed data envelopment analysis (DEA) meta frontier and group frontier approaches to calculate and compare average efficiency for each regime as well as analysis of the gap ratios. At the end, bootstrapped truncated regression was used to regress the factors affecting efficiency differences between the two regions. The study revealed that irrigated farms were typically more technical efficient then the rain-fed farms since the later were more expose to water shortage due to the uneven rainfall pattern.

The last study last study is by Watkins, et al. (2014), which examined the efficiency and its factors for rice growers in Arkansas using data envelopment analysis (DEA). The data consists of 137 farms in the University of Arkansas for the period 2005 to 2011. The results indicated that the majority of the farms have high technical efficiency score of 89 percent and mean allocative and economic efficiencies were 0.696 and 0.625 respectively. Although the analysis indicated that a variety selection had a significant impact on the efficiency score and fields using multiple inlet irrigation produced higher efficiency scores relative to others.

2.9.2.2 Empirical Studies Related to Agriculture of Pakistan

This subsection reviews eleven studies, which deals with technical inefficiency measurements and its determinants using data from Pakistan agriculture (Table 2.3).

The first study reviewed in this section is by Battese, et al. (1993) that analyzed technical efficiency for wheat growers located in four districts of Pakistan including Faisalabad, Attock, Badin, and Dir, by using panel survey data from 1986 to 1991. The data were taken from IFPRI. The study used stochastic production frontier. Technical inefficiency was measured by applying two alternative models time-variant and time-invariant. In two districts, Faisalabad and Badin, the technical inefficiency existed and with the passage of time technical inefficiency declined while in Attock and Dir technical inefficiency declined over time but was not statistically significant. Within each district significant variation is shown by technical efficiencies of wheat farmers with respect to time. Mean technical efficiency found to vary between 57 to 79 percent in four districts. The study suggested policy implications that better extension services and adoption of new technology would improve efficiency at wheat farms.

Battese and Broca (1997) is the second study chosen for review, which used wheat growers' farm level panel data of four years from Faisalabad districts and applied stochastic frontier production function technique. Technical inefficiency measures were estimated using three alternative models proposed by Battese and Coelli (1992 and 1995) and Huang and Liu (1994). The translog functional form was considered to the preferred form with no technical change and Cobb-Douglas was considered to be the preferred functional form when the technological change was taken as neutral. The predicted technical efficiency of wheat growers ranged from 50 percent to 100 percent. The estimates of the elasticities with respect to different inputs were also compared under different model specifications.

The third empirical study that used data form Pakistan agriculture sector is by Ahmad, et al. (1999). This study applied Cobb-Douglas stochastic production frontier to estimate the farm level technical efficiency of Basmati rice farms. The data used in this study were collected for the crop season 1996-97 from three villages of the district Sheikhpura in Pakistan. Stratified random sampling technique was employed for data collection from 84 farms. As a results of this study a significant variation of 57 to 96 percent in average technical efficiencies across farms has been estimated.

The results indicated that the number of years of education of the farmers and age have positive impact on the technical efficiency. However, the effect was statistically non -significant. The results further identified that agricultural extension services and the availability of agricultural credit as a significant factors in improving technical efficiency.

The fourth study by Ahmad, et al. (2002), which analyzed technical efficiency of wheat growers. This study used stochastic frontier approach in three provinces of Pakistan. The farm specific and socioeconomic variables were explicitly incorporated in the function. The data for this study were acquired from a fertilizer use survey conducted in 1997-1998 by the Pakistan Institute of Development Economics. The results indicated that the average technical efficiency was about 68 percent. Farm size was found negatively related to technical inefficiency. It was also indicated that the farmers with better access to markets and credit and who used proper amount of fertilizer and had a reliable irrigation system available were more efficient. The small farmers were operating at a lower level of production frontier; their use of inputs and their output was low. Farmers in Punjab were more efficient than those in Sindh and NWFP. Wheat productivity was inversely related to the proportionate farm area devoted to rice crop indicating land degradation in rice growing areas. The study suggests that price incentives were not enough to increase production. Investment in rural infrastructure such as roads, markets and financial institutions, education, agricultural research and extension was more important.

Ahmad (2003) is fifth empirical study that investigated the determinant of agricultural productivity and efficiency in Pakistan applying stochastic production frontier approach. This study incorporated different poverty levels in the frontier function. Data for 1112 irrigated farms for the cropping year 2000-2001was extracted from a large survey—Pakistan Rural Household Survey (PRHS), conducted by the PIDE. Dependent variable was the weighted output index constructed for all crops at the farm level. The explanatory variables were agricultural inputs, irrigation source, indicators of soil quality and the proportion of the area devoted to major crops. Poverty groups were constructed on the basis of per capita household food expenditures. To access the impact of socioeconomic characteristics on production efficiency variables, such as education, age, land fragmentation, the number of plots, tractor, and tubewells ownership and access to loans are included in the model. The results showed significant difference in the elasticities of production input through the groups. The elasticity of production of inputs for the rich was higher as compared to poor farmers. The average technical efficiency varied across farms from 17 percent to 62 percent. The study also concluded that increase access to inputs for the poor is expected to raise agricultural productivity and reduce poverty.

The sixth empirical study reviewed here in this section is by Hassan and Ahmad (2005) that measured technical efficiency of wheat growers applying Cobb-Douglas stochastic frontier model in a mixed farming system of Punjab. About 112 farm households were surveyed by the authors. The households were categorized as farms located at the head, middle and tale of the lined/unlined water courses in the mixed farming system. The variables used in inefficiency explanation were operational area, age, education of farmer, dummy variable for sowing time, location of farm on the watercourse, a dummy variable indicating lined watercourses and water shortage measured as the percentage of total water used supplied by the tube well, dummy variable for credit and tube well ownership, dummy variable for sowing method (that is if sown with drill, then it has a value of one otherwise zero). The results have shown that technical efficiency varied between 0.58 and 0.98. The average production level of poor performing farmers, medium farmers and high performing farmers were 32.61, 36.97 and 42.82 mound per acre, respectively. The average loss of production due to technical inefficiency was only around 7 percent. The study recommended that among other factors canal water deficiency increased the inefficiency of the farmers. Punjab's mixed farming zone mostly depends on natural precipitation; therefore, excess rainy water should be tapped with the help of additional water storage capacity.

Javed, et al. (2009) is seventh study chosen for brief review. This study analyzed technical efficiency of farming households of cotton-wheat cropping system in Punjab. They applied the DEA technique. The results showed that the average technical, economic efficiency and allocative efficiency were 0.87, 0.37, and 0.44, respectively. The study indicated that the farmers of Rahim Yar Khan were more efficient than the farmers of Muzaffargarh. The results also indicated that 51 percent farmers were having technical efficiency greater than 0.90. About 1.55 percent farms had technical efficiency between 0.80-0.90. The technical efficiency of 20.5 percent farmers was found between 0.70-0.80 and 9 percent farms had technical efficiency between 0.61 and 0.70. Only 4 per cent farms had technical efficiency less than 0.61. The study suggests that efficiency of farmers can be increased by setting up markets and building roads near the farms.

The eighth study is Javed, et al. (2011) that used farm level survey data from rice-wheat cropping system of Punjab, Pakistan. Two districts, Hafizabad and Gujranwala, were selected for the study. Using the DEA technique, the study concluded that the average pure technical efficiency was 0.87, 0.79 and 0.81 and average scale efficiency was 0.79, 0.94 and 0.94 for small, medium and large farms, respectively. Around 83 percent of small farms faced increasing returns to scale.

Positive relationship existed between farm size and efficiency. In the large farm group, 34 percent of farms faced increasing returns to scale, and 42 percent of farms had decreasing returns to scale. The study concluded that the farm level inefficiency could be reduced by following better management practices and by the adoption of new agricultural practices.

The ninth empirical study using Pakistan agriculture data is by Sohail, *et al.* (2012). This study focused only on Sargodha district of Punjab to measure technical efficiency of wheat farmers. Data was collected through farm survey from 17 villages and 83 farmers during 2007 through structured interviews. The total value of wheat output and citrus grown in field was used as a dependent variable and nine inputs variables that included threshing labor, total labor, cultivated area, total seed, total tractor, total nutrients and farm yard manure, weedicide cost, and number of irrigation were used in this study. The DEA technique was applied in the analysis. In second step, inefficiency variables such as experience and education, distance from market, and family size were also regressed to examine their impact on efficiency scores by the Tobit regression model. The mean efficiency level was 0.87. It also showed that distance of the village from markets and farm size negatively affected the efficiency levels while seed and proper irrigation improved the efficiency levels. The study suggested that construction of new dams and improving infrastructure could raise productivity performance of wheat farmers in the area.

Hussain, et al. (2012) is tenth study which used data from Pakistan agriculture. This study measured technical efficiency of wheat growers in different cropping zones of Punjab. Hussain, et al. (2012) applied stochastic production frontier using Cobb-Douglas functional form. The cross sectional data from 70 farmers for the cropping year 2009-10 was collected. The results indicated that two third farmers face financial and technological problems. The average technical efficiency in mixed zones, cotton-wheat and rice-wheat zone was 76.2, 76.9, 83.5, respectively. The mean technical efficiency of farmers in the rain-fed zone was 56.8 percent. The predicted results have shown that farm size was positively related to technical efficiency. The farm level inefficiency of wheat farms was influenced by farm specific characteristics such as education and access to credit. It was found that farmers could improve wheat yield by 18 percent to 43 percent by adopting advanced production methods as well as promoting rural education and access to credits.

The last empirical study reviewed in this section is by Khan and Ghafar (2013), which estimated technical efficiency of 120 tomato growers in district Peshawar applying stochastic production frontier. The dependent variable was output obtained per hectare, while cultivated area under tomato production, number of seedlings, pesticide, fertilizer, labor days, tractor hours, number of irrigation application per hectare were used as inputs. Household specific socio-economic characteristics like education, total area cultivated, experience in years, credit, and age of the farmer were explicitly incorporated in the inefficiency model. The mean value of technical efficiency at 92 percent indicated that farmers were highly efficient. The study further revealed that farmers had increasing returns to scale in production which will increase the level of production and efficiency of the growers. Among inefficiency variables only experience and age were found to be negative and significantly affected farmer's technical inefficiency while all inputs except fertilizer positively and significantly affected crop yield.

In above two sub-sections in total thirty five studies have been reviewed which used frontier methodologies, and are briefly summarized in Tables 2.2 and 2.3. The methodologies used in these studies are either parametric stochastic frontier (SFA) or non-parametric, DEA. However, all of them examined what factors influence (in)efficiency. The estimated technical efficiency indices revealed technical efficiency ranged from 2 to 98 percent. The most popular functional form applied to measure efficiency was the Cobb Douglas type SFA. Almost all studies appraised the variations in technical (in)efficiency have been due to the farm- or farmer specific characteristics. None of them used climate variable as a technical efficiency determinants. Furthermore no attempt has been made in farm level studies to test the impact of climate change on farm production.

The study in hand focuses on measuring the impact of climate change on farm production, technical and profit efficiencies, while controlling by the other farm level inputs use as well as socio-economic factors. Keeping in view the detailed review of the previous work in agriculture, the stochastic production/profit frontier model is considered more appropriate because of their inherent advantages over other methodologies to achieve the objectives of the present study.

2.9.3 Frontier Applications in Climate Change Impact Studies

This section is reserved for brief review of empirical applications of frontier functions in agriculture. These studies try to capture the impacts of climate change on productivity/yield and farm efficiency. We found fifteen relevant studies to briefly review in here, which are also summarized in Table 2.4.

The very first study on subject that we found in literature is by Demir and Mahmud (2002). This study estimated the effect of climatic variables on technical inefficiency of Turkish agriculture. For this purpose, the translog stochastic production frontier technique was applied under four different model specifications. Data from 67 provinces covering the period of 1993 to 1995 was used. The total value from agriculture including both crop and animal husbandry served as a dependent variable while land ownership, labor, capital index, land quality and precipitation were used as inputs. In addition to these inputs, climatic variables and technology were also incorporated. For precipitation, a dummy variable was included that takes the value one if it was above the average national level, otherwise it took zero value. The study concluded that incorporating agro climatic factors improved the efficiency estimates. Therefore, the omission of such variables from the analysis leads to inappropriate estimates of inter-regional technical inefficiencies. The results have further shown that the marginal impacts of production inputs were also influenced by the agro-climatic conditions.

Coelli, et al. (2003) is second study, which measured total factor productivity growth, technical efficiency and technological changes in crop agriculture for 16 regions of Bangladesh from 1960/61 to 1991/92. A stochastic production frontier model was used by considering flood and drought proneness along with other agricultural inputs and socioeconomic variables. It was concluded that technological change followed a U-shaped pattern while the overall rate of technical progress was 0.27 percent per year due to adoption of new rice varieties during Green Revolution years of 1970s. TFP declined by 0.23 percent per year because of the depletion of soil nutrients among other factors. However, technical efficiency decline remained persistent through the years, at an estimated annual rate of 0.47 percent. It was recommended that Bangladesh requires policies to promote the adoption of new technologies as well as improve efficiency.

The third study is by Vicente (2004) that relates to the subject review. This study used a nonparametric frontier model (DEA) under constant returns to scale to measures the technical, allocative and economic efficiency levels of crop producers in Brazil for the year 1995. The aggregate agricultural output was represented by a fisher quantity index which served as a dependent variable. The model was estimated in two steps. In the first step efficiency level was constructed by incorporating input variables such as cultivated land, total labor, machines, fertilizers, pesticides, seeds and seedlings. In the second step the inefficiency index was regressed by using Tobit estimation procedure to analyze the effects of human capital, land quality, rainfall, air temperature and their interaction, hydric deficiency, irrigation use and technical assistance on efficiency levels. The study concluded that the mean technical efficiency was 72 percent and the allocative efficiency was 46 percent. The results revealed that crop production would increase by more than 30 percent if full technical efficiency level was achieved. On average, the results suggest that the sector suffers from both technical and allocative inefficiencies, the latter being greater. Climate, soil conditions, irrigation and education affected technical efficiency levels significantly. Likert-scale indicators of input underutilization and overutilization were also constructed. It takes the value of -1 for overutilization, 0 for adequate level and +1 for underutilization. It was found that land and labor were over utilized, while fertilizers and pesticides were underutilized. The results indicated that investments in education as well as agro ecological zone diversity positively contributed to efficiency in agricultural production. The study further suggested that there was considerable difference in efficiency level across different regions.

Kompas and NhuChe (2006) is fourth study which applied SFA to measure technical efficiency of dairy farms in New South Wales and Victoria states of Australia. The analysis of impact of droughts on diary production was its special focus. The data comprising of 415 observations for 252 farms, was acquired from annual farm and technology surveys held in 1996, 1998 and 2000.The study indicated a substantial reduction in dairy output of 10 percent as a result of drought in 1998 in the Victoria State. The principal determinants of efficiency differences were dairy shed technology, the proportion of land irrigated, feed concentration, and the number of dairy cows milked at peak season. The farm level efficiency ranking concluded that high-efficiency groups employed either rotary or swing-over dairy shed technology to compensate for the impact of drought. The study recommended that water and its availability was a major determinant for both the production and efficiency of Australian dairy industry and a major challenge for policy makers.

The fifth study selected for review here in this section is Songsrirote and Singhapreecha (2007) which measured and compared technical efficiency of conventional and certified organic rice farms by applying SFA using Cobb-Douglas and Translog model specifications. Primary data were collected from 330 farms in Yasothon province of China, which consisted of 165 farms in each farm category during 2005-06. The dependent variable was the farm's total output. The total amount of seed, labor, organic fertilizer, chemical fertilizer and machinery were used as explanatory variables. Multiple regression analysis was used for analyzing the effects of different socioeconomic characteristics on technical inefficiency. Inefficiency variables were categorized into seven groups, farmer learning and health, demographic and location factors, farm management activities, household finance, farmer management characteristics, infrastructure access, climate and government support. These characteristic are measures in ratio or rating scale. Output-based Timmer (1971) index and input-based Kopp (1981) indices were compared in each cropping system. The mean value of Timmer and Kopp index was found to be 0.7145 and 0.4499 in conventional farms and in organic farms it was 0.8666 and 0.7165 respectively. This analysis showed that, on average, organic farms were more efficient than their conventional counterparts. Additionally, the study concluded that on average, there can be reduction of 55 and 28 percent in input use and increase of 29 and 13 percent in output of conventional and certified organic farms respectively. Among other variables rainfall was found positively and insignificantly related to inefficiency of traditional and organic farm. They concluded that excess rainfall could create higher (in) efficiency.

Sotelsek and Laborda (2010) is sixth study reviewed in this section. This study analyzed total factor productivity by incorporating environmental factors in Latin America for 18 countries during 1980 to 2004. Malmquist productivity indices were constructed to decompose total productivity into its components. Data envelopment analysis and a stochastic production frontier were used to estimate each component. Efficiency was analyzed in terms of the ratio of increase in output to decrease in carbon dioxide emission. In addition, kernel density functions were employed to analyze convergence in the efficiency estimates. The study concluded that incorporating environmental factors improved the estimates as compared to traditional approaches.

The seventh empirical study which incorporates environmental factors in the analysis is by Hughes, et al. (2011). The authors measured technical efficiency by capturing the impact of climatic variables. The study introduced aggregate productivity index methodology to capture the impact of climate variability on farm productivity using data from Australian Commodity Statistics for the period from 1977 to 2008. The stochastic production function was employed with Fisher output index as dependent variables while inputs included land, labour, material and service index. Spatial climate data on individual farms in quadratic form was incorporated along with farm variables. The climatic variables included total rainfall, minimum and maximum temperature for winter and summer seasons. They concluded that declining climate condition causes significant decline in productivity growth and decline in technical change. The quadratic relationship between output and rainfall was observed and it showed that rainfall had a statistically significant effect and extreme temperature had a negative impact on output. The study did not incorporate the demographic characteristics while measuring technical efficiency, however suggested that further work was needed to estimate the impact of climatic variables in combination with socio-economic variables.

Deressa (2011) is eighth study that aimed to measures the impact of climate change and agro ecological characteristics on production efficiency using Ethiopian agriculture data. Primary data for the years 2003-04 comprising a sample of 1000 farmers were used. Secondary data included long-term average climate (normal), and soil and hydrological data (flow and runoff). Stochastic frontier approach was employed by using Cobb-Douglas specification to measure the farm level technical efficiencies in two steps. The value of crops produced per farm was used as a dependent variable. Tobit regression model was employed in second step to analyze how climatic and agro-ecological settings affect efficiency scores derived from the first step. Results from the first step indicated that average technical efficiency of the farmers was 50 percent with significant output elasticity of labor, draft power and tractor while the elasticities of fertilizer, farm size and seed were positive but insignificant. The study concluded that agro-ecology based adaptation measures to climate change can reduce its negative impact and increase efficiency of production.

The ninth empirical study found in literature is by Makki, et al. (2012) that evaluated the impact of climate change on productivity and technical efficiency of paddy farms in the tidal swamp land in Banjar district of Indonesia. The data was collected from 180 growers. The study uses stochastic frontier production function with Cobb-Douglas specification. Climate variable dummy was explicitly incorporated in production function—whether the land is affected by climate change or not. The analysis showed that land, fertilizer, pesticides, labor and climate have positive and significant impact on rice production. The mean technical efficiency was 0.78—ranging from 0.48 to 0.99. The study recommended that better management practices at farm level were important in increasing production efficiencies in times of climate vagaries. For this purpose better extension services needs to be provided with emphasis on farmers trainings in adaptation to climate change.

Pereda and Alves (2012) is the tenth study that evaluated the effects of climate change and climate variation on agricultural profitability. The study measured the size of inefficiency caused by extreme climate events for nine[22] crops in Brazil. The study used profit frontier approach. The study analyzed both the short and long-run changes in climatic factors on agriculture using cross-section Census data for the year 2006.The inputs used were land, fuel and long run average temperature and rainfall as quasi-fixed inputs while labor and fertilizers as variable inputs. Farmers' education, land type, farm size, and climatic shocks for each season calculated as the difference between the current observed value and the long-term average temperature and rainfall were included in the inefficiency model. The mean of this PE distribution is 51.3%. The results showed that climate deviations affected profit efficiency negatively. The data showed that there were low rainfalls, while the sampled areas experienced unexpected decrease in temperature during the harvest period. The study suggested that the use of technological instruments such as hybrid seeds, confined cattle, tillage and irrigation techniques would help reduce the climate impacts and encourage adaptation measures to climate change.

[22] These include temporary crops; permanent crops, livestock and planted forests

The eleventh study we selected for review in this section is by Mukherjee, et al. (2013), which focused on evaluating the impact of climate change on dairy farms using translog stochastic production frontier analysis. Data was collected for a sample of 103 dairy farms from Florida and Georgia. It was an unbalanced panel including 77 farms from Florida and 26 from the state of Georgia, over the period of 1995 to 2008—having total of 419 observations. Climatic variables were Temperature Humidity Index (THI) and Equivalent Temperature Index (ETI). The results revealed that both THI and ETI had significant nonlinear negative effect on milk production. The inefficiency model included dairy herd size and expenses per cow as a regressors. The results further indicated that average TE increased from 68 to 90 percent during the period of study. The results were suggestive of adapting strategies like using combination of fans and sprinklers to moderate the adverse impacts of climate change—that would effectively compensate production losses resulting from heat stress.

Auci and Vignani (2014) is twelfth study chosen for review in this section. This study analyzed the economic impact of climate change on agricultural sector by considering two main meteorological factors that are rainfall and minimum temperature in Italy. The maximum-likelihood method was used in the analysis to estimate the parameters of the stochastic production frontier and farm inefficiency. Assuming constant returns to scale, Cobb-Douglas functional form was used. Data was taken from 20 regions comprising 200 observations for the period of 2000-2010. Yield was used as a dependent variable and the inputs list included irrigated area, seed, fertilizer and labor man-days, while in inefficiency model variables like deviation of annual total rainfall and minimum temperature from respective long-term means—30 years moving average and dummies for regions were used. Estimation was done under three model specifications: one each for rainfall and temperature, and the third using both variables. The results revealed that fertilizer used in irrigated areas showed a positive and significant sign, while seed and human capital had a negative and insignificant impact. Technical inefficiencies were also estimated for each region, using the third model specifications. The regions were ranked according to the levels of inefficiency reached in 2000. The study concluded that rainfall variable had a positive impact on efficiency while minimum temperature variable reduced the technical efficiency. The regional efficiency ranking indicated that the difference in impact was due to the difference in climatic conditions across the region as well as diversity in their capability of adaptation.

The thirteenth empirical study found for brief review is by Key and Sneeringer (2014). The major aim of this study was to evaluate the impact of expected climate change on efficiency—used Temperature Humidity Index, on technical efficiency of US dairy farms applying stochastic frontier production function. The results indicated a significantly negative relationship between expected heat stress and technical efficiency. Partial output elasticities at the sample mean of five inputs included in the model show that the number of milk cows have the largest elasticity followed by feed, and other inputs. This result implied that the larger sized dairy enterprises were more productive. Aged farmers were less efficient. The results of this study have also shown that milk production of an average dairy farm would decline by 0.60 percent to 1.35 percent due to the change in climate by 2030—assuming constant production technology and location. The estimated total annual welfare cost of climate change-induced heat stress was $106 to $269 million due to decrease in production and soaring prices.

The fourteenth empirical study relating to the impact evaluation of climatic factors on productivity and efficiency is by Lachaud, et al (2015). This study analyzed the growth in agriculture productivity across Latin America and Caribbean (LAC) countries using Stochastic Production Frontier (SPF) models. Climate Adjusted Total Factor Productivity was estimated by introducing climatic variables as annual maximum temperature, precipitation and the number of rainy days, their monthly intra-year standard deviations, and the number of rainy days. The study further decomposed TFP into Technical Efficiency (TE) index, Technological Progress (TP), Scale Efficiency (SE) index and Climate Effects (CE) to identify the main drivers of productivity growth within countries. To identify unobserved heterogeneity from transient and persistent inefficiencies, a Generalized True Random Effects estimator technique was applied. An Error Correction Model was used to investigate the convergence within and across LAC countries assuming Argentina as frontier in LAC. The data covered the period from 1961 to 2012 for 112 countries worldwide. The results indicated that the combined effect of temperature, precipitation irregularity, and frequency of rainfall had a negative impact on production and agricultural productivity in the region. Moreover, the results show that the effect of climatic index has, on average, an increasingly negative impact on production over time. Climatic variability also affected production and productivity unevenly across time and space and had a particularly negative effect on most of the Caribbean and Central American countries. Comprising

The last study reviewed here is by Lingqiao Qi, et al (2015) that examined the impact of climate change on dairy farm industry in Wisconsin using stochastic production frontier analysis. The study used the seasonal[23] averages of temperature and precipitation to measure the effects of climate change on milk production. Data were collected from 54 dairy farms covering 52 regions of Wisconsin during the period of 1996 to 2012. Fixed and random effects models were also applied to analyze the data. The study found inverse relationship between temperature and output in summer while rise in temperature positively affected milk production in winter. The greater rainfall had adversely affected dairy productivity. The result showed that average technical efficiency score was found to be 92 percent. This study further constructed Climate Effect Index (CEI) based on the estimated coefficients of climatic variables holding all else constant. The results revealed that there existed a negative association between milk production and CEI over the period of time. The study recommended that extension services are required to promote adaptive strategies to climate change.

The above reviewed studies indicate that trend of including weather or climatic variables in the inefficiency effects model or exploiting their role in explaining the variations in output are mixed. Five studies incorporated climatic variable in frontier functions as determinants of technical efficiency. Three of the above reviewed studies tried to capture the impacts of climatic variables in deterministic part of the production frontier model as well as in (in)efficiency part of the model. Climatic variable are mostly in the form of index or dummy variable, and only a few incorporated the short- and long-run impacts of climate change. There are various other non-climatic variables that also affect the efficiency levels, which have however been used in frontier models as determinants of efficiency in these studies. However, we found no work in the context of Pakistan that analyses the impacts of

[23] This study divides the year into four seasons: summer including June to September; winter comprising of December, January, February and March; spring last from April to May and autumn covering October and November.

climate change both in the short- and long-run applying the stochastic frontier technique.

The present study fills this gap and uses stochastic production and profit frontiers to evaluate the impacts of climatic variables on farm output, and technical efficiency and then food security. For this purpose, 20 years moving average of precipitation and temperature to better capture the impact of climate change on agricultural production—assuming it is a long-term phenomenon. Similarly, this study also captures the impact of weather shocks on efficiency along with farm and farmer-specific characteristics.

Furthermore, most of the reviewed studies were conducted at the zone or district level using aggregate data instead of farm level survey data. The former has a limited capacity to explain the results at the household level efficiency. More importantly, none of these studies linked production efficiency with the household food security status. The present study will try to incorporate all relevant variables that are supposed to affect the efficiency of farmers in agriculture production at farm level including socioeconomic, demographic, farm specific inputs along with the climate variable at household level. The present study goes step further and establishes the link between household food security and climate change.

2.9.4 Food Security and Climate Change Studies

This section reviews the literature on food security. First, those studies are discussed which analyzed the determinants of food security, and then, some empirical studies are chosen for review which analysed the impact of climate change on household food security. These studies are summarized in Tables 2.5 and Table 2.6 respectively.

2.9.4.1 Food Security Studies

There is dearth of empirical work related to what is food security, how it is determined and what factors influence food security. We found 13 studies related to food security analysis using data from varied countries.

The first study reviewed here is done by Haile, *et al.* (2005). This study analyzed the factors that determine household food security using a logistic regression method. The study used 108 households' survey data from Oromia region of Ethiopia. Household food security status was determined by taking difference in calories availability and demand for each household. If availability was greater than their per capita calories demand then the household was categorized as food secure and assigned a value of 1; otherwise 0. This variable was used as dependent variable. About 29 percent of the households were found food secure and the remaining 71 percent were food insecure. The list of determinants of household food security included farmland size, oxen ownership, and fertilizer application, education level of household heads, household size, and per capita production. The results showed that the respective parameter estimates were significant and carried the expected signs. Analysis of partial effects revealed that the households that used fertilizer and have educated head were likely to be more food secure.

Amaza, *et al.* (2006) is second study that analyzed food security and its determinants. This study used data from 1200 households in Nigeria. The Cost-of-Calories method and Logit model were used as analytical procedures for the study. Food insecurity line was first established which was based on the recommended daily energy levels of 2,250 kcal or US 176.87$ per adult equivalent per year. It was found that 58 percent of the sample households were food insecure. The explanatory variables included age, farm income, farm size, household size, farming experience, co-operative membership, education, distance to input source, gender of head of household, diversification index, assets value, household production, credit access, child dependency ratio, extension services, commercialization, remittances received per adult equivalent per annum and hired and family labor. Majority of them were found to have statistically significant impact on food security/insecurity. The study emphasized on strengthening agricultural extension for quick transfer of production technologies, and raising the production efficiency—that in turn would likely to improve household food security.

The third study found relevant to this section is by Qureshi (2007), which assesses the food insecurity in Bolivia by constructing an index of food security components. Household level primary data was used which had been collected during 2005 and 2006. The main focus of the study was to make a comparison of the characteristics of food-secure and insecure households on the basis of demographic and anthropometric variations and to compare the variations in food security index between the two periods. Some agricultural related variables, representing the availability of food were used. The indicators of food availability included cultivated area, planting of major food crops, storing major food crops from last harvest and stored seeds. While Kilocalories of food consumed taken as an indicator of nutritional wellbeing, covers the utilization aspects of household food security status and the value of modern assets owned by the households representing food accessibility. More weight was given to availability of food and accessibility to food in creating food security index with the help of PCA.

Tesfaye*, et al.* (2008) is fourth study that evaluated the impact of small scale irrigation on food security in Ethiopia. The Heckman Two-Stage procedure was used for this purpose. The food security index was constructed using a survey data from

200 farmers. It was found that 70 percent households which used irrigation were food secure, while only 20 percent were food secure in the category of those who were non-users of small scale irrigation. The study found that small-scale irrigation was positively and significantly related to household food security. With the accessibility to small scale irrigation farmers were able to grow off season crops that resulted in increased production, income and consumption sustainability and hence improved household food security.

The fifth study that analyzed food security and its influencing factor is by Khan and Gill (2009). This study was conducted in Pakistan, and estimated three components of food security—availability, accessibility and absorption. It was found that food crops and land ownership positively affected food availability. Female and male literacy rates and electrification of villages were important factors in determining the access to food. Further findings of the study showed that child immunization, safe drinking water, facility of hospitals and ownership of domestic assets were important in food absorption in Pakistan.

The sixth study which investigated food security and its determinants using data from New Zealand for the period 2002-2010 is by Carter, et al. (2010). It investigated the impact of demographic and socio-economic impacts on food insecurity. Logistic regression analyses were used for this purpose 18,950 respondents were classified as food insecure based on three question whether in the past 12 months they often have no fruit and vegetables, buy cheaper food or used food banks food grants. The prevalence of food insecurity was much greater in females (19%) than males (12%). The adjusted odds of food insecurity was significantly higher in females compared to males. Study recommended that targeted policy interventions are needed aimed at increasing money available to particular households.

Arene and Anyaeji (2010) is the seventh empirical work related to food security and its determinants. This study used data from Nuska state of Nigeria. To gauge food security, expenditure method was applied. Per capita monthly food expenditure was considered to classify the households as food secure or insecure. The binary logistic regression was used to determine the effects of some socioeconomic characteristics such as gender, household size, income, credit access, and age of head and level of his education on household food security status. It was found that there was 60 percent food insecurity. Age and income of the household head were significant factors in determining food security status. The remaining variables turned out to be not important determinants of food security.

Sultana and Kiani (2011) that analyzed the factors affecting food security at household level in Pakistan is the eighth study found relevant for review in this section. This study used binomial logistic regression procedure. For empirical analysis, they used Social and Living Standard Measurement Survey (PSLM) for the year 2007-08. The Cost of Calories Approach (CCA) was used to calculate the food security and almost 50 percent level food insecurity was observed. Five main variables used to assess their impact on food security including place of residence, dependency ratio, social capital[24], educational level and employment status of the head of household. The results showed that the place of residence, dependency ratio and educational level were significant, while the remaining were not statistically significant. The analysis found that place of residence (Urban) and dependency ratio had a negative effect on household's food security status while educational attainment

[24] payments received by a household in the form of cash from relatives, non-relatives, non-governmental organizations (NGOs) and trusts in case of emergencies

level of household's head beyond intermediate level positively impacted on food security status of household. While social capital and employment do not effect household's food security significantly. Study suggests that different policies and programs are needed to improve the livelihood of the household in specific areas.

The ninth study which relates to food security analysis is by Bogale (2012). Cross-sectional data was collected from three districts, Haramaya, Kersa and Tulo of eastern Ethiopia to capture agro-ecological, economic and social diversities within the sample. The survey sample was 277 households. The probability that any given household's food consumption expenditure would fall below a specified threshold level was also computed and vulnerable households were identified. It was based on the capacity of households to spend a predetermined amount of money on food required to achieve the daily minimum dietary requirement of 2100 kcal per adult equivalent. The study estimated the expected mean and variance in food consumption expenditure using three-step Feasible Generalized Least Squares (FGLS) procedure. The study concluded that susceptibility to food insecurity depends on several factors such as family size, cultivated area, soil fertility, tenure status, access to irrigation, use of fertilizer, improved seed and extension services. The results revealed that 32.5 percent of the households were food insecure as their food consumption expenditure was below the poverty line and were identified as highly susceptible to food insecurity. Households suffering temporary food insecurity status were 4.69 percent being currently food insecure but having low vulnerability to food insecurity and 2.88 percent of the sample households were presently food secure but faced the danger of being food insecure in the future. While 60 percent households enjoyed relatively stable levels of food security as they were both food secure and not vulnerable. This implies that design and implementation of food security policies were needed which not only focused on food insecure group, but also establish social security mechanisms to prevent households from further falling into food insecurity situation.

Aidoo, et al. (2013) is the tenth empirical study that evaluated the determinants affect food security in Ghana. They conducted a survey through a structured questionnaire of 100 households. Logistic regression was applied to analyze the factors affecting food security. Among 10 variables included in the model, five were statistically significant. These were marital status, household size, farm size, off-farm income activity and access to credit while other variables like age, gender, education of household head, fertilizer used by household and remittances were not significant in explaining the food security status of households. It has been found that household size and marital status had a negative relationship with food security while others positively contributed among the significant ones. The study recommended that off-farm business activities as well as rural credit market are needed to improve the food security status at household level.

Ali and Khan (2013) is eleventh study that analyzed the food security and its determinants. However, the major focus of investigation was to quantify the impact of livestock ownership on food security in Pakistan. They carried out a comprehensive survey to collect data from Hafizabad, Gujranwala and Shekhupura from 234 households in the rice-wheat area of Pakistani Punjab. The study employed the Poission Regression Analysis technique to assess the determinants of ownership of livestock. Further, the Propensity Score Matching technique was also applied to find what impact livestock ownership has on food security. They also drew a comparison between owners of livestock and those who did not own. Results revealed that food security levels were higher ranging 19 to 41 percent for households having livestock ownership in comparison with those having no livestock ownership. The findings of the study suggested that livestock ownership positively affected food security in Pakistan and the comparison showed livestock owning households were more food secure than non-owners.

Sajjad, et al. (2014) is twelfth study that analyzed food security. Food Security Index (FSI) was constructed using three components that are availability, accessibility and utilization. The FSI captures both spatial and temporal variation in food security at block level in district Vaishali during 2000-03 and 2007-10 in India. Division by mean method[25] was adopted for the construction of the index. In this method the mean value for each indicator of the component for each block was calculated. Then the value of each indicator for a given component of the corresponding block was divided by their respective mean. The outcome is known as the Scale Free Value. The linear sum of this value was weighted by the inverse of the number of variables in each component which resulted in the FSI. The food 'Availability' component comprises of per capita crop value, proportion of irrigated area, and rural connectivity. The food 'Accessibility' component consists of the proportion of agricultural labor to the total number of workers, proportion of scheduled castes and scheduled tribes to the total population and female literacy rate. The food 'Utilization' component includes the percentage of households having safe drinking water facilities, primary health care and primary school enrolment per 1000 population. At the end, these blocks were ranked on the bases of FSI taking more than 1.0 value as progressive blocks having better claim to food security. Similarly the blocks with FSI lower than 1.0 were known as retrograde blocks holding poor circumstances for sustainable development of food security during the reference period. The study concluded that the FSI does not only identify the blocks which require instant attention for improving food

[25] In case of positive indicator the value of each block is divided by the corresponding mean value of independent indicators while for negative indicator the mean of an indicator is divided by the corresponding value of each block. The outcome is called *Scale Free Value (SFV).*

security but by using time series data it also identified the priorities of its three components. The FSI approach can be utilized for analyzing food security situation and the progress that has been made over a period of time for sustainable food security condition.

The last study reviewed here in this section is by Bazezew (2014), which evaluates the determinants of household food security in three food insecure agro-ecological zones—Dega, Woina-Dega and Kolla[26], in Amhara National Regional State of Ethiopia. These were purposely selected because of the difference occurring in agro climatic conditions in these areas. The primary data was collected from 201 households during 2011. Household food availability was converted into kilocalories per capita per day to serve as dependent variable. Based on the minimum requirements of kcal per capita per day, 48 percent of the sampled households' were food insecure in Dega, 82 percent in Kolla and 92.9 percent in Woina-Dega zones. The results suggested that total yield per capita, household size, agro-ecological zone, number of oxen and total income were significant determinant variables in per capita kilocalorie availability of the sample households. The study recommended that among other factors, enhancing the kilocalorie supply of the poor households through crop and livelihood diversification has to be given top priority by decision makers. The result further showed that food availability was a serious problem in the study area that needed enhancing crop production through the application of agricultural inputs.

[26] Dega is cool, Woina-Dega is temperate and Kolla is hot tropical.

2.9.4.2 Food Security Studies Focusing on Climate Change Impacts

This section briefly reviews those studies that are directly relevant to the analysis of the present study. We found only five studies, which intended to investigate the impact of climate change on food security.

Butt, et al. (2005) was found to be the first study that projected the impact of change in climate variables on agriculture sector in Mali and its implications for food security. The study focused on its effects on crop yield, forages, and livestock and tried to establish their link to risk of hunger. Climate change predictions were made by using two global circulation models HADCM and CGCM for the year 2030. Results indicated that under climate change, crop yield would increase varying 6 percent to 17 percent at the national level while forage yields would decrease by 5 to 36 percent and livestock production would increase by 14 to 16 percent. Moreover, there was an expected increase in prices between 1 to 5 percent by 2030. The study suggested a number of management strategies that were needed to alleviate the effects of climate change such as development of heat resistant varieties, changing the cropping pattern and expansion of cropland. The study concluded that adopting to climate change would lower the risk of hunger to below 28 percent.

The second study reviewed here was done by Kar and Kar (2008) which examined the vulnerability of households to adverse climate variability and events like flood and cyclones, and identified the important factors obstructing food security within the subsistence production structure. Primary and secondary data were collected from Orissa state of India because this part is severely affected by deforestation and soil erosion. The response of the farmers with regards to farm level adaptation remained very poor. A total of 250 farmers were surveyed out of which around 40 percent adapted farming practices in response to climatic variability at farm level. A Cobb Douglas type production function was used for the purpose of analysis.

They found that lack of access to adequate credit and extension services were the major hindering factors to take short and long term improvement of the land. The estimated results showed that farm income was largely dependent upon input prices such as seed, fertilizer and livestock. It is expected that with increased use of bullock power and fertilizer and with the increase in duration of rainfall, farm income would increase by 27 percent. Highly significant response of farm income to precipitation implied that investment in irrigation is the best adaptive strategy to cope with adverse climatic impact on the income of poor farmers.

Demeke, et al. (2011) is the third study which analyzed the impact of rainfall variability on rural households' food security and vulnerability over time by using household panel data in Ethiopia. Household food security index was constructed by applying Principal Component Analysis (PCA) on food security indicators. The determinants of farm household level food security included physical, financial and natural human and social capital. Food security index was used as a dependent variable in a fixed effects regression model to determine the determinants of household food security over time and found that rainfall level and variability significantly impacted household food security. The results in general show that the highly food secured households tend to have higher level of human and livestock capital and experience favorable rainfall as compared to less food secured households.

The fourth study is by Abafita and Kim (2014) that measures the impact of rainfall on household food security status in rural Ethiopia. FSI index was generated using Principle Component Analysis (PCA) and by self-reported questionnaire[27]. OLS and instrument variable regressions were used to see the impacts of food security determinants. The data included 1577 peasant households from 15 villages for the year 2009. Land area, availability of food stock, number of crops cultivated,

[27]Self-reported questionnaire is recoded to take the value I if secure and zero for insecure

ownership of livestock, utilization of sanitary services were used in constructing the index. The result revealed that age and education of household head, adequacy of rainfall index[28], livestock possession, off farm income, soil conversation practices and per capita consumption expenditure positively and significantly related to household food security. While access to credit and remittance negative contributed to food security status. The study suggests that joint and judicious efforts are needed in improving the livelihood of the people in rural area.

Belloumi (2014) is the fifth study which measures the impact of climate change on food security indicators in the presence of control variables. The data cover the period of 1961-2011 for 10 Eastern and Southern African countries. Fixed effect model was used for this purpose. Food production index, mortality rate of people under five years of age and life expectancy at birth serves as food security indicator while GDP per capita, inflation, population growth, and land under cereal production, average precipitation and mean annual temperature used as food security determinants. Results indicated that overall rainfall has a positive and significant effect on food security, whereas the effect of temperature is negative so the countries that experience unstable rainfall and increases in temperature could have adverse effects on food production, malnutrition, and mortality rates. The study recommended that modern agricultural techniques such as improved irrigation systems are needed to mitigate the impact of climate change.

The first set of food security studies reviewed in this section used the common determinants and indicators of food security status such as socioeconomic and income sources with little focus on the impact of climate change on the households as summarized in Table 2.5. The second set of studies summarized in Table 2.6 and

[28] The subjective rainfall index is generated to calculate rainfall adequacy in the preceding agricultural season. Responses are dichotomized in such a way that favorable responses are recoded into one and unfavorable into zero; sum of these recoded responses is then divided by the number of rain related questions.

briefly reviewed here are found capturing the climatic variable as a determinants for food security. However, the climatic variables used are weekly average precipitation in the sample area, rainfall index, average precipitation and mean annual temperature. The methodologies used to compute the food security index has been the principle component analysis, fixed or random effect models, and/or multinomial logit model.

The aforementioned empirical studies that measure the impact of climate change on household food security use proxies for climatic phenomena like drought intensity, rainfall zones dummies and dummies for climate change perceptions and rainfall satisfaction index. The present study captures the impacts of climate shocks (climatic deviation from long run normal) on food security. In addition to this the present study extends the analysis by incorporating farm efficiencies—both production and profit, as important components of the food security definition. It also determines the household food security status overtime. It explores the effects of socioeconomic characteristics in addition to climate change across the food security groups applying the logit model approach.

Table: 2. 1 Climate Change Impact Studies in Agriculture

S.NO	Author(s)/Country	Sample Size, Time period and Data	Method	Dependent Variables	Control Variables	Climatic Variables	Major Results
1	Deschenes and Greenstone (2006) United States	2,268 counties; 1987, 1992, 1997, 2002 Balanced panel	Hedonic price FEM	Farmland values	Soil character, Socio-econ & locational attributes	Growing season degree day days and mean temperature and total precipitation	Climate change agri. ↑ profit by /annum
2	Schlenker and Roberts (2006) United States	1,839 U.S. counties; 1950 to 2004.	Yield simulation models	Corn yields	nil	Growing degree days, average precipitation	Corn & soybean yields increased linearly with temperature until 29°C and for cotton up to 33°C
3	Lobell, et al. (2007) California	12 crops, 961-2000	Second order polynomial regression	Yield of crops	nil	minimum and maximum temperature, total precipitation	Climatic variables cause two third of observed yield variance in most crops
4	Guiteras (2007) India	200 Districts; 1956-1986	Semi Ricardian approach FEM	Total Production	Labor, capital, Irrigation & fertilizer	average monthly precipitation & growing-season degree days	Climate change causes the total losses of 1-1.8 percent of output per year.
5	Molua (2008) Cameroon	200 districts; 1961–2001	FEM	Quantity index of permanent and arable crops,	Cultivated area, labor, fertilizer, pesticides, capital and irrigation.	Rainfall & temperature deviations from monthly mean divided by standard deviation	Economic value of predicted output in 2050, based at 1998 prices--ranged US$3.5-7.1 billion, which was 41% less & 18.5% greater than 1961–2001 mean respectively in the presence of climate change
6	Hanif, et al. (2009) Pakistan	11 districts; 1970-2009	Hedonic price FEM with FGLS	Land prices per acre	Pop. density, per capita income, area under cultivation	mean minimum and maximum temperatures; mean precipitation (both kharif and rabi)	An increase in maximum temperature by 1^0C caused agri. land price to increase by Rs.25208.66 per acre and ↑ in precipitation of one mm, agricultural land price will ↓ by Rs. 860 per acre

Table: 2.1 Continue…………

S.NO	Author(s)/Country	Sample Size, Time period and Data Type	Method	Dependent Variables	Control Variables	Climatic Variables	Major Results
7	Ahmed and Schmitz (2011) Pakistan	Four provinces, 1987-2004	FEM and REM	Yield/hac of wheat, rice and maize	Fertilizer, credit, tube wells, labor and tractors,	average rabi temperature, & precipitation, drought —rainfall deviation from long-term normals,	1^0C ↑ in temperature ↓ crop yields by 44 kilos/hectare. Drought also negatively and significantly affected food crop yields
8	Auffhammer, et al. (2012) India	9 states, 1966-2002	FEM and Monte Carlo simulation	Rice yield	Irrigated area, HYV area, fertilizer, labor, Solar radiation,	Total Rainfall, Drought, Extreme Rainfall, Minimum Temperature	Monsoon effect was nonlinear and yield would have been 5.67% higher in absence of climate change.
9	Lee and Nadolnyak (2012) U.S.	48 states, 2000-2009 Pooled data	OLS, FEM	Profits from crops and livestock production	Input price, output prices, age, non-farm participation	growing season drought index, severity index and crop moisture index	A unit ↑ Drought index leads to 5.5%, 4% & 5% ↑ in farm profits, while a unit ↑ in Moisture Index leads to ↑ profits by 13.9%, 9% & 14%,
10	Siddiqui, et al. (2012) Pakistan	8 districts; 1980-2008	OLS, FEM	Productivity of Rice, Wheat, Cotton, Sugarcane	nil	monthly averages of temperature & precipitation; their square terms	Climate change impacted wheat productivity positively, rice, cotton & sugarcane influenced negatively beyond a certain optimal level.
11	Ahmed, et al. (2014) Pakistan	14 district; 1987-2010	FEM	Basmati and Coarse Rice Yield	Area, Fertilizer	20 year moving averages of temperature and precipitation, square terms, and deviations	Existed a nonlinear relationship between precipitation and rice productivity. Combined effect of climatic variables was found significant in case of Basmati rice
12	Javed, et al. (2014) Pakistan	67 Districts; 1981-2010	FEM, GMM	Laspeyres quantity index for 33 crops and revenue (Y)	Lagged Y, tubewells, tractors, area and fertilizer	20 year moving averages of temperature and precipitation, deviations and square terms	Agricultural production positively affected by ↑ in precipitation; ↑ in temperature negatively affected
13	Ahmad, et al. (2014) Pakistan	19 districts; 1981-2010	FEM	Wheat yield	Area, Fertilizer	20 year moving averages of temperature and precipitation, deviations and square terms	1°C ↑ temperature at sowing reduces wheat yield by 7.4%, increases yield by 6.2% at vegetative stage, no impact at maturity stage. Precipitation normal & their deviations positively impacted wheat yield

Note: FEM=Fixed effect model; REM=Random Effect model; FGLS=Feasible generalized least square; OLS=Ordinary Least Square; GMM=General method of moment

Table: 2. 2 Empirical Studies Related to Countries other than Pakistan

S.No	Auther(s)/ Country	Sample Size and Time Period	Functional Form	Method	Dependent Variables	Explanatory Variables	Technical Efficiency Determinants	% of Efficiency
1	Kalirajan (1991) India	30 farms; 1983 to 1986	TL	SFA (MLE) OLS	Output of rice in tones	labor, Rice area, expenditure on inputs & seasonal dummy	education, confidence in technology, extension services & farm size	TE=53 to 95
2	Bravo-Ureta and Pinheiro (1993) Developing countries'agriculture.	30 articles from 14 developing countries					Education, experience, extension services, agricultural credit &farm size.	TE=72
3	Battese and Coelli (1995) India	14 farmers; 1975-76 to 1984-85	CD	SFA(MLE)	Total value of rice output	total area, operational area, labor, bullocks & cost of variable inputs	age, schooling year & year of observation involve	nil
4	Yao, et al. (2001) China	30 provinces;1987–92	CD and TL	SFA(MLE)	Total grain output	area sown, labor, fertilizer, total machinery input & the irrigation ratio.	number of research and development personnel, the disaster index, cropping index, rural population & crop labor share in the total rural labor force.	TE= 55
5	O'Neil and Matthews (2001) Irish	2,603farms;1984 to 1998 Unbalanced	TL	SFA(MLE)	Gross farm output (Tornqvist-Theil (TT) value indices)	labor, capital & variable inputs	farmer's age, farm borrowing/ farm assets ratio, off-farm job, location ,household & farm size	TE= 65 to 70
6	Wadud (2003) Bangladesh	150 farmers; 1997	CD	DEA and SFA	Rice production in kg	land ,labor, irrigation, fertilizers, pesticides & their prices	age, year of schooling, land fragmentation, irrigation, infrastructure, land degradation	TE=80 AE=77 EE=61 with SFA TE=86 AE=91 EE=78 ;TE=91 AE=87 EE=79 with DEA
7	Rahman (2003) Bangladesh	380 farms; 1997	TL	SFA(MLE)	Farm Profit	fertilizer price, seed, pesticide, animal power, labor wage, , area under modern rice varieties & farm capital	tenure, education, experience, extension, infrastructure, soil fertility & non-agricultural income	PE=0.77.
8	Binam, et al. (2004) Cameroon	450 farmers; 2001-02	CD	SFA(MLE)	Quantity of maize and groundnut	cultivated land , family labor, exchange labor, hired labor & farm capital	Education, credit, fertile areas, organizations' membership, extension& distance from road	TE= 73

Table: 2.2 Continue……

S.No	Auther(s)/ Country	Sample Size and Time Period	Functional Form	Method	Dependent Variables	Explanatory Variables	Technical Efficiency Determinants	% of Efficiency
9	Adam, et al. (2005) Sudan	100 tenants; 2002-03	CD	SFA(MLE)	Yield of sorghum	credit , cultivated area, family labor, hired labor, fertilizer, number of irrigations & capital	age, family size, farm size, education, experience, location, off-farm income & extension	TE=67
10	Thiruchelvam (2005) Srilanka.	45 owners and 45 share growers; 2004	CD	SFA(MLE)	Output index for chilies and onion	land holding, cost of labor, machinery power, agrochemicals & seeds	Farm ownership, farming category, debt level, farmer participation score, distance-from-home & age.	TE=88 & 76
11	Rios and Shively (2005) Vietnam	209 farmers; 2004	LP	DEA, TR	Yield of coffee and total cost of coffee production	family labor, hired labor, fertilizer, herbicides & pesticides	education, tenure, Credit ,Pump number& irrigation pipe (length in meters)	TE=.82 to.89 CE=.42 to .58
12	Kibara (2005) Kenya	2017 household; 2003-04	TL	SFA(MLE)	Maize Yield	fertilizer, seed &labor,	FYM, tractor, hybrid seed, school years, age ,off-farm income, obtained credit & region potential	TE=.49
13	Alemu, et al. (2007) Ethiopia	254 farmers; 2007	CD	SFA(MLE)	Aggregate Crop Output	labor, fertilizer, draft power, farm implements, land & volume of modern inputs	age, sex, literacy, extension, market distance, poverty, credit, male members, family size, livestock owns, off-farm activity	TE=75.68
14	Kariuki, et al. (2008) Kenya	1340 farmers; 2008	CD	SFA(MLE)	Total value of farm output	land size, cost of manure, inorganic fertilizer, land preparation, seed & dummy variables for main source of water	credit, tenure status & membership to farming groups	TE=60 to 66
15	Fakayode (2009) Nigeria	264 growers; 2007 and 2008	CD	SFA(MLE)	Rice output	farm size, labor, seed, credit, fertilizer & herbicide	Experience, household size, education, extension & rice variety planted	TE=40.1 &60

Table: 2.2 Continue……

S:No	Auther(s)/ Country	Sample Size and Time Period	Functional Form	Method	Dependent Variables	Explanatory Variables	Technical Efficiency Determinants	% of Efficiency
16	Solis, et al. (2009) Central America	693 farms; 2002.	TL	SDF	staple crop, cash crops, livestock products & off farm income	land, family labor, hired labor, off farm labor, purchased inputs & land's slope	age, education, gender, ownership, credit &participation in farm organizations	TE=78
17	Nganga, et al. (2010 Kenya	40 farmer; 2006 to 2008	CD	SFA(MLE)	Farm Profit	feed cost, drug cost, wage & herd size.	age, education, experience & household size	PE=60
18	Kyei, et al. (2011) Ghana.	100 households; 2009-10.	CD	SFA(MLE)	Total output of cocoa	labor, fertilizer, pesticides, modern equipment's, age of trees & farm sizes.	age , family size, educational, experience, credit, technical assistance, training to farmers	TE=0.0279
19	Theodoridis and Anwar (2011) Bangladesh	240 farms; 2003-04	TL	DEA and SFA	Value of gross output of farm	land , labor, contract and instant paid of input costs	Age, education; land degradation & training or attended any seminar of crop production,	TE=0.82, & under CRS & VRS, 0.77, 0.82
20	Linh (2012) Vietnam.	595 farms; 2003-2004 survey	CD	DEA and SFA TR	Rice quantity	fertilizers, pesticides, seed, equipment, family labor, hired labor, owned fixed asset ,equipment value, asset hire and maintenance, small tool and energy, farming expenditure & rice land	education, farm size, regional factors, number of cultivation. adult ratio, household size, irrigation, age ,extension services & others	TE= 0.634 & under CRS&VRS 0.70 &0.76
21	Dhehibi, et al. (2012) Africa	51 growers; 2008–2009	CD	DEA and SFA	Wheat production	land, labor, seed, fertilizer & machinery	education, rotation of crops, share of wheat area, share of family labor and presence of livestock	TE=76

Table: 2.2 Continue……

S:No	Auther(s)/ Country	Sample Size and Time Period	Functional Form	Method	Dependent Variables	Explanatory Variables	Technical Efficiency Determinants	% of Efficiency
22	Thibbotuwawa, et al. (2013) Sri Lanka.	90 farms during 2007	LP	DEA Metafrontier	Rice yield	seed, fertilizer, chemicals, labor and machinery &their prices	water availability, seed quality, land extent & ownership, labor participation & machinery use	TE, AE, CE and SE were 0.87, 0.80, 0.69 & 0.92 respectively
23	Adedeji, et al. (2013) Nigeria.	60 farmers;2012	CD	SFA(MLE)	Total egg produce	number of birds, family and hired labor, drugs, vaccine, chemicals and feed	Credit, age, education, farming experience, stock size, number of extension contact & membership of farmers associations.	TE=66
24	Watkins, et al. (2014) Arkansas	137 farms; 2005 to 2011.	LP	DEA TR	Rice production value	agriculture inputs and their prices	field typography, rice varieties, farm size, irrigation type, soil texture & field location,	TE=89,AE=.69 & EE=0.625

Note: TE =Technical Efficiency; AE = Allocative efficiency; EE = Economic Efficiency; CE = Cost Efficiency; SE =Scale Efficiency; PE =Profit Efficiency; CD = Cobb-Douglas; TL= Translog; LP=linear programming; SFA=Stochastic frontier approach; SDF= Stochastic distance frontier; CRS=Constant return to scale; VRS=Variable return to scale; GTRE=Generalized True Random Effects; MLE=Maximum likelihood estimates; TR=Tobit regression; DEA=Data envelopment analysis; GLM=Generalized Linear Model; OLS=Ordinary Least Squares regression;

Table: 2. 3 Empirical Studies Related to Agriculture of Pakistan

S.No	Author(s)/Districts	Sample Size and Time Period	Functional Form	Method	Dependent Variable	Explanatory variables	Determinants of Technical Efficiency	% of Efficiency
1	Battese, et al. (1993) Faisalabad, Attock, Badin, and Dir	109, 138, 113, and 139 farmers; 1986 to 1991	CD	SFA(MLE)	Wheat in kg	Permanent &hired labor, land, NPK, land preparation, seed, land ownership & #plough	age, year of schooling, ratio of adults	TE=57 to 79
2	Battese and Broca (1997) Faisalabad	87, 77, 81 and 85 growers; 1986 to 1991.	CD and TL	SFA(MLE)	Wheat in kg	Land, labor, fertilizer & seed	age, year of schooling, credit & ownership	TE=50 to 100
3	Ahmad, et al. (1999) Sheikhpura	84 farms; 1996-97	CD	SFA(MLE)	Output of Basmati 385 in maunds per farm;	nursery, land preparation, fertilizer, irrigation, pesticide & weedicide cost & zinc	age, extension services, credit facilities, ratio of farm area owned	TE=57 to 96
4	Ahmad, et al. (2002) KPK, Punjab and Sindh.	2228 farmers;1997-1998	CD	SFA(MLE)	Wheat output per acre	NPK, seed, FYM, source of irrigation, ratio of area under rice & cotton crop	age, education, farm ownership status, farm size, market ,credit facilities, extension services	TE=68
5	Ahmad (2003) KPK, Balochistan. Punjab and Sindh.	1112 farms; 2000-2001	CD	SFA(MLE)	Weighted index of output from all crops grown	agricultural inputs, irrigation source, soil quality & proportion of the area devoted to major crops	education, age, land fragmentation, the number of plots, tractor and tube wells ownership and access to loans	TE=17 to 62
6	Hassan and Ahmad (2005) Punjab	112 wheat farmers; 2005	CD	SFA(MLE)	Total wheat production (in maunds i.e. 40 kg)	wheat area, irrigation, weedicide, fertilizer, FYM, family labor & seed	sowing time, farm area, education ,location at the watercourse, credit, sowing method ,tube well	TE=0.58 to 0.98.
7	Javed, et al. (2009) Punjab	200 farmers;2005/06	LP	DEA TR	The total income from crops and livestock	tractors, seed, NPK, pesticide , labor, irrigation , fodder & concentrates	schooling , age , contact with extension agents, mket distance, credit, and tenancy	TE=0.87, EE=0.37, AE=0.44

Table: 2.3 Continue…………

S.No	Author(s)/Districts	Sample Size and Time Period	Functional Form	Method	Dependent Variable	Explanatory variables	Determinants of Technical Efficiency	% of Efficiency
8	Javed, et al. (2011) Central Punjab	200 farms;2006-07	LP	DEA	The total income from crops and livestock	land, tractor, seed, NPK, pesticide, labor, irrigation, fodder & concentrates	Nil	TE= 0.87, 0.79 & 0.81 SE= 0.79, 0.94 & 0.94
9	Hussain, et al. (2012) Cropping zones in Punjab	70 farmers;2009-10	CD	SFA(MLE)	Yield of wheat	cultivated area, ploughings number, seed, weedicide costs, irrigations numbers, NPK & FYM	age, education, experience ,sowing time, operational area, extension & credit service	TE = 76.2, 83.5 &76.9
10	Sohail, et al. (2012) Sargodha	83 farmers; 2007	LP	DEA TR	Total value of wheat and citrus output	threshing labor, total labor, cultivated area, seed, tractor, nutrients, FYM weedicide & irrigation#	experience, education, distance from market & family size	TE =0.87
11	Khan and Ghafar (2013) Peshawar	120 growers; 2012	CD	SFA(MLE)	Tomato output obtained per hectare	cultivated area, # of seedlings, pesticide, fertilizer, labor, tractor & irrigation#	education, area cultivated, experience, credit & age	TE =92

Note: TE =Technical Efficiency; AE = Allocative efficiency; EE = Economic Efficiency; SE =Scale Efficiency; CD = Cobb-Douglas; TL= Translog; LP=linear programming; SFA=Stochastic frontier approach; MLE=Maximum likelihood estimates; TR=Tobit regression; DEA=Data envelopment analysis;

Table: 2. 4 Frontier Application in Climate Change Impact Studies

S.No	Auther(s) Country	Sample Size and Time Period	Functional Form	Method	Dependent Variables	Explanatory Variables	Determinants of TE	% of Efficiency	Major Results
1	Demir and Mahmud (2002) Turky	67 provinces; 1993 to 1995	TL	SFA(MLE)	Total value including both crop and animals	land ownership, labor, capital index, land quality & precipitation	land ownership, land quality, cropping pattern & rainfall (a dummy variable)	TE=.02 to .97	Inclusion of agro climatic factors improved efficiency estimates. Marginal impacts of inputs got influenced by them.
2	Coelli, et al. (2003) Bangladesh	16 regions; 1961 to 1992	TL	SFA(MLE)	Aggregate crop output (Value)	labor, land area, animal power, fertilizer dummy for 1989 flood	green revolution tech., education ,flood proneness, drought proneness, infrastructure, extension & research	TE=0.47	TFP ↓ by 0.23%/ year due depletion of soil nutrients among other factors and TE ↓ remained persistent
3	Vicente (2004) Brazil	All crops;1995-96	LP	DEA TR	Fisher quantity index	Cultivated land, total labor, machines, fertilizers, pesticides, seeds & seedlings.	human capital, land quality, mean rainfall, air temperature and their interaction, hydric deficiency, irrigation and technical assistance	TE=72 and AE=46	Climate affected TE significantly and crop production ↑ by more than 30 % if full technical efficiency level was achieved
4	Kompas and NhuChe (2006) Australia	252 farms; 1996, 1998 and 2000	CD	SFA(MLE)	Total output: gross value from milk and dairy cattle sold	livestock capital, land area, labor, fodder, materials & services, plant & structure capital & 1998 drought dummy	dairy shed technology, the proportion of land irrigated, feed concentration & the number of dairy cows milked	TE= 87 and 84	water & its availability was a major determinant for both the production and efficiency
5	Songsrirote and Singhapreecha (2007) China	165 farms; 2005-06.	CD and TL	SFA(MLE) Timmer and Kopp indices	Farm's total rice output	seed, labor, organic and chemical fertilizer and amount of machinery use	Learning, health, demographic, location, management, household finance, climate (Rainfall in rating or ratio scale), government support & infrastructure access	TE=0.4499 to 0.8666	Rainfall was found positively and insignificantly related to inefficiency of traditional and organic farm.
6	Sotelsek and Laborda (2010) Latin America	18 states; 1980 to 2004	**nil**	MPI	GDP	Co2 emissions,	nil	nil	Environmental factors improved the estimates as compared to traditional approaches of efficiency measurement

Table: 2.4 Continue…………

S.No	Auther(s) Country	Sample Size and Time Period	Functional Form	Method	Dependent Variables	Explanatory Variables	Determinants of TE	% of Efficiency	Major Results
7	Hughes, et al. (2011) Australian	4255 farms; 1977–78 to 2007–08	TL	SFA(MLE)	Fisher quantity index	Land, labor, capital, material price index ,total rainfall, average monthly max & min temperature	nil	nil	Quadratic relationship between output & rainfall; rainfall positively affects & extreme temperature negatively impact output.
8	Deressa (2011) Ethiopia	1000 farmers; 2003-04	CD	SFA(MLE) TR, OLS	Value of crops produced per farm	fertilizer, labor, animal power, tractor, farm size & seed	seasonal average precipitation and temperature, education, size of household ,soil type & dummy for agro climatic zones	TE=4.2 to 87	↑ spring & summer temperatures ⇒ ↓ TE, while ↑ in fall season ⇒ ↑ TE. ↑ in precipitation in winter & fall ↓ TE, while ↑ in summer & spring ⇒↑ TE
9	Makki and Ferrianta (2012) Indonesia.	180 growers; 2012	CD	SFA(MLE)	Rice production	land, seed, fertilizer urea, inorganic fertilizers besides urea, drugs & labor and dummy if land is affected by climate change	age, education & experience		Climate change negatively impacted local rice varieties' production in tidal land. Farm level management practices ⇒↑ production efficiencies under climate vagaries
10	Pereda and Alves (2012) Brazil.	9 crops; 2006.	TL	SFA(MLE) TR,OLS,LR	Farm net profit	land, fuel, long run average temperature & rainfall, labor & fertilizers	education, land type, farm size, climatic shocks for each season calculated as the difference between the current observed value and the long-term average temperature and rainfall divided by standard deviation	PE=51.3	↓ rainfall impact only soybean profit shares, while ↑ temperatures negatively affected maize, coffee and beef; climate deviations affected profit efficiency negatively; Total loss from lack of rainfall estimated 5.6% of farmers current profit
11	Mukherjee, et al. (2013) United States	77 in Florida and 26 in Georgia;1995 to 2008	TL	SFA(MLE)	Annual milk sold per farm	number of dairy cows, annual feed use, permanent workers, capital flow, dummy for growth hormones used,	dairy herd size and expenses per cow	TE=68 to 90	Temperature Indexes had significant nonlinear negative effect on milk production

Table: 2.4 Continue…………

S.No	Auther(s) Country	Sample Size and Time Period	Function al Form	Method	Dependent Variables	Explanatory Variables	Determinants of TE	% of Efficiency	Major Results
12	Auci and Vignani (2014) Italy	20 regions; 2000-2010.	CD	SFA(MLE)	Crop yield	irrigated area, seed, fertilizer & labor man-days	annual total rainfall and min temperature from respective long-term means—30 years moving average and dummies for	TE=.08 to .99	Rainfall had a positive impact on efficiency while minimum temperature ↓ the technical efficiency
13	Key and Sneeringer (2014) United States	24 states; 2005 and 2010	TL	SFA(MLE), GCMs	Milk production	milk cows, feed, labor, capital, expenditures on medicine and veterinary services	Education, age, experience, operation size, milk sales a share of total dairy, temperature humidity index (deviation from long run	nil	Negative relationship between expected heat stress and technical efficiency & milk production of an average dairy farm would ↓ by 0.60 to 1.35 % due to the change in climate
14	Lachaud, M. A., et al (2015) Latin America and Caribbean (LAC), Asia, Sub-Saharan, Africa, Middle East and North Africa, Europe	112 countries; 1961 to 2012	CD	GTRE, SFA and panel data techniques	Gross Output which combines aggregate crop and livestock products	tractors, fertilizer, animal stock, land, labor, mean total precipitation, number of rainy days, annual max. temperature and monthly intra-year standard deviations	Nil	TE=.82	The combined effect of temperature, precipitation irregularity & frequency of rainfall had a negative impact on production. climatic index has, on average, ↓ impact on production over time
15	Qi, Lingqiao., et al (2015) United State	54 dairy farms;1996 to 2012.	CD	SFA,FEM and REM	total milk equivalent production	number of adult cows, labor, concentrate feed, depreciation, animal & crop expenses, average seasonal temperature & precipitation	Nil	TE=92	Temperature & output is negative associated in summer, while is positive in winter. Greater ↑ in rainfall adversely affected dairy productivity. Negative association existed between milk production and climate effect index

Note: TE =Technical Efficiency; AE = Allocative efficiency; EE = Economic Efficiency; CE = Cost Efficiency; SE =Scale Efficiency; PE =Profit Efficiency; CD = Cobb-Douglas; TL= Translog; LP=linear programming; SFA=Stochastic frontier approach; SDF= Stochastic distance frontier; CRS=Constant return to scale; VRS=Variable return to scale; FEM=Fixed effect model; REM=Random effect model; GTRE=Generalized True Random Effects; GCMs=General Circulation Models; MLE=Maximum likelihood estimates; TR=Tobit regression; MPI=Malmquist productivity indices; DEA=Data envelopment analysis; GLM=Generalized Linear Model; OLS=Ordinary Least Squares regression; LR=Logit regression

Table: 2. 5 Food Security Studies

S.No	Auther(s) Country	Sample Size and Time Period	Method	Food Security Indicators	Food Security Determinants
1	Haile, et al. (2005) Ethiopia.	108 households;2003	LR	calorie availability and calorie demand	Farm land size, oxen ownership, fertilizer application, education level of household heads, household size and per capita production.
2	Amaza, et al. (2006) Nigeria	1,200 households;2004	CCA LR	Daily energy levels per adult equivalent per year.	Age, farm income, farm size, household size, experience, co-operative membership, education, distance to input source, gender of head, diversification index, assets value, production, credit access, child dependency ratio, extension services, commercialization, remittances received/adult equivalent/annum, hired and family labor.
3	Qureshi (2007) South America	275 household; 2005 and 2006.	PCA	Cultivated area, planting of major food crops, storing major food crops from last harvest and stored seeds. Kilocalories of food consumed, value of modern assets	Nil
4	Tesfaye, et al. (2008) Ethiopia.	200 farmers;2005/2006	HTSP	users and non-users of small scale irrigation	Household endowment, household characteristics, access to information & services
5	Khan and Gill (2009) Pakistan	120 districts; 2003	OLS	food availability, accessibility and absorption categories	immunization rate, female literacy rate, provision of safe drinking water and number of hospitals in the district and locality, household income, other socioeconomic variables,
6	Carter, et al. (2010) New Zealand	18,950 families; 2002 to 2010	LR	socioeconomic position for individuals	Demographic and socioeconomic variables.
7	Arene and Anyaeji (2010) Nigeria	60 respondents; 2009	LR	per capita monthly food expenditure	gender, household size, income, credit access, and age and education
8	Sultana and Kiani (2011) Pakistan	(PSLM) for the year 2007-08.	LR,CCA	Calories intake	place of residence, dependency ratio, social capital, educational level and employment status of the head of household
9	Bogale (2012) Ethiopia	277 households; 2010	FGLS	Household’s food consumption expenditure	family size, cultivated area, soil fertility, tenure status, access to irrigation, use of fertilizer, improved seed and extension services
10	Aidoo, et al. (2013) Ghana.	100 households; 2011	LR	home production, stocks, purchase, barter, gifts, borrowing or food aid	marital status, household size, farm size, off-farm income activity and access to credit, age, gender, education of household head, fertilizer used by household and remittances

Table: 2.5 Continue…………

S.No	Auther(s) Country	Sample Size and Time Period	Method	Food Security Indicators	Food Security Determinants
11	Ali and Khan (2013) Pakistan	234 households; 2010	PRA	ownership of livestock	market distance, age, caste, settler, education, family size, land holding, refrigerator, Tractor, Motorcycle Car , Tube well , Radio , Credit, Agri. Extension , Income from livestock sale
12	Sajjad, et al. (2014) India	16 blocks; 2000-03 and 2007-10	DMM	per capita crop value, proportion of irrigated area, and rural connectivity, agricultural labor to the total number of workers, proportion of scheduled castes and scheduled tribes to the total population and female literacy rate. safe drinking water facilities, having primary health care and primary school enrolment	Nil
13	Bazezew (2014) Ethiopia.	201 households;2011	LR	kilocalories per capita per day	total yield per capita, household size, agro-ecological zone, number of oxen and total income

Note: FGLS=Feasible Generalized Least Squares; DMM=Division by mean method; PRA =Poission Regression Analysis; IVR =Instrument variable regressions; MLM =Multinomial logit Model; GCM =Global circulation models; CCM =Cost-of-Calories method; LR= Logit regression; PCA=Principle Component Analysis; HTSP =Heckman Two-Stage procedure; OLS=Ordinary Least Square regression ;CCA=Cost of Calories Approach

Table: 2. 6 Food Security Studies Focusing on Climate Change Impacts

S.No	Auther(s) Country	Sample Size and Time Period	Method	Food Security Indicators	Food Security Determinants	Major Results
1	Butt, et al. (2005) Mali	17 weather station;1996-2005	GCM	crop yields, forage yields and animal weight	CO2 level	Crop yield would ↑ varying 6 to 17 % at the national level while forage yields would ↓ by 5 to 36% and livestock production would ↑ by 14 to 16 % Moreover, there was an expected increase in prices between 1 to 5 % by 2030.
2	Kar and Kar (2008) India	250 farmers; 2008	CD-production function	gross farm revenue per hectare	Price of agricultural inputs, bullock power, labor fertilizer, pesticides, weekly average precipitation & dummy variable for adaption methods like changing cropping patterns	With ↑ use of bullock power, fertilizer and with the ↑ in duration of rainfall, farm income would ↑ by 27 %.
3	Demeke, et al. (2011) Ethiopia.	1477 households; 1994, 1999 and 2004	PCA,FEM,REM, MLM	Cultivated land, availability of stored crops, types of crops grown, food groups consumed & oxen owned	Physical, financial, natural (raifall index) human & social capital	Rainfall level and variability significantly impacted household food security. ↑ food secured households tend to have ↑ level of human and livestock capital and experience favorable rainfall as compared to less food secured households
4	Belloumi (2014) Africa	10 countries; 1961-2011	FEM	food production index, mortality rate of people under five years of age and life expectancy at birth.	GDP per capita, inflation, consumer prices, pop growth, land under cereal production, average precipitation in depth, mean annual temperature	Overall rainfall has a positive and significant effect on food security, whereas the effect of temperature is negative so the countries that experience unstable rainfall and ↑ in temperature could have adverse effects on food production, malnutrition, and mortality rates
5	Abafita and Kim (2014) Ethiopia	1577 household; 2009	PCA, OLS IVR	land area, availability of food stock, number of crops cultivated, ownership of livestock, utilization of sanitary services	Age, education, adequacy of rainfall index, livestock possession, off farm income, soil conversation practices, per capita consumption expenditure, credit & remittance	Adequacy of rainfall index along with soil conversation practices positively and significantly related to household food security

IVR =Instrument variable regressions; MLM =Multinomial logit Model; GCM =Global circulation models; LR= Logit regression; PCA=Principle Component Analysis; OLS=Ordinary Least Square regression; CD=Cobb Douglas; FEM=Fixed effect model

2.10 Summary

The empirical literature on inefficiency reveals that farmers in the third world are inefficient both technically and allocatively. In fact the former is more severe than the latter. A number of studies [Demir and Mahmud (2002), Coelli, et al. (2003), Vicente (2004), Kompas and NhuChe (2006), Songsrirote and Singhapreecha (2007), Hughes, et al. (2011), Deressa (2011), Pereda and Alves (2012), Mukherjee, et al. (2013), Key and Sneeringer (2014) and Qi, Lingqiao, et al (2015)] consider variability in climatic factors are important cause of farm level technical inefficiency. This suggests that there is substantial scope for increasing production efficiencies by addressing issues of climate change, We have, but a few, studies [Hughes, et al. (2011), Deressa (2011), Pereda and Alves (2012), Auci and Vignani (2014), Qi, Lingqiao., et al (2015) and Lachaud, et al (2015)] which have focused on the impact of change in climatic variables such as rainfall and temperature in measuring the productivity and efficiency of agriculture crops. Nevertheless these variables have considerable impact on crop productivity.

In this chapter, we reviewed the methods used in the studies. Frontier methods were used in farm performance studies applying output and input oriented approaches. In the case of output oriented approach "the focus is on the output to be maximized for a given level of input use" while in input oriented approach "the focus is on the minimum use of input for a given level of output". In frontier literature both parametric and non-parametric approaches are used for efficiency studies. Following the review of these studies, the present study favors using parametric approach—stochastic frontier (SFA) is selected because it has a particular advantage over the others specific to agriculture sector efficiency measurement.

All the studies reviewed above measured the impact of different variables on farm output in different parts of the world. However such work has not been extensively carried out in Pakistan due to paucity of primary data at micro level.The aggregate nature of these studies does not provide any insight on the impact of climate change on agriculture sector, farm efficiency and food security at farm household level in rural Pakistan. Therefore, the present study will evaluate the impact of different variables such as climatic, socioeconomic and farm characteristics on farm efficiency in rural Punjab, Pakistan. It also evaluates farm households' food security, and how is it influenced by climate change.

Chapter 3

METHODOLOGICAL FRAMEWORK

3.1 Introduction:

This chapter describes the statistical approaches used to measure the impact of climate change on agriculture productivity, farm level efficiency and farm household food security. The statistical technique combines both non-parametric and parametric approaches (Bauer 1990 and Berger and Mester 1997). This study uses the parametric approach applying stochastic frontier (SFA) framework for analyzing the impact of climate change on efficiency. The study first uses the production frontier incorporating technical efficiency effects in the model and then makes use of profit frontier capturing the profit inefficiency effects by applying single step estimation technique (Battese and Coelli 1995).The present study is also aiming to link the impact of climate change and farm specific levels of efficiency on farm household food security. By adopting principal component analysis a food security index is constructed to achieve this objective. It would serve as a target variable, and shall be regressed on socio-economic and climatic variables to assess the impact of climate change on the household food security status. The farm household would be categorize in to two groups food secure and insecure and then applies the logistic model approach.

This chapter is organized into five sections. Section two discusses the stochastic production frontier approach in general and different functional forms used for the efficiency model. Section three presents the model specification for measuring different types of efficiencies—Technical and Profit using climatic and non-climatic variables. The fourth section deals with the construction of household food security index using principal component analysis, and the empirical model used to investigate the impact of climatic and non-climatic variables on household food security status. The last section sums up the conclusion.

3.2 Stochastic Frontier Analysis

The production frontier applying estimated stochastic frontier method is more appropriate way to measure production efficiencies while using unit level datasets such as the household farm survey (Hughes, *et al.* 2011).The stochastic frontier model also allows producers specific random shocks (Thiam and Bravo-Ureta 2001). The traditional deterministic approaches can lead to overestimation of technical inefficiency because of not taking account of noise. The stochastic frontier approach uses a 'composite error term' having two components. One is technical inefficiency that is 'farm deviations from the production frontier,' and the other is statistical noise capturing the effect of random shocks on each producer characterized by the environment under which he/she operates (Coelli 1995). Additionally, this method also allows the statistical test of hypotheses' in respect of the production structure and the degree of inefficiency.

3.2.1 Functional Form of the Model

The parametric approach, which is also known as the econometric approach, requires a particular functional form. Different functional forms have been in the literature to evaluate the performance of farm. The most commonly used functional forms by researchers to measure the efficiency in the agriculture sector are the Cobb-Douglas and translog functions. The translog function is more flexible functional form and is most often written in its logarithm form such as

$$ln(Y_{it}) = \alpha_o + \sum_k \beta_k lnX_{kit} + \sum_j \beta_j ln\, X_{jit} + \frac{1}{2}\sum_j \sum_k \beta_{jk} lnX_{jit} lnX_{kit} \dots \dots (3.1)$$

Boisvert (1982) views this function in three ways: first, it is an exact production function; second, it's a second order Taylor series approximation to a general, but an unknown production function; and third, it is a second order approximation to a CES production function. Boisvert (1982) interpreted the exact production function as if all ($\beta_{jk} = 0$) the above function reduces to Cobb Douglas functional form as

$$ln(Y_{it}) = \alpha_o + \sum_k \beta_k lnX_{kit} + \sum_j \beta_j lnX_{jit} \dots \dots (3.2)$$

We preferred using Cobb Douglas functional form mainly due to reason that this study uses a large number of exogenous variables where a huge number of parameters to be estimated. Assuming n production factors, the numbers of parameters to be estimated would be equal to n(n+3)/2, which increase the probability of the occurrence of severe multicollinearity that may lead to contradictory signs of the estimated parameters (Pavelescu 2011). The present study uses the modified CD production function to assess the impact of climate change on farm productivity. Modified CD production function in a sense that climatic variables enters in the function in non-log form[29] (Ahmad and Ahmad 1998) and can be written as

$$Y_{it} = e^{\alpha_\circ + \sum_k \gamma_k X_{kit}^c} \prod_j (X_{jit}^{nc})^{\beta_j} e^{\varepsilon_{it}} \dots \dots (3.3)$$

[29] A number of studies has used log of climatic variables including Mahmood, et al. (2012), Acquah, and Kyei (2012), Bhandari (2013). However, the application of log on climatic variables will yield the elasticities that are interpreted in terms of percent change in the dependent variable due to 1 percent change in climatic variable. Whereas it may be more relevant to find out the impact of say $1^\circ C$ increase/change in long run norm of the temperature or 1mm decline/change in long run norm of precipitation on dependent variable (crop productivity, profit, revenue, land value etc.). Further, the disadvantage of taking log of temperature or precipitation is that it would requires strictly positive values of the climatic variable that in general can have 0 values (temperature as well as precipitation) or negative values (temperature). Thus taking log may truncate the data (Dell, Jones and Olken 2013, footnote 7, p. 8-9).

Natural logarithm on both side of equation has been taken to rewrite the equation in linear form as

$ln(Y_{it}) = \alpha_o + \sum_k \gamma_k X_{kit}^c + \sum_j \beta_j ln X_{jit}^{nc} + \varepsilon_{it}$ … … … … … … i = 1, 2, 3, … , N … …(3.4)

Where

ln denotes the natural logarithm to the base e

Y_{it} is the ith farm output in year t and t =1,2,3

X_{kit}^c stand for the climatic variables k (including rainfall, temperature) representing 20 year average of monthly mean temperature and precipitation

X_{jit}^{nc} is vector of non-climatic variables—these are j inputs (land, labor, capital and material) of the i^{th} farm during time t

γ_k is vector of parameters of climate variables

β_j is vector of parameters of non-climate variables

α_o is the constant term

ε_{it} is the random error term

3.2.2 Model Specification

Based on the review of literature, the present study prefers to use both production frontier and profit frontier analysis techniques. The reason of applying both procedures is that technical efficiency is related to farmer's long run profitability[30] (Ali and Chaudhury, 1990 and Hughes, et al.2011). In the presence of this inefficiency it is not possible for the farmer to operate on efficient profit frontier. So we drive nonprofit maximization problem in the presence of technical inefficiency and profit efficiency in this case is profit technical efficiency which can be understood as percentage loss in profit due to output technical inefficiency independent of input and output prices (Kumbhakar 2001).

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[30]Both variations in productivity and terms of trade (the ratio of output to input prices) determine profitability. As producers are price-takers, terms of trade is mainly given not under farmers' control, the main source of long-term profitability growth is productivity growth. Long-term productivity improvements traditionally enabled the farmers to balance the effect of decrease in prices on farm profitability. Technical change and technical efficiency improvements are explicitly good both for productivity and profitability (Hughes, et al.2011).

3.2.2.1 Stochastic Production Function under Climate Change

An average production function can be specified as

$Y_{it} \;=\; f\left(X_{kit}^{c}, X_{jit}^{nc}, \beta\right)\exp(\varepsilon_{it})$ i=1….N … …(3.5)

An average production assumes that all farmers are producing in a technical efficiency manner and the representative (average) farm defines the frontier (FAO 2003).The variations from the frontier are assumed to be random attributed to missed or unmeasured factors. On the other hand production frontier assumes that the production boundary is defined by the best practice farms. Production function therefore indicates the maximum potential output produce given the level of inputs.

Secondly, the addition of socioeconomic variables in the average production function is criticized because of its 'round about' effects on production which makes it unfit for inclusion in the model (Kalirajan and Obwona 1994). Since the study applies a stochastic production function analysis technique, the error term ε_{it} is decomposed into two components one is usual error term accommodating white noise v_{it} and u_{it} is one sided error representing the inefficiency at the farm level. The stochastic production function thus can be written as

$Y_{it} \;=\; f\left(X_{kit}^{c}, X_{jit}^{nc}, \beta\right)\exp(v_{it} - u_{it})$ i=1….N … … (3.6)

In this equation u_{it} represents the effects associated with technical inefficiencies of the farm and assume non-negative truncation on the normal distributed N $(0, \sigma_u)$ or have an exponential distribution. Whereas v_{it} is a random error having mean zero and constant variance σ_v (Battese, Malik and Gill 1996). Observed output Y_{it} is bounded above by the stochastic quantity $f\left(X_{kit}^{c}, X_{jit}^{nc}, \beta\right)\exp\left(v_{it,}\right)$ and thus the term stochastic frontier (Battese 1992).

The stochastic model proposed independently by Aigner, lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977), indicates that the technical efficiency can be defined as "the ratio of observed production Y_{it} to potential production Y_{it}^{*}". Hence, the technical efficiency of farm i at time t, in the context of the frontier production function is expressed as

$$TE_{it} = f\left(X_{kit}^{c}, X_{jit}^{nc}, \beta\right) \exp(v_{it} - u_{it}) / f\left(X_{kit}^{c}, X_{jit}^{nc}, \beta\right) \exp\left(v_{it,}\right) \quad \text{i=1....N}$$

$$= \exp\,(-u_{it}) \dots \dots (3.7)$$

Following Battese and Coelli (1995) the technical efficiency effects u_{it} can be written as

$$u_{it} = d_1 Z_{it} + e_{it}$$

The technical inefficiency affects u_{it} generated in the above equation specified as

$$TE_{it} = \exp\,(-d_1 Z_{it} - e_{it}) \dots \dots . (3.8)$$

Where u_{it} is a function of a set of explanatory variables normally including farm and farm specific Z_{it} and unknown vector of coefficients *d.* We extend this efficiency model given in Equation 3.8 by including the weather shocks variables DV_{it}, consequently the equation can be written as

$$TE_{it} = \exp\,(-d_1 Z_{it} - d_2 DV_{it} - e_{it})$$

Where e_{it} is a random variable having truncated normal distribution with zero mean and constant variance δ^2.The point of truncation is $-Z_{it} d_{it} - d_{it} DV_{it}$ indicating $-e_{it} \geq -Z_{it} d_{it} - d_{it} DV_{it}$.

This study uses Cobb Douglas (CD) production frontier function accommodating climatic and non-climatic variables as well as technical inefficiency effect model to capture the effects of weather shocks. The CD production frontier function is written in the linear form as follows

$$\ln(Y_{it}) = \alpha_o + \sum_k \gamma_k X_{kit}^{c} + \sum_j \beta_j ln X_{jit}^{nc} + v_{it} - u_{it} \dots \text{i} = 1, 2, 3, \dots, \text{N} \dots \dots (3.9)$$

And the technical inefficiency affects model u_{it} generated in the above equation is specified as

$$u_{it} = d_{\circ} + d_1 Z_{it} + d_2 DV_{it} + e_{it} \dots \dots . . (3.10)$$

where Z_{it} are the vectors of farmer and farm specific characteristics of the i^{th} household during year t, DV_{it} are the climate deviations from long run average (20 year moving average), e_{it} is the error term.

Battese and Coelli (1995) proposed the maximum likelihood method (MLE) applied for the simultaneous estimation of parameter of the stochastic production frontier and the inefficiency model. The MLE method shall make use of following variance parameter: δ^2 is total error variation, $\delta^2 = \delta^2{}_v + \delta^2{}_u$ and $\gamma = \frac{\delta_{\mu}^2}{\delta^2}$ which indicates the technical inefficiency contribution to total error variation with the help of R-frontier package in single step procedure. Battese and Coelli (1995) and Battese, *et al.* (1996) criticized the two-step modeling approach on the ground that it violated one of the most vital assumptions of stochastic frontier model i.e. ‘identically independently distributed technical inefficiency effects’.

To test the validity of the model various statistical test[31] can be performed. There is specific interest in testing the null hypothesis $H_0 = \gamma = 0$ that the technical inefficiency effects are not present in the model and are not random. Further, the null hypothesis that the household specific characteristics have not any influence on technical inefficiency level described in Equation 3.10 is expressed by $H_0 = d' = 0$,

[31] The generalized likelihood-ratio statistic λ is defined as λ = -2 ln [$L.(H_0)/L.(H_1)$], where H_0 and H_1 are the null and alternative hypotheses specifications. If H_0 is true, then it is distributed asymptotically as a chi-square random variable.(see Coelli 1995 and 1996)

where d' denotes the vector of parameter, d with the constant term d_0 omitted, assumed that it is included in the expression $Z_{it}d'$.

3.2.2.2 Stochastic Profit Function under Climate Change

The profit approach is a partial equilibrium model founded on the microeconomic production theory. By specifying profits, it is possible to obtain the farmer's optimal input-output allocation by optimization. However, optimal allocation only happens when there is no inefficiency. Farmers try to maximize following profit function which is the function of input and output prices and exogenous variables *F*.

$$\pi = R - C = \pi(p, w, F) \dots \dots (3.11)$$

Let the firm produces the optimum output 'y°', given factor input and output prices and exogenous variables *F*, it can be written as

$$y^{\circ} = argmax_y\{\pi(p, w, F)\} \dots \dots (3.12)$$

Assumption is that farmers allocate their x variable inputs for y types of production. As we are dealing with multiple output and inputs in the production function, the number of inputs and output denoted by Y and they are collectively named netputs. The vector Y denotes the netputs, then Y ≥ 0 when an output, and $Y \leq 0$ when it is an input. The number of inputs and outputs range from 1 to m. Each producer faces a quasi-fixed inputs represented by *F*. The *F* vector includes some exogenous variables that are fixed in the short run such that *F* is vector of exogenous climatic and non-climatic variables (technology variables) F=X^c+X^{nc}. The transformation function is called joint production function (Y/F) which is conditional on the presence of these fixed inputs.

Given the market is competitive the farmers decide the quantity of production and the quantity of inputs to be used by solving the profit maximization problem. Thus, prices $p = p_1 \dots\dots p_m$, and $w = w_1 \dots\dots w_m$, are respectively vectors of outputs and inputs prices and are considered as exogenous. Prices significantly affect production and factor use decision, i.e. $Y = Y_1 \dots\dots . Y_m$. The farmer optimization problem can be expressed as

$max_{\{Y_1 \dots\dots Y_m\}} = \sum_{m=1}^{M} \pi_{y \geq 0}(p, w, F)$ subject to the technology $f(\text{Y}) \leq 0 \dots \dots$ (3.13)

Where production function *f (.)* transforms inputs into outputs. By choosing multiple outputs and inputs allocation given an endowment of fixed factors (fixed in the short-run), prices and time, farmers maximize a short-run restricted profit function.

The solution of the above equation (3.13) provides the optimal allocation Y*, which is a function of prices and other quasi-fixed inputs, By substituting the optimal solution for profit function, the optimal profit function can be written as

$\pi^*(p, w, F) = argmax_{Y \geq 0} \sum_{m=1}^{M} \pi^* \, (p, w, F) \dots \dots$ (3.14)

As discussed earlier, prices are exogenous as the approach considers farmers to be price-takers and agricultural markets as perfect (no losses due to technical changes); then the farmers are assumed to be fully efficient in enhancing profit (Eaton and Panagariya 1982).

By relaxing the assumption of no-inefficiency and using the same approach by assuming that the farmers face the right relative prices under perfect competition, inefficiency may arise because of technical issues: the producers do not achieve the maximum profit they could achieve because they use more of an input or produce less of an output than a hypothetically fully efficient producer (Berger, *et al*. 1993) and by considering the existence of technical efficiency corresponding to the underlying production function $Y_{it} = f\left(X_{kit}^{c}, X_{jit}^{nc}\right)\exp(-u_{it}) \;\; u_{it} \geq 0$ and $0 < e^{-u_{it}} \leq 1$ as discussed in Equation 3.7. The profit function corresponding to the above equation by assuming that technical inefficiency exists, i.e., $u > 0$ is modified as

$$\pi(p, w, F, u,) = \pi(pe^{-u}, w, F) \ldots \ldots (3.15)$$

$$\pi(pe^{-u}, w, F) = \pi(p, w, F)\varphi(u) \ldots \ldots (3.16)$$

Where $\pi(p, w, F)$ is the maximum profit—as discussed in Equation 3.13, $\pi(Pe^{-u}, w, F)$ is observed profit and $\varphi\,(u)$ is profit efficiency[32] underlying the production function. Here we assume that profit efficiency does not depends on prices of inputs and output; it depends on the production oriented technical efficiency u and efficiency gained would be the ratio of observed profit in the presence of inefficiency to maximum profit (Kumbhakar 2001) as defined below

$$\varphi(u) = \frac{\pi(pe^{-u}, w, F)}{\pi(p, w, F)} \leq 1 \ldots \ldots (3.17)$$

Where the maximum profit function constitutes the profit frontier if u=0. In this case the profit efficiency would be equal to 1 indicating that the firm is operating efficiently on a profit frontier curve. Profit inefficiency is any deviation from this; it is attributed as profit loss which is specified as

$$PE = \exp(-u) \ldots \ldots (3.18)$$

This expresses that the smaller the nonnegative inefficiency component u the more efficient farm i would be.

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[32] In the case of a underlying homogeneous Cobb-Douglas production function, the relationship between profit efficiency and output technical efficiency is expressed as $n\varphi(p, w, F, u) = 1\,(1 - r)u$, where *r* is the degree of homogeneity. Scale effect is defined as the difference between profit efficiency and output technical efficiency (Kumbhakar 2001, footnote 9, p. 5).

Specification of the profit function is needed for empirical approach. This is parameterized as a Cobb Douglas profit frontier function. In addition, the function is also normalized in terms of the output price in order to impose homogeneity in prices. Hence, the restricted normalized stochastic profit function is expressed as

$$\ln\left(\frac{\pi_{it}}{P_{it}}\right) = \beta_\circ + \sum_{j=1}^{n} \beta_j \ln(W_{jit}/\, P_{it}\, e^{-u_{it}}) + \sum_{k=1}^{n} \beta_k\, lnF_{kit} + v_{it} - u_{it} \ldots\ldots (3.19)$$

The normalization imposes the restrictions that $\sum_{j=1}^{n} \beta_j = 1$ and $\sum_{j=1}^{n} \beta_{jk} = 0$ and the function is continuous and convex in prices, non-decreasing in *p* and non-increasing in *w* and concave and continuous in fixed input factors. Here $\frac{\pi_{it}}{P_{it}}$ is the normalized profit of the ith farm. Where P_{it} is output price, W_{ij} is the farm specific input prices whereas *F* is vector of the *k* fixed factors employed at the ith farm.

Following Battese and Coelli (1993) the technical inefficiency effects of u_{it} gain in the above equation are specified as.

$u_{it} = d_\circ + d_1 Z_{it} + d_2 DV_{it} + e_{it}$ … … (3.20)

Where $Z_{it}$the vector of socioeconomic characteristics of the ith farm household in year t, and DV_{it} are farm specific deviations of climatic factors from the long run norms (weather shocks), and e_{it} captures the inefficiency error term. We finally estimate the profit efficiency of each producer based on the distributional assumption discussed above (Coelli 1993). The coefficients are estimated by MLE using R-Frontier software.

3.3 Climate Change, Technical Efficiency and Food Security

To explore the relationship between climate change, production efficiency and food security, this section is divided into two parts the first deals with the construction of household food security index and the next is related to model specification to capture the impacts of weather shocks on household food security status along with other control variables.

3.3.1 Construction of Household Food Security Index (FSI)

The first step involves in the construction of FSI is the selection of indicators. In literature researchers have used different indicators and determinants of food security depending on the objective under consideration, types of respondents, data availability and policy consideration (Demeke, *et al*. 2011; Deaton and Dreze 2009; Souza and Jolliffe 2012; Qureshi 2007). On the basis of FAO definition of food security which comprises of three components i.e. availability, accessibility, and utilization[33] FSI is constructed. Being complex phenomenon and not directly observable, in current study we tried to analyze food security with help of selected indicators which represent its multiple dimensions. The selection of indicators was inspired by food security literature drawing mainly from various studies (e.g. Adewumi and Animashaun 2013; Matchaya and Chilonda 2012; Demeke, *et al.* 2011; Babatunde 2010; Smith and Subandoro 2007; Qureshi 2007; Alene and Manyong 2006; Hoddinott and Yohannes 2002; Jolliffe 2001; Hoddinott 1999 and Haddad, *et al*. 1994) as well as data availability. These indicators are farm efficiencies, per capita production, expenditure on health, number of food crops grown, cultivated area, animals' adult units and farm assets value.

Per capita cereal production (wheat, maize and rice) is an important indicator of food security representing the availability component (Sheikh 2007 and Funk and Brown 2009). The increase in *efficiency in production* can result in increase in per

[33] The first component concerns with the obtainability of food for a particular household through its own production or by any means such as from market or some other source. The second aspect deals with economic accessibility to food by people or households as revealed by their ability to purchase food from market or other source. The third component relates to the actual processing and nutrient absorption capacity of the body as provided by the supplied food. As our respondents are farm households whose major consumption is based on domestic household production (FAO 2007).

capita production and farm income (Adewumi and Animashaun 2013). *The variety or number of food crops sown* is used as a proxy for dietary diversity. It is an essential determinant of nutritional adequacy (Arimond and Ruel 2004) and an important indicator of food and crops income diversification (Demeke, *et al.* 2011) and thus of food security. *Health expenditures* are taken as a proxy for well-being of the household since availability of sufficient health facilities is a prerequisite for better livelihood. Better health care can enhance utilization capacity of the individuals (Ruel, *et al.* 1998). *The value of household assets* captures household wealth and wealth is a buffer against uncertainty and risk and can yield return to scale. Asset variables entail justification that these assets work as wealth at the time of adverse shocks and these are functioning as a rescue for households to avoid food shortage. An amalgamation of all these variables determines the persistent physical and economical provision of food. Agricultural assets such as livestock are more valuable in the long term and crucial for livelihood generation is an indicator of physical and economic access of food (Demeke, *et al.* 2011). The value of modern assets (tractor, farm implement and tube-well) owned by the household representing food accessibility were considered by Qureshi (2007). *Land under cultivation* (both barani and irrigated) is used as a proxy for farm income since more cultivated area means more agriculture output which the household can sell and generate more income and increase household security (Qureshi 2007). We select indicators for food security index for the household which is more comprehensive than the earlier indices in terms of both the scope as well as their deliberation.

The food security indicators identified above would be related to farm household *technical and profit efficiencies* (also done by Adewumi and Animashaun 2013). The increase in technical efficiency can result in increase in per capita production through enhanced productivity. Similarly, per capita cereal production can also be increased by bringing more area under cultivation. Efficiency in profit is an important indicator of farm income and hence accessibility component of food security indicator. However, how does efficiency gain lead to increase in food security and sustainable development is a complex and interrelated issue (Schneider and Gugerty 2011).Nonetheless, technical and profit efficiencies are important indicators of food security index (Adewumi and Animashaun 2013).

Further, to analyze the relationship between climate variability and household food security status, FSI is constructed by applying Principal Component Analysis (PCA) on food security indicators[34]. It is a factor analysis method to construct a set of new variables from a linear combination of individual ones. FSI is constructed in the following two steps:

Step 1: All indicators used in the construction of the index are not in the same units and more importantly these have different ranges—have different minimums and maximums values. Therefore, it would make no sense to sum their values or to take their average in order to obtain a composite index. In order to circumvent these problems, individual series are normalized for every indicator based on the following general formula as:

$H_t = (x_{itn} - \bar{x}_n / s_n) \dots \dots (3.21)$

Where

H_t refers to the index value of variable x , in year t ,

x_{itn} refers to the actual value of indicator n in year t for the i^{th} household, and

$\bar{x}_n$ refers to the mean value of indicator n

[34] Per capita cereal production and technical efficiency in production will be used for household food availability, while the number of food crops grown and health expenditure cover the utilization aspects. Profit efficiency, Animal adult units, cultivated area, and farm assets value are used as a proxy for access to food.

s_n refers to the standard deviation of indicator n

This method is applied to the original value of x measured as the deviation of x from their mean divided by standard deviation. It can therefore be applied to the variables measured at different units (Cavatassi, *et al*. 2004 and Vyas and Kumaranayake 2006).

Step 2: Since we are using a three year household panel dataset, we also need to generate the index that is comparable over time. To this end, following Cavatassi, *et al.* (2004) we first pooled the normalized data for the three years and estimate the principal components over the combined data. Then we constructed the resulting weight for each indicator by applying the PCA and multiplied that to the indicator series of combined data set values. Their linear summation would give the food security index using Equation 3.22 below. Hence their respective weights remain the same in all the three year data set—suitable to compare changes over time (Qureshi 2007 and Demeke, *et al.* 2011). Based on these weights, FSI is constructed and it can be written as

$$FSI_{it} = \mathrm{w_{i1}x_{it1}} + \mathrm{w_{i2}x_{it2}} + \mathrm{w_{i3}x_{i3}} \dots\dots\dots.. \mathrm{w_{in}x_{itn}} \dots \dots (3.22)$$

Where w represents the weight for the i^{th} principal component and the n^{th} indicator subject to the constraint that the sum of the square of weights is equal to one. Equation 3.22 can also be expressed as

$$FSI_{it} = \sum_{i=1}^{n} W_n \, [(H_t)] \dots \dots (3.23)$$

where FSI_{it} is the Food Security Index of ith household in time t, which follows normal distribution with zero mean and a standard deviation of one. Here W_n is the grand sum of weight of each policy variable (Qureshi 2007).

3.3.2 Model Specification

In addition to constructing the food security index as specified above, we empirically analyze the relationship between climate variability and household food security status using logit model. Its purpose is to recognize the factors that are related with the possibility that the household will become food secure. The model compares the probability of one state of food security to the probability of the second (the alternative category).

The next methodical step involves identifying factors which influence household food security using regression analysis. The determinants of household food security are those that affect domestic household production system and hence accessibility and utilization. These are the socioeconomic characteristics that include age and education level of the household head, dependency ratio and tenure status; the climatic variables include temperature and rainfall deviation and the non-climatic variables are farm related factors such as the source of irrigation and cropping zones dummies. The general model of food security can be written as

$$(FSI)_{it} = f\{(X^{nc})_{it,}, (DV)_{it}, (S)_{it}\} \ldots i = 1 \ldots \ldots N \quad \ldots \ldots \ldots (3.24)$$

where

$X^{nc}{}_{it}$ is a vector of non-climatic variables

DV_{it} defines the weather shocks (climatic deviation) and

S_{it} is the vector of socioeconomic characteristics of i^{th} household in time t .

We examined the impact of climatic variables on household food security status by using Logistic regression on household characteristics and other non-climatic variables representing the vector of control variables for analysis. To specify logistic regression we need to convert the dependent variable into a binary outcome. To achieve this, household are classified into two groups based on FSI: negative values indicate food insecurity and positive values suggest food security. Thus the dependent variable

FSI can take only two values: 0 stands for food insecure and 1 for a food secured household[35].

Logistic regression can be applied to this problem because it 'directly estimates the probability of an event occurring for more than one independent variable, ie for k independent variables' (Hailu and Regassa 2007).

Logit regression analysis permits estimating the probability of an event occurring or not by predicting a binary dependent outcome from a set of independent variables (Greene 2012, 763–766). It applies maximum likelihood estimation technique. In this way, the logistic regression estimates the odds of a certain event taking place. To generate odd ratio of a certain event a probability model[36] is required to satisfy this condition as

$$p_{fsit} = pr\left(FSI_{it} = 1 \middle| Z_{fsit} = z_{fsit}\right) + \varepsilon_{it}$$

$$p_{fsit} = E\left(FSI_{it} = 1 \middle| Z_{fsit}\right) = \frac{1}{1 + \exp\left(-z_{fsit}\right)} \ldots\ldots (3.25)$$

where z_{fsit} is the vector of all explanatory factors that affect the food security status of the i[th] household at time t and ε_{it} is the error term.

$$z_{fsit} = \beta_{1t} + \beta_2\,(X^{nc})_{it} + \beta_3(DV)_{it} + \beta_4\,(S)_{it} + \varepsilon_{it} \ldots\ldots (3.26)$$

Then equation (3.26) is written as

$$p_{fsit} = E(FSI_{it} = 1 \mid Z_{fsit}) = \frac{1}{1 + \exp[-(\beta_{1t} + \beta_2\,(X^{nc})_{it} + \beta_3(DV)_{it} + \beta_4\,(S)_{it} + \varepsilon_{it})]}$$

This equation takes the variables as specified in Equation 3.24. p_{fsit} is the probability of i[th] household to become food secure. β_1 provides the log odds of a

[35]Conversion of FSI from continuous variable into a binary variable would result in loss of information. However, it is also important to analyze the impact of explanatory variables included in the model on probability of a household being food (in)secure. For which it is necessary that the dependent variable should be in binary form (0 or 1). In our case it takes value of 1 if the household is food secure and zero otherwise. The regression model is estimated by using logistic technique.

[36] The model can be treated as a qualitative response model and the equation is known as commutative logistic distribution function where Z_{fsit} ranges from $-\infty$ to $+\infty$ and p_{fsit} ranges from 0 to 1. It is non-linearly related to Z_{fsit} and thus satisfies the conditions required for a probability model (Greene, 2003).

household being food insecure when $z_{fsit} = 0$ and β_2 show how these odds differ for food secure households when $z_{fsit} = 1$ (Morgan and Teachman 1988).

Equation 3.26 can be written in terms of odds as

p_{fsit} shows the probability of being food secure is given by

$$p_{fsit} = \frac{1}{1 + \exp(-z_{fsit})} \ldots \ldots (3.27)$$

And $1 - p_{fsit}$ is the probability of not being food secure (insecure) is given by

$$1 - p_{fsit} = \frac{1}{1 + \exp(-z_{fsit})} \ldots \ldots (3.28)$$

By equating Equations 3.28 and 3.29 can be expressed as

$$\frac{p_{fsit}}{1 - p_{fsit}} = \frac{1 + \exp(z_{fsit})}{1 + \exp(-z_{fsit})} \ldots \ldots . . (3.29)$$

Here $\frac{p_{fsit}}{1-p_{fsit}}$ is the odd ratio in favor of being food secure i.e. the ratio of the probability that a person will be food secure to the probability that he/she will be insecure. Estimation problem has been created in satisfying this requirement because p_{fsit} is nonlinear not only in z_{fsit} but also in parameter β_k (McFadden 1973).

Taking the natural log of the above equation (3.29) will give us; the natural log of the odds of the dependent variable occurring or not.

$$L(P_{fsit}) = \ln\left(\frac{p_{fsit}}{1-p_{fsit}}\right) = z_{fsit} = \beta_1 + \beta_2\,(X^{nc})_{it} + \beta_3\,(DV)_{it} + \beta_4\,(S)_{it} + \varepsilon_{it} \ldots \ldots . (3.30)$$

The log of the odds ratio is not only linear in X, but also linear in the parameters. L stands for Logit and refers to the logistic regression comparing the household which are food secure to those which are not. For further details it is written as

$$\text{Logit}(P_{fsit}) = \ln\left[\frac{(pr(food\ secure|X)}{pr(insecure|X)}\right]$$
$$= \beta_1 + \beta_2\,(X^{nc})_{it} + \beta_3(DV)_{it} + \beta_4(\,S)_{it} + \varepsilon_{it} \ldots\ (3.31)$$

Since the estimated coefficients β_1 of logistic models are not directly interpretable, therefore the results will also be presented straight in the form of odds; or more precisely, in the form of odds ratio (OR) (Greene 2003) because the ratio is equal to the probability of the event to the probability of opposite event.

3.4 Conclusion

In this chapter we discussed the reduced form average production function and profit equation in the microeconomic context. This reduced form profit equation shows that the change in factor input and output prices leads to change in farm profit. Then we modified the production and profit function under theoretical framework of efficiency method by incorporating the inefficiency term and then explained different types of efficiencies, particularly technical and profit efficiency. We also built a relationship between both types of efficiency based on the literature and microeconomic framework at individual household level.

Chapter 4

DATA AND ANALYTICAL PROCEDURES

4.1 Introduction

This chapter describes the data to be used and the empirical models both production and profit frontiers, to examine the impact of climate change and weather shocks on farm productivity and profitability as well as the farm efficiency. Furthermore, this chapter also provides the details of the data and analytical technique to evaluate the impact of farm efficiency measured under the changing climate besides other climatic and non-climatic variables on household food security.

This chapter is divided into five sections; the second section describes the study area, various farm specific types of dependent and independent variables, their source, definition and method of construction used in different econometric models. Section three outlines the empirical equation used for the measurement of climate change impact on technical and profit efficiency. Fourth section describes household food security status and descriptions of variables in construction of food security index have been explained at the end of this section. Last section concludes the chapter.

4.2 Study Area and Data

The area of this study is Punjab Province of Pakistan while data is taken from different agro ecological zones i.e barani, partial barani and irrigated zone following to the reason that their specific agronomic characteristics can provide important insights for our research questions. In crops wheat, rice, maize, sugarcane, cotton and others[37] are taken for simplification because these crops cover the major area of Punjab under cultivation. The farm level panel data collected by Punjab Economic Research Institute

[37] Include Pulses, Vegetable, Orchards, Groundnut, Gram, Fodder and Oil seed.

(PERI) from 537 farm families in the study area is available for the agricultural years 2005-06, 2006-07 and 2007-2008. The sample included fair representation of small, medium and large size farm households[38].

The data includes information regarding households' socioeconomic characteristics, farm specific characteristics, farm level inputs used, management practices, and output(s) produced at each farm etc. The data belongs to sampled households from 17 district covers all the agro-ecological zones of Punjab[39]. In each district one tehsil was selected for the household survey[40]. The selected districts include Rawalpindi, Chakwal, Bhakkar, Khushab, Jhang, Faisalabad, Sargodha, Okara, Hafizabad Nankana Sahib, Sailkot, D.G Khan, R.Y Khan, Vehari, Multan and Khanewal districts of Punjab. A cluster of two villages was taken from each tehsil selected for the study. Thus the respondents were randomly selected from 34 villages (PERI Survey Methodology, 2007-08). Climatic data including monthly mean temperature and precipitation were taken from Pakistan Meteorological Department.[41]

[38] 'Small-A defined as farms with farm size less than 5 acres; Small-B, farms with size between 5 to 12.5 acres; Medium, farms with size between 12.5 and 25 acres; and Large, farms with size 25 acres or more.

[39] Barani, Partial Barani and Irrigated zone. Irrigated zones are Cotton-Wheat, Rice-Wheat and Mixed wheat zone.

[40] These include tehsils of the Kallarsaiedan, and Chakwal (representing barani zone); Kalurkot and Noorpur Thal (representing partial barani zone;. Jhang, Faisalabad, Tandilianwala, Sargodha, Okara (representing mixed zone), Hafizabad, Nankana Sahib, Sailkot (Rice-wheat zone); and D.G Khan, R.Y Khan, Vehari, Multan and Khanewal (representing cotton-wheat zone).

[41] This data is the output of ECHAM5 GCM (It is a Global Climate Model developed by the Max Planck Institute for Meteorology, one of the research organizations of the Max Planck Society, Germany) downscaled by the Regional Climate, Providing Regional Climates for Impact Studies (RCM PRECIS) under A1B scenario. The output of the RCM PRECIS is in the Network Common Data Form (NetCDF) format. We have used Grid Analysis and Display System (GrADS) software to obtain the temperature data at desired locations (latitude, longitude). [Pakistan Meteorological Department (2013)]. For precipitation data, the software gives biased values. For that we used actual data set about precipitation recorded by Meteorology Department. For the location for which such data are not available, we used precipitation data recorded at the nearest metrological station.

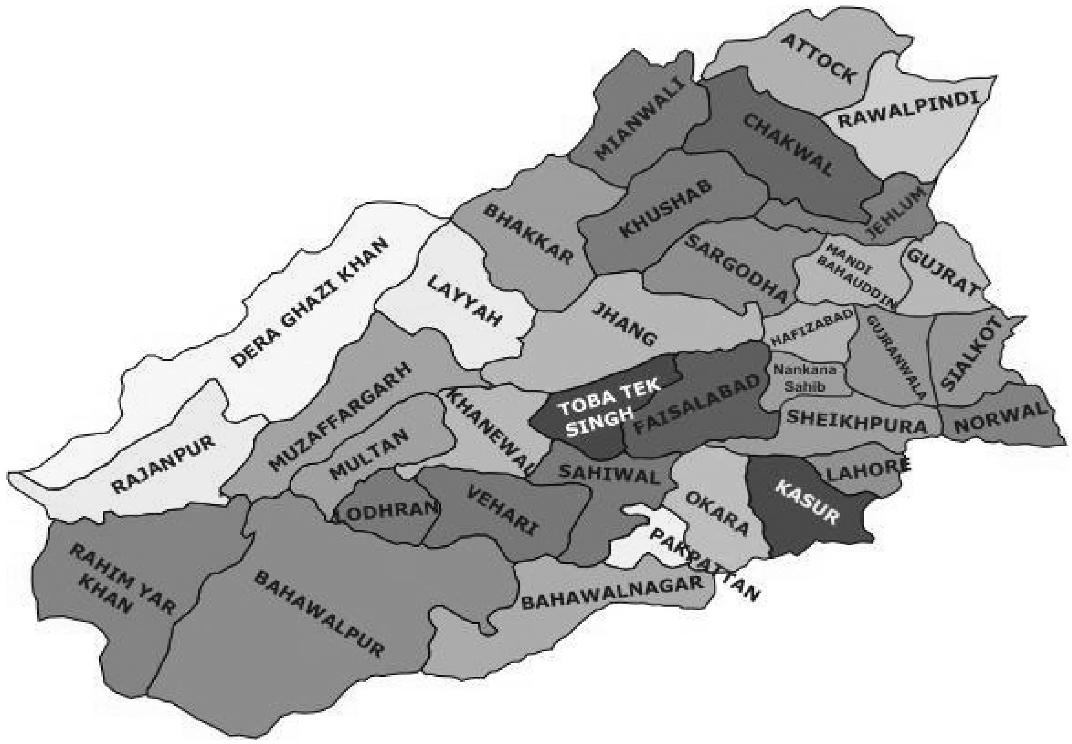

Figure 4.1: Map of Punjab Showing District Boundaries

4.3 Description of Variable Used in Econometric Model

4.3.1 Dependent Variables

Agriculture is a multi-output and multi-input production process. Since we are using production function technique, outputs of several crops for each household are aggregated to a single output. We created output quantity indices for each of the agricultural year over three years' panel data set. The output quantity indices include five main crops and several minor crops. The major crops are wheat, rice, maize, sugarcane and cotton. The minor crops are groundnuts, vegetable, orchards, pulses, gram, sunflower, oilseeds, fodder and others. Quantity indices are generated by dividing the total value of crops' production with Fisher Price Index (FPI) using 2005 as base year. The advantage of this method is that it controls for inter temporal variation in prices. The construction of output quantity index involves the following equation

$Y_{it} = \sum_{j=1}^{J} R_{iyt} / FPI_{it} \ldots \ldots$(4.1)

where Y_{it} is quantity index related to i^{th} farm in year t. R_{iyt} is the revenue of the y^{th} crops grown at i^{th} farm in year t and FPI_{it} is Fisher price index of crops grown on i^{th} farm in year t. In case of profit frontier, Profit (Gross Margin) serves as dependent variable which is computed as difference of revenues from crop outputs and variable costs involved.

$\pi_{it} = \sum_{=y}^{Y} P_{iyt} Y_{iyt} - \sum_{=j}^{J} W_{ijt} X_{ijt} \ldots\ldots$ (4.2)

π_{it} represents profit for i^{th} farm in year t which is defined as farm revenue less variable costs. P is the prices of outputs and Y represent the outputs, W is vector of prices of j inputs and X includes the quantity of these inputs applied at farm i during year t. Profit (Gross Margin) is calculated as total revenue from crop production minus the variable cost. Total revenue includes revenue obtained from selling of crops and by products. The variable cost includes labor, fertilizer, seed, irrigation, pesticides and weedicides and farm yard manure, involved in production of y^{th} crop at i^{th} farm during year t.

4.3.2 Independent Variables

Area is the main variable on which the physical operations of crop production are carried out. It is measured in total area of the farm under cultivation and is calculated as total farm area minus uncultivated area (both measured in acres). Labor used is taken as the sum of man-days of labor engaged in various operations from sowing to harvesting of all the crops grown at a farm. A man-day of labor is considered as 8 hours' work.

In order to use aggregate data for crops seed we used seed cost to construct the index as follows

$S_{it} = \sum_{j=1}^{J} C_{iyt} / FPI_{it} \ldots\ \ldots (4.3)$

where S_{it} is seed value index, C_{ijt} is the cost of seed for the y^{th} crop grown at i^{th} farm during time t and FPI_{it} is the Fisher price index of prices of seeds.

Chemical fertilizers are among the most important inputs for crop production at a farm. Sample household used four major type of fertilizers these are *Di-Ammonium Phosphate* (DAP), *Nitrophos* (NP), *Single superphosphate* (SSP) and *Urea*, all of these available in 50Kg bags. The fertilizer nutrients used at a farm for crop production are found by converting the quantity (in bags) of various fertilizers used into component nutrients of Nitrogen (N) and Phosphorus (P) using the following formulations: a bag of DAP includes 46 percent of P and 18 percent of N; a bag of Urea includes 46 percent of N; and a bag of NP includes 23 percent of N and 23 percent of P and a bag of SSP includes 9 percent of P (NFDC). Total amount of nutrients used at the i^{th} farm is computed by summing all nutrients applied to various crops. The fertilizers used by the sample farmers do not contain potash nutrients in their composition. Canal and tube well are the main source of irrigation for the farmers. Irrigation is the sum of total number of irrigations from canal and tube well applied to various crops multiplied by respective areas of crops treated with irrigation. Similarly pesticide use is also computed by summing the total number of pesticide sprays applied to various crops multiplied by acreage treated of the respective crops. Farm Yard Manure (FYM) data is available as total number of cartloads applied in the treated acre of various crops therefore FYM in total cartload is the sum of number of cartloads applied to each treated acre of various crops (treated with FYM) multiplied by acreage treated of respective crops. Total tractor hours is computed as the sum of total tractor hours used for different crop production operations like ploughing, planking, leveling, spraying, and harvesting and threshing etc.

In Punjab agricultural year consists of two seasons *Kharif* and *Rabi*. In order to explore how overtime changes in climatic factors affect the performance of crops grown during these seasons and at various stages of crop growth, the temperature and precipitation variables were defined over four quarter of the agricultural year[42]. Temperatures as well as precipitation are respectively the average of mean monthly temperatures and precipitation received per month in respective quarter. To capture the impact of climate change on total crops output, 20 year moving average is computed from the data on climatic variables for the corresponding quarter of the agricultural years under consideration (2005-08). Similar long period moving averages of climatic variables have been used by a number of authors including Demir and Mahmud (2005), Deschenes and Greenstone (2006), Wang, *et al*. (2009), Pereda (2012), Segerson and Dixon (1999) and Cabas, *et al.* (2010)[43]. A further prerequisite of the climate variables was that they are available at a suitable spatial scale to enable the derivation of farm-specific measures of climate according to geographical location. For this purpose we first found the latitude and longitude value of villages. Then we used Grid Analysis and Display System (GrADS) software to obtain climatic data at desired locations (latitude, longitude). Finally, we matched the climatic data with farm production data.

In profit frontier we used six quasi-fixed variables: four inputs--land, seed, permanent labor and capital; and two climatic variable—temperature and precipitation measured as 20 years moving average; and three variable inputs (labor, irrigation, and material inputs). The prices of three variable inputs are wage rate (labor), per irrigation

[42]Kharif Season lasts from April to September comprising of 1st quarter of agricultural year (April – June) and the 2nd quarter (July-September); Rabi Season lasts from October to March and covers 3rd quarter (October - December) and 4th quarter (January – March) of the agricultural year

[43] These studies used 20 to 30 years moving averages of temperature and precipitation data as climatic variable in the production frontier to measure the impact of climate change on crop yields more effectively.

price, and price index of material inputs (fertilizer, charges per chemical application (weedicide and pesticide), price of farm yard manure (FYM) per cartload).

We constructed input price index for the inputs other than labor and irrigation inputs. The Fisher Price Index (FPI)[44] is used to aggregate individual prices of material inputs (fym, pesticide and weedicide and fertilizers) into a single price index for each farm using quantities as weights. It involves a nested indexing procedure across the major categories of inputs. For three year data 2005-06, 2006-07, and 2007-08 the year 2005-06 is used as base year to calculate the Laspeyres Price Index (LPI) and Paasche Price Index (PPI). The geometric mean of LPI and PPI is called Fisher Price Index (FPI) (after Irving Fisher).

$$FPI_{it} = \sqrt{(LPI_{it})(PPI_{it})} \ldots\ldots \; \ldots. \; (4.4)$$

Where

$$PPI_{it} = \frac{\sum_{j=1}^{J} w_{ij}^{t+1} x_{ij}^{t+1}}{\sum_{j=1}^{J} w_{ij}^{t} x_{ij}^{t+1}}$$

$$LPI_{it} = \frac{\sum_{j=1}^{J} w_{ij}^{t+1} x_{ij}^{t}}{\sum_{j=1}^{J} w_{ij}^{t} x_{ij}^{t}}$$

[44] FPI is preferred indexing procedure to use. The difficulty with the LPI and PPI number formulas is that they are consider similar but overall they will give different results. Diewert (1993) and Walsh (1901) also proposed FPI index in one of his numerical examples while pointing the differences between the Laspeyres and Paasche indices.

For prices Index, the price in the numerator and denominator correspond to different time periods while quantity has the same period in both numerator and denominator. Where w is the price of j^{th} inputs during time t for the i^{th} farm, t stand for base year which is 2005-06 and t+1 stands for current years 2006-07 and 2007-08.

In Paasche index prices must be determined in each period of interest whereas LPI index is based on constant prices of base year this result in overvalue and undervalue the change in prices and therefore it is useful to consider a geometric mean of these two, which leads to the Irving Fisher (1922) ideal[45] index. For quasi-fixed inputs, land is total cultivated area in acres while seed index used is same as constructed above, labor is permanent hired and family labor involved in farm work measured in male adult equivalent MAE. Labor is an important factor in farm productivity. Those farmers who don't have their own labor they hired them who are paid in kind and/or cash. Male adult equivalent (MAE) is define as a person working 100 percent for 300 days per annum or 8 hours daily for 25 days per month was consider as one male adult equivalent. The labor unit's male adult equivalent was worked out as per detail given in Table 4.1.

Table 4. 1: Labor Units Male Adult Equivalent

Age(years)	For male worker (MAE)	For female worker(MAE)
16-60 years	1	0.50
Above 60	0.50	0.25
12-15	0.50	0.25
10-12	0.25	0.12

Source: Punjab Economic Research Institute Farm Account Report (2007-08)

Capital is the total of the present value of farm implements, tractors and tubewells owned by the farmers. The farm implements include cultivators, trolley,

[45] In efficiency literature, Tornqvist and Malmquist indexes are also used for aggregation (Allen and Diewert 1981). The Tornqvist equation generally gives numbers close to Fisher index but in practice the Fisher index is preferred owing to its applicability of handling zero quantities without special exceptions.In comparison, Tornqvist index calculations break down at zero quantity.

thresher, reaper, sprayers, and other farm implements and climatic variables are 20 year moving average of monthly precipitation and temperature.

According to Battese (1997), it is also necessary to incorporate dummies for variables having zero values in the data to describe various production systems for farmers who use definite inputs as compared to those who do not. Using Cobb-Douglas or Translog functional forms in absence of dummies could lead to biased parameter estimates of production function.. This procedure applied by many including Battese and Broca (1997), Ahmad (2003), Ahmad, *et al.* (2002) and Nasim, Dinar and Helfand (2014). All the inputs in the sample contain at least some zero values, to account for zero values in the Cobb Douglas function we follow Battese and Broca (1997) adding a dummy variable D_k in the production function and transforming lnx_k to lnx_k^* where k is the input for which this dummy specifies.

$$D_k = \begin{cases} 0 & if x_k = 0 \\ 1 & if x_k > 0 \end{cases} \text{and } x_k^* = ArgMax(x_k, 1 - D_k) \ldots\ldots (4.5)$$

The above transformation implies that when the inputs x_k is applied then $x_k^* = x_k$ but when x_k is not applied $x_k^* = 1$ the inclusion of dummies signifies that the intercept term differs between farmers that apply the input and farmers that do not apply the input.

A widespread variation in profitability is observed on analysis of cost and returns of the sample producers. This promotes the role of production efficiency in profitability. The future of Pakistani farmers depends on their ability to boost economic performance by improving production effectiveness under changing conditions. The determinants of inefficiency include variables like age, education, farm size, tenure status, and climate shocks/deviation. The age of the farmer is taken in years and education is measured as years of schooling. Farm size is also included in this study to see the impact of farm size on inefficiency. The operational size of farm (defined as sum of area owned, area rented in and area shared in minus the sum of area rented out and area shared out) is used as an explanatory variable. Dummy variables for tenure status are used in the production function ‘to account for effect of different regimes for farming (entitlement of the grower to farm land i.e. tenants, owners and owner-cum tenants) (Battese, *et al.* 1993 and Battese 1996). Rainfall and temperature deviations from long term climate normal influence crop production and efficiency in the short run (Chang 2002). These are also called weather shocks and calculated as deviations of quarterly average rainfall and temperature from their respective long run normal --20 years moving average value in our case.

Table 4. 2: Definition of Variables and their Descriptive Statistics

Variables	Definition	The Stats are in Actual (non-log)			
Production Frontier		mean	S.D	min	max
$\ln y_{it}$	natural log of index of outputs value produced at ith farm from jth crop grown at time t	203,743	350,073	2,880	4,600,000
lnfym	natural log of farm yard manure (FYM) in total cartloads numbers.	13.34	15.12	0.00	100.00
Dfym	dummy variable[46] assuming value of One if FYM=0 and Zero for FYM>0				
Lnpest	natural log of the pesticide number when Pest>0, and assumes Zero values when Pest=0;	18.58	54.50	0.00	790.00
Dpest	dummy variable assuming value of One when Pest=0 and takes Zero for Pest>0;				
Lnirri	natural log of total no of irrigation when Irri >0, and assumes Zero values when Irrit=0;	104.06	155.56	0.00	1632.00
Dirri	dummy variable representing zero for positive values of irrigation and value=1 for zero values				
Lnlab	natural log of total labor mandays (1 mandays=8hours)	137.92	97.34	2.08	574.91
Lnseed	natural log of index of seed value used at ith farm from jth crop grown at time t	108.34	238.60	1.65	6983.03
lnNP	natural log of fertilizer nutrients if NP>0, otherwise Zero; and NP stands for Nitrogen, Phosphorus, respectively;	832.93	1319.40	0.00	14892.00
dNP	dummy variable representing value equal to One if NP is equal to Zero; and assumes Zero for positive values of NP				
Lntrtrhr	natural log of total tractor hrs in land preparation (ploughing, Leveling, Planking and sowing operation)	79.75	126.69	1.50	2375.00
lnA	natural log of area under cultivation in acres	9.28	12.73	1.00	174.00
Cropping zones Dummies—Common in Both Production and Profit Frontier and Food Security Determinants					
Dcw	dummy variable assuming value of One if farm is located at cotton wheat zone , otherwise Zero;	0.32	0.47	0	1
Drw	dummy variable assuming value of One if farm is located at rice wheat zone , otherwise Zero;	0.21	0.41	0	1

[46] Following Battese (1997), dummies are used for variables having zero in the data to describe various production systems for farmers who use definite inputs as compared to those who do not. Using Cobb-Douglas or Translog functional forms in absence of dummies could lead to biased parameter estimates of production function

Dmw	dummy variable assuming value of One if farm is located at mixed wheat zone , otherwise Zero;	0.22	0.41	0	1
Time Dummies—Common in Both Production and Profit Frontier and Food Security Determinants					
dt_2	dummy variable assuming value of One if agriculture year is 2006-07, otherwise Zero;	0.33	0.471	0	1
dt_3	dummy variable assuming value of One if agriculture year is 2007-08, otherwise Zero;	0.33	0.471	0	1
Profit Frontier		mean	S.D	min	max
$\frac{\pi}{p}$	natural log of restricted normalized profit	196755	290982	975	5024080
Lnmat	natural log of material price index normalized by output price.	1.14	0.37	0.00	4.88
Lnwag	natural log of wage rate of hired labor normalized by output price.	81	131	0	1,250
Lnirri	Natural log of price of irrigation normalized by output price	547	2352.68	0	26920
lnCA	natural log of area under cultivation in acres	9.28	12.73	1.00	174.00
lnPFL	natural log of permanent family labor in MAE	3.67	1.75	1.25	12.5
lnFI	natural log of present value of farm implement	117,910	170,593	0	1,223,980
Lnseed	natural log of seed index value	108.34	238.60	1.65	6983.03
Climate variables-- Common in Both Production and Profit Frontier					
T_1	20 years moving average of mean temperature for first quarter months (April-June).	34.09	1.66	30.43	36.02
T_2	20 years moving average of mean temperature for second quarter months(July-Sep)	31.13	2.33	27.51	34.57
T_3	20 years moving average of mean temperature for third quarter months(Oct-Dec)	17.26	1.66	14.90	20.17
T_4	20 years moving average of mean temperature for fourth quarter months(Jan-March)	16.46	1.36	13.50	18.70
P_1	20 years moving average of mean precipitation for first quarter months (April-June).	35.24	12.23	18.63	68.89
P_2	20 years moving average of mean precipitation for second quarter months(July-Sep)	89.22	29.11	40.78	161.39
P_3	20 years moving average of mean precipitation for third quarter months(Oct-Dec)	16.68	8.75	8.10	50.22
P_4	20 years moving average of mean precipitation for fourth quarter months(Jan-March)	9.77	5.98	3.32	27.50
Variables for inefficiency determinants-- Common in Both Production and Profit Frontiers and Food Security Determinants					
age	age of the head of household in years;	43.31	14.14	14.00	80.00
edu	education of the head of the household in years of schooling;	6.44	4.66	0.00	16.00
farmsize	total area of farm in acres.	39.38	56.02	1.00	581.00
dtenant	dummy variable assuming value of One if the farm is rented in, otherwise Zero;	0.03	0.18	0.00	1.00
DVt1	Deviation of first quarter average temperature from 20 year moving average of these months (Celsius degree).	-1.00	0.43	-2.42	-0.20
DVt2	Deviation of second quarter average temperature from 20 year moving average of these months (Celsius degree).	-2.01	1.71	-5.90	-0.18
DVt3	Deviation of third quarter average temperature from 20 year moving average of these months (Celsius degree).	-0.92	1.45	-4.63	0.69
DVt4	Deviation of fourth quarter average temperature from 20 year moving average of these months (Celsius degree).	0.72	1.96	-2.46	3.48
DVP1	Deviation of first quarter average rainfall from 20 year moving average of these months (mm).	23.51	23.54	-43.42	75.24
DVP2	Deviation of second quarter average rainfall from 20 year moving average of these months (mm).	23.52	26.09	-24.76	96.74
DVP3	Deviation of third quarter average rainfall from 20 year moving average of these months (mm).	-0.29	7.56	-21.00	26.29
DVP4	Deviation of fourth quarter average rainfall from 20 year moving average of these months (mm).	4.74	11.76	-9.86	45.01

Source: Author’s own calculation

4.4 Descriptive Analysis

We start from a descriptive analysis to see through the detailed descriptions of the variables. The statistics show that for technical efficiency estimation 1611 observations are taken for three years for the farmers. The data consists of inputs used by the farmers in the production of crops and climatic variables that affect crop production. The study used total value from crop production as dependent variable in the form of index; different farms used different levels of inputs under different climatic conditions to produce different levels of outputs therefore the output level will vary across the farms. The inputs variables were used on quantities' basis. The efficiency variables included were the age and education of the farmers, total area of the farm, tenure status and climate deviations.

The study used output index as dependent variable. This is constructed by dividing total value from crop production by Fisher output price index. The mean total output index value from crop production is Rs.203, 743 with the minimum and the maximum of Rs.2,880 and Rs.4600,000 per farm, respectively. The total area cultivated for each household varies from one to 174 acres. The mean value of seed index is Rs.238. Other farm inputs such as farm yard manure, pesticides and weedicides' number of treatments, number of irrigations, labor man-days used and the total nutrients of NP applied were shown in table. The mean value of FYM and NP nutrients are 13 cartloads and 832kgs per farm, respectively. The mean value of tractor hours is 79 hours. The mean value of pesticide number is 18 and number of irrigation are 104. The mean profits from crop production are Rs.192, 948 and mean value of material price index is 1.14 and average wage rate per day is Rs.81 and irrigation rate is Rs.547. The quasi fixed inputs such as permanent family labor mean value is 3.67 in MAE, average value of farm implement is Rs.117,910 and area under cultivation is about 10 acres and the value of seed is Rs. 108.34.

The efficiency variables included were the age and education of the farmers, total area of the farm and tenure status dummies. The average age of household head is 43 years and average schooling is 6 years. Youngest household head is 14 years old while the maximum age of household head is 80 years. The data shows that average farm size is around 39 acres and maximum size is 581 acres which is pretty high whereas minimum acres are one. About 83 percent of the household heads are owner of the farms and the remaining are either tenants or owner-cum-tenants. The mean precipitation of first quarter is 35mm while second and third quarter precipitation is about 89mm and 16mm and least is in fourth quarter which is 9mm. The temperature data shows that mean temperature in first quarter is 34^0C while second and third quarter mean temperature is 31^0C and 17^0C and least in third quarter which is 16^0C. The mean, maximum and minimum values of climatic deviation from long run average has been reported in Table: 4.2

All farm inputs should be positive and statistically related to farm output (Ahmad, *et al.* 2002; Baksh 2007 and Kumbhakar, *et al.* 1991). The parameters of explanatory variables i.e. pesticides, FYM, NP, total tractor hours, labor man-days, irrigation and seed variables are expected to have positive signs showing positive impact on farm productivity (Ahmad 2003; Hassan and Ahmad 2005; Ahmad, *et al.* 2002; Baksh 2007; Kumbhakar, *et al.* 1991 and Battese, *et al.* 1993).

Based on the previous literature, the tenure security s expected to have positive relationship with farm efficiency (Pender, *et al.* 2004 and Deininger and Jin 2006). Ahmed, *et al.* (2002) though concluded that the statistically tenants were more efficient than the owner and owner-cum tenants. It is known from literature that socioeconomic circumstances of farmers like farming experience and education are variables that influence farm management. Farmer education and characteristics were found to be vital elements of efficiency (Xu and Jeffrey (1998), Abdulai and Huffman 1998; Bhasin 2002; Rahman 2003; Kolawole 2006 and Bozoglu and Ceyhan 2006).Understanding of technology related to agricultural production and use of advanced techniques is enhanced by increase in the education level of farmer, ceteris paribus. (Ali, Parikh and Shah 1994 and Coelli and Fleming 2004). Thus, betterment in education can encourage the spread of technical transformation (Huffman and Evenson 1989). Also, farm size is another pertinent variable that effects farmer’s efficiency (Ali, Parikh and Shah 1994; Ali and Flinn 1989; Wang, Wailes and Cramer 1996 and Xu and Jeffrey 1998; Tzouvelekas, Pantzios and Fotopoulos 2001). In general, the literature indicates an inverse relationship between farm size and efficiency (Ahmad, *et al.* 2002 and Hassan and Ahmad 2005). While some found positive impact on technical inefficiency of farms which implies that small farms were technically less inefficient than large farms (Javed, *et al.* 2011 and Musemwa, *et al.* 2013).

4.5 Stochastic Production Frontier

Modified Cobb-Douglas (CD) functional form is preferred for empirical investigation because we are dealing with large no of variables and the use of translog type function may result in severe multicollinerarity among the independent variables. The CD functional form is preferred to measure farm efficiency in most of the studies despite its known weaknesses (Saleem 1988; Kalirajan and Obwona 1994; Dawson,et al 1991; Nsanzugwanko, *et al*. 1996 and Battesse and Safraz 1998). Interaction terms in translog form results in insufficient degrees of freedom which turns out to be potential problem. Furthermore, these interaction terms of the translog are also economically meaningless (Abdulai and Huffman 2000) in measuring efficiency. Cornwell, Schmidt and Sickles (1990) also preferred to estimate the technical efficiency using Cobb Douglas instead of translog because the latter presented major multicolinearity problem. Similarly Ahmed and Bravo-Ureta (1996) measured the technical efficiency of dairy farms by means of various modifications of CD and translog under time variant and invariant specifications and found fairly consistent results across alternative model specifications. Following this argument and the conclusions of this study, we prefer to use modified CD function due to its simplicity and to avoid possibility of collinearity among the independent variables.

The stochastic frontier model with Cobb-Douglas specification is given below:

$$lnY_{it} = \beta_0 + \beta_1 \mathrm{lnlab_{it}} + \beta_2 \mathrm{lnA_{it}} + \beta_3 \mathrm{lnpest_{it}} + \beta_4 \mathrm{dpest_{it}} + \beta_5 \mathrm{lnseed_{it}} + \beta_6 \mathrm{lnirri_{it}} + \beta_7 \mathrm{dirri_{it}} + \beta_8 \mathrm{lntrtrhr_{it}} + \beta_9 \mathrm{lnfym_{it}} + \beta_{10} \mathrm{dfym_{it}} + \beta_{11} \mathrm{lnNP_{it}} + \beta_{12} \mathrm{dNP_{it}} + \beta_{13} \mathrm{dcw}_i + \beta_{14} \mathrm{drw}_i + \beta_{15} \mathrm{dmw}_i + \beta_{16} \mathrm{dt_2} + \beta_{17} \mathrm{dt_3} + \beta_{18} \mathrm{T_{1it}} + \beta_{19} \mathrm{T_{2it}} + \beta_{20} \mathrm{T_{3it}} + \beta_{21} \mathrm{T_{4it}} + \beta_{22} \mathrm{P_{1it}} + \beta_{23} \mathrm{P_{2it}} + \beta_{24} \mathrm{P_{3it}} + \beta_{25} \mathrm{P_{4it}} + v_{it} - u_{it} \ldots\ldots (4.6)$$

The technical inefficiency model where it depends on various explanatory variables is reported in the following equation

$$u_{it} = d_0 + d_1 \mathrm{age}_{it} + d_2 \mathrm{edu_{it}} + d_3 \mathrm{farmsize_{it}} + d_4 \mathrm{dtenant_{it}} + d_5 \mathrm{DVt}_{1it} + d_6 \mathrm{DVt}_{2it} + d_7 \mathrm{DVt}_{3it} + d_8 \mathrm{DVt}_{4it} + d_9 \mathrm{DV}p_{1it} + d_{10} \mathrm{DVp}_{2it} + d_{11} \mathrm{DVp}_{3it} + d_{12} \mathrm{DVp}_{4it} \ldots (4.7)$$

4.6 Stochastic Profit Frontier

Specification of profit function is parameterized Cobb-Douglas log function[47] which is used as an empirical approach. It is assumed that the farmers are producing single or multiple crops by using the fixed inputs including capital, labor, land and environmental factors—temperature and precipitation normal, and the profit function is specified as a restricted profit function. This implies that these inputs are specified as

[47] We also estimated the model with one of the flexible functional form, such as the translog, but in our case Cobb-Douglas performed better in terms of economically reasonable parameter estimates.

being fixed in the short run. Moreover, in order to impose the property a function being homogeneous in prices, that function is normalized with respect to output price. Hence, the stochastic restricted normalized profit function is specified and estimated using capital, land, seed and labor input factors in the presence of variable inputs prices under different climatic conditions as follows.

$$\ln\left(\frac{\pi_{it}}{p_{it}}\right) = \beta_0 + \beta_1 \mathrm{lnCA_{it}} + \beta_2 \mathrm{lnPFL_{it}} + \beta_3 \mathrm{lnFI_{it}} + \beta_4 \mathrm{lnseed_{it}} + \beta_5 \; ln \; \frac{mat_{it}}{p_{it}}$$

$$+ \beta_6 ln \; \frac{\mathrm{wag_{it}}}{p_{it}} + \beta_7 ln \; \frac{\mathrm{Irri_{it}}}{p_{it}} + \; \beta_8 \mathrm{dcw}_i + \beta_9 \mathrm{drw}_i + \beta_{10} \mathrm{dmw}_i + \beta_{11} \mathrm{dt}_2$$

$$+ \beta_{12} \mathrm{dt}_3 + \beta_{13} \mathrm{P_{1it}} + \beta_{14} \mathrm{P_{2it}} + \beta_{15} \mathrm{P_{3it}} + \beta_{16} \mathrm{P_{4it}} + \beta_{17} \mathrm{T_{1it}} + \beta_{18} \mathrm{T_{2it}}$$

$$+ \beta_{19} \mathrm{T_{3it}} + \beta_{20} \mathrm{T_{4it}} + v_{it} - u_{it} \; \ldots \ldots (4.8)$$

Where

$$\left(\frac{\pi_{it}}{P_{it}}\right) = [(\textstyle\sum_{i=1}^{n} P_{it}\, Y_{it} - \sum_{i=1}^{n} W_{it}\, X_{it})/p_{it})] \ldots\ldots (4.9)$$

$\frac{\pi}{p}$ is restricted normalized profit computed for i[th] farm defined as farm revenue less variable costs divided by output price—wheat price which is major crop produced by all the sample farmers.

The Profit inefficiency model is given in the following equation:

$$u_{it} = d_0 + d_1 \mathrm{age}_{it} + \; d_2 \mathrm{edu_{it}} + d_3 \mathrm{farmsize_{it}} + d_4 \mathrm{dtenant_{it}} + d_5 \mathrm{DVp}_{1it} + d_6 \mathrm{DVp}_{2it}$$

$$+ d_7 \mathrm{DVp}_{3it} + d_8 \mathrm{DVp}_{4it} + d_9 \mathrm{DVt}_{1it} + d_{10} \mathrm{DVt}_{2it} + d_{11} \mathrm{DVt}_{3it}$$

$$+ d_{12} \mathrm{DVt}_{\,4it} \ldots (4.10)$$

4.7 Modeling Food Security, Technical Efficiency and Climate Change

4.7.1 Description of Variables

The procedure of constructing FSI has been discussed in detail in Section 3 of Chapter 3. However, just to refresh our memory a brief description is given here. The measurement of food security is a complex phenomenon. Nonetheless, this study follows closely the previous work to identify the indicators/determinants of FSI (for example, Babatunde 2010; Smith and Subandoro 2007; Qureshi 2007; Alene and Manyong 2006; Hoddinott and Yohannes 2002; Jolliffe 2001; Hoddinott 1999 and Haddad, *et al*. 1994). Three components of food security namely, availability of food, accessibility of food and utilization of food are the bases of measurement. Keeping in view the empirical literature and the limitations of the available data to be used in this study, various indicators are selected to represent different components of food security and same are reported in Table 4.3.

Table 4.3: Description of Variables Employed to Generate Food Security Index (FSI)

No.	FSI Variables	Units	Mean	Std .D	Min	Max
Production variables						
1	Per capita cereal production (wheat, maize, rice)	Mound (40 kg)	40.56	61.86	2.11	835.00
2	Technical efficiency scores	Scores	0.82	0.12	0.15	0.96
Consumption Variables						
3	Health expenditure	Rupees	1,881	2,461	0	75,000
4	Variety of food crops planted	Nos	1.79	0.74	1.00	4.00
Accessibility variables						
5	Profit efficiency	Scores	0.72	0.15	0.02	0.95
6	Present value of farm assets (implements, tractors, tube-wells)	Rupees	117,910	170,593	0	1,223,980
7	Cultivated area	Acres	9.28	12.73	1.00	174.00
8	Livestock owned	aau (animal adult units)	3.51	1.89	0.00	9.47

Source: Author's own calculation

Total cereals produced by the household (in mounds of 40kgs) is divided by their household size in order to convert it into per capita production by each household. Sheikh (2007) found per capita cereals production as one of the important factors in food security indicators. The number of food crops grown by the farmers on the farm is an important indicator for food diversification (Demeke, *et al.* 2011)—this number varies from 1 to 4 on the sampled farms. Numbers of crops grown by the farmers depends on the availability of land, timing of growing season etc. Technical efficiency in production is important indicator for the availability of food for the household overtime (Adewumi and Animashaun 2013). This is captured by the technical efficiency score of each household generated by production function frontier as discussed earlier. Expenditure on health by the household covers the utilization aspects of food security component measured in rupees (Omotesho, *et al.* 2007). Profit efficiency, farm assets value, livestock and cultivated area capture the accessibility component of food security. Farm assets include present value of farm implements, tractor and tubewells. Farm implements include cultivator, thresher, trolly, drill, plough, sprayers, drums and others. Livestock owned (converted into animal adult units) is also an important asset for assuring food security (Demeke, *et al.* 2011 and Qureshi 2007). Livestock assets enhance the probability of a household to be food secure (Bashir, *et al.* 2010 and 2012 and Haile, *et al.* 2005). The conversion factors used for determining the adult animal units has been reported in Table 4.4.

Table 4.4 : Adult Animal Units (AAUs)

Animal	Adult	Young
Buffaloes	1.28	0.96
Cow	0.72	0.54
Bull	1.0	0.50
Goat or Sheep	0.2	-
Donkey	0.57	-
Horse	1.0	-
Camel	1.75	-

Source: Punjab Economic Research Institute Farm Account Report (2007-08)

This study also used area that is under cultivation. It is calculated as total farm area in acres minus total uncultivated area. It was used by various studies like Bjornsen and Mishra (2012), Babatunde and Qaim (2010) and Tesfaye, *et al.* (2008).

The variables used in food security model have already been discussed in some detail in Table 4.2. However, the dependency ratio (DR) which is calculated by using the formulation: DR= (number of people aged 0−15+ those aged 65 and over) /(total number of household members aged 15−64) ∗100 and the source of irrigation represented by dummy variable (assuming value of one if the farm uses canal, tubewell or canal plus tubewell irrigation otherwise zero).

The empirical literature relating to factors determining the food security status shows diverse results. Increase in the year of education of the household head decrease the chance of household becoming food insecure and hence improve the food security (Kaiser, *et al.* 2003; Mariara, *et al.* 2006; Amaza, *et al.* 2006; Ojogho 2010 and Bashir, *et al.* 2010 and 2012). An increase in the age of the household head reduces the chance of becoming food secure (Titus and Adetokubo 2007 and Bashir, *et al.* 2010 and 2012) and food insecure (Onianwa and Wheelock 2006). Farm size positively contributed to food security status (Omotesho, *et al.* 2007). Increase in the family size or dependency ratio increases the probability of food insecurity (Bashir, *et al.* 2010 and 2012 and Sindhu, *et al.* 2008 and Omotesho, *et al.* 2007). Rainfall deviation from the normal found to be negatively associated with food security indicating that higher the amount of rainfall from the normal less the food security (Gregory, *et al*. 2009 and Demeke, *et al.* 2011). Land tenure is also one of the central factors determining food security and sustainable development (Moyo 2000).

4.7.2 Descriptive Analysis of Food Security Variables

Descriptive analysis of the indicator variables are presented in Table 4.3. The data consists of production, consumption and farm asset variables. The statistics show per capita agriculture production of food commodities is 40 mounds and mean value of technical efficiency score is 0.82 with minimum score is 0.14 and maximum is 0.90. The study used present value of farm implements, tractors and tubewells in rupees, cultivated area in acres and animal adult units as assets. The mean value of profit efficiency is 0.74. The mean value of farm assets is Rs. 117,910. Average cultivated area is 9.28 acres and animal adults units are 3.51. The mean value of consumption variables show that number of food crops grown is 1.79 while health expenditures are Rs.1881.

4.7.3 Empirical Model Specification

The binary logistic regression is used to analyze the food security determinants. The dependent variable (household food security) is binary—assigned value 1 if food secure, and 0 for food insecure. The general form of the logistic regression equation is written as follows (Burns and Burns 2008).

$$\text{Logit}(P_{it}) = \delta_0 + \delta_1\text{age}_{it} + \delta_2\text{edu}_{\text{it}} + \delta_3\text{farmsize}_{\text{it}} + \delta_4\text{dtenant}_{\text{it}} + \delta_5\text{Dep}_{it} + \delta_6\text{dcw}_{\text{i}} + \delta_7\text{drw}_{\text{i}} + \delta_8\text{dmw}_{\text{i}} + \delta_9\text{DVt}_{1it} + \delta_{10}\text{DVt}_{2it} + \delta_{11}\text{DVt}_{3it} + \delta_{12}\text{DVt}_{4it} + \delta_{13}\text{DVp}_{1it} + \delta_{14}\text{DVp}_{2it} + \delta_{15}\text{DVp}_{3it} + \delta_{16}\text{DVp}_{4it} + \delta_{17}\text{dcantub} + \delta_{18}\text{dcanal} + \delta_{19}\text{dtub} + \delta_{20}dt_2 + \delta_{21}dt_3 + e_{it} \dots\dots (4.11)$$

Where P_{it} is the probability that a household is food secure with reference to alternative category i.e. food insecure (in case of binary logistic regression food secure =1 and insecure = 0)

δ_0 is intercept constant

δ_k are the parameters to be estimated

DVp_{1it} to DVp_{4it} are the rainfall deviation for four quarters of the i^{th} household in time t

DVt_{1it} to DVt_{4it} are the temperature deviation for four quarters of the i^{th} household in time t

$dcanal_{it}$ is the dummy for canal irrigation of the i^{th} household in time t

$dcantub_{it}$ *and* $dtub_{it}$ are dummies for canal plus tubewell source and only tube well source of irrigation

Dep_{it} stands for dependency ratio of the ith household in time t

age_{it} is the age of household head in time t

$farmsize_{it}$ is the farm size of the i^{th} household in time t

edu_{it} is the education of the i^{th} household in time t

$dtenant_{it}$ is dummy for tenant household

dcw_i, drw_i and dmw_i are the dummies for the cropping zones i.e. rice-wheat, cotton-wheat and mixed zones

dt_2 and dt_3 are time dummies variables $t2$ stands for the year (2006-07) and $t3$ for the year (2007-08) while 2005-06 was considered as a base year and e_{it} is usual error term.

4.8 Data Limitation

This study uses farm survey data collected by Punjab Economic Research Institute in order to analyze the farm accounts, family budgets of rural families and cost of production of major crops in Punjab. The data lacks information on soil quality and moisture retention capacity, transport and market facilities, drought intensity as well as farmers perceptions about climate change and adaptive strategies to climate change which may result in over or underestimation the true impact.

Finally, we would be unable to measure the impact of extreme weathers generally measured in minimum and maximum daily temperature or degree days because of unavailability of daily data on climate variables for a reasonably long time period. The impact can be overestimated as estimates are not controlled for crop switching.

4.9 Summary

The aim of this chapter was to provide the description of the survey design, study area and data collected. The study used both primary and secondary data to fulfill the objective under consideration. Primary data was collected by the experts of Punjab Economic Research Institute (PERI) that covers the information regarding farm variables and farmers demographic characteristics. While secondary data includes climatic variables, which was acquired from Pakistan Metrological Department Pakistan. In total 537 crop growers were interviewed for each cropping year under consideration (2005-08) covering 17 districts representing various cropping zones in Punjab. As information were collected from the same household(s) for a period of years, it became more useful for the sake of comparing agricultural productivity, efficiency and household food security over time as well as across the households and to derive policy implications. The sample of farmers taken from various districts were based on farm house population in the sample districts and further distribution of sample farm household on farm size basis was made proportionally on the basis of population of various farm size categories in the sample village. Data on outputs, inputs used and farm specific variables were collected for each sample units. It also highlights the limitation of data availability on some important variables. This chapter describes the variables used in the analysis. It further describes the empirical application of frontier production function for the analysis of technical and profit efficiencies. Empirical model incorporating the impact of production efficiencies on household food security status was also discussed.

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Introduction

We have already discussed in chapter two the theoretical foundation and efficiencies concepts. In this chapter, we empirically measure the impact of climate change on the technical and profit efficiency in Punjab, Pakistan by using stochastic frontier approach and applying modified Cobb Douglas functional forms. The remaining chapter is allocated into four sections. The following Section 5.2 presents the results from estimation of stochastic production frontier. Section 5.3 discusses the results obtained from estimation of stochastic profit frontier. Section 5.4 provides the results of food security analysis followed by summary and conclusions in the last section.

5.2 Stochastic Production Frontier: Empirical Results

A modified Cobb-Douglas production frontier incorporating inefficiency effects given in Equation 4.1 is estimated by using R-frontier statistical package. The results have been described in Tables 5.1 and 5.2. Table 5.1 reports the results of the tests of hypotheses. These tests are performed using generalized likelihood-ratio statistics (LR) which is defined as "$LR =$ -2 ln $[L.(H_0)/L.(H_1)]$", where $L.(H_0)$ and $L.(H_1)$ are the values of the log likelihood function under null and alternate hypotheses specifications. The LR test statistic has an asymptotic chi-square distribution with degrees of freedom equal to the difference between the number of parameters in the unrestricted and restricted models (Coelli 1996).

The first null hypothesis is '$H_\circ$: $\gamma = d_\circ = \dots\dots d_n = 0$', which identifies that the technical inefficiency effects are not existing in the model indicating that the stochastic production frontier is not different than the traditional average production function that can be estimated using ordinary least square technique. This null hypothesis was rejected. The second tested null hypothesis was that the factors determining the technical inefficiency are not existed in the inefficiency model, $i.e.$ $H_{\circ}: d_1 = \dots\dots d_n = 0$). This hypothesis was again rejected implying that various factors/variables in the inefficiency model jointly play statistically significant role in explaining technical inefficiencies at the farm level. Given this result, the third null hypothesis which was tested relate to weather shocks that they do not influence farm level efficiency, i.e. $H_{\circ}: d_5 = \dots\dots d_{12} = 0$. This hypothesis was again rejected, which implies that weather shocks/deviations of climate variables from their respective long-term means significantly play role in determining the farm level efficiency.

The results of parameter estimates have been reported in Table 5.2. These results show that most of the parameter estimates are statistically significant at least at the 10 percent level of probability, and also carry the expected signs. The parameters of sigma-square, σ^2, and gamma, γ [48], are significant at the 1% critical level also imply that average production function is not adequate representation of the data, and suggest the presence of technical inefficiency effects in the model.

Table 5.1: Generalized Likelihood-Ratio Tests of Hypothesis for Parameter of CD-SFA

Null Hypothesis	LR	DF	Critical Value X^2	Decision
$H_{\circ}: \gamma = 0$	481	1	2.7	Reject $H_{\circ}$
$H_{\circ}: \gamma = d_{\circ} = \dots d_n = 0$	117	14	23	Reject $H_{\circ}$
$H_{\circ}: d_1 = \dots\dots d_n = 0$	370	13	21	Reject $H_{\circ}$
$H_{\circ}: d_5 = \dots\dots d_{12} = 0$	36	8	14	Reject $H_{\circ}$

These critical values in use are taken from Table: 1 of Kodde and Palm (1986) at 5% level of significance.

[48] The γ is defined as σ_u / σ_s where $\sigma_s = \sigma_u + \sigma_v$.

Table 5.2: The Maximum Likelihood Estimates for Cobb-Douglas Production Frontier

Variables		Parameters	Coefficients	Std.Error
Production Frontier				
	(Intercept)	β_0	1.03	0.80
Log of labour	Lnlab	β_1	0.25***	0.02
Log of cultivated area	LnA	β_2	0.16***	0.02
Log of number of pesticide sprays	lnpest	β_3	0.11***	0.02
Dummy variable for pesticide	Dpest	β_4	0.23***	0.04
Log of seed value index	lnseed	β_5	0.14***	0.01
Log of irrigation number	Lnirri	β_6	0.41***	0.02
Dummy variable for irrigation	Dirri	β_7	1.41***	0.10
Log of tractor hrs	lntrtrhr	β_8	0.16***	0.02
Log of farm yard manure	Lnfym	β_9	-0.10***	0.02
Dummy variable for farm yard manure	Dfym	β_{10}	-0.13**	0.05
Log of fertilizer nutrients	lnNP	β_{11}	0.07***	0.02
Dummy variable for fertilizer nutrients	dNP	β_{12}	0.53***	0.10
Dummy variable for cotton wheat zone	Dcw	β_{13}	-0.05	0.07
Dummy variable for rice wheat zone	Drw	β_{14}	0.10*	0.06
Dummy variable for mixed zone	Dmw	β_{15}	-0.01	0.05
Dummy variable for year 2006-07	dt1	β_{16}	-0.12***	0.03
Dummy variable for year 2007-08	dt2	β_{17}	0.06**	0.03
Temperature normal for April-June	T_1	β_{18}	0.36***	0.04
Temperature normal for July-Sept	T_2	β_{19}	-0.16***	0.05
Temperature normal for Oct-Dec	T_3	β_{20}	-0.02	0.06
Temperature normal for Jan-March	T_4	β_{21}	-0.04	0.05
Precipitation normal for April-June	P_1	β_{22}	-0.01**	0.00
Precipitation normal for July-Sept	P_2	β_{23}	-0.01***	0.00
Precipitation normal for Oct-Dec	P_3	β_{24}	0.00	0.01
Precipitation normal for Jan-March	P_4	β_{25}	0.06***	0.01
Inefficiency model				
	Constant	d_0	-3.92**	1.94
Age of household head	Age	d_1	0.00	0.01
Education of household head	Edu	d_2	0.00	0.02
Total area of farm in acres.	Farmsize	d_3	-0.02**	0.01
Dummy variable if the farm is rented in	dtenants	d_4	0.63	0.55
Deviation of first quarter average temperature.	DVt1	d_5	3.05***	1.08
Deviation of second quarter average temperature.	DVt2	d_6	-0.22*	0.30
Deviation of third quarter average temperature.	DVt3	d_7	0.12	0.35
Deviation of fourth quarter average temperature.	DVt4	d_8	0.99***	0.31
Deviation of first quarter average rainfall	DVp1	d_9	0.14***	0.05
Deviation of second quarter average rainfall.	DVp2	d_{10}	-0.01	0.01
Deviation of third quarter average rainfall	DVp3	d_{11}	0.07***	0.02
Deviation of fourth quarter average rainfall	DVp4	d_{12}	-0.02	0.02
	Variance Parameters			
	sigmasq	σ^2	0.84***	0.31
	gamma	Γ	0.88***	0.04
	LL		-700.003	

***, **, * indicate significance at 0.01, 0.05 and 0.1 probability levels

Source: Author's estimation

The parameter estimates of stochastic production frontier reported in Table 5.2 show that 28 parameter estimates out of 37 are statistically significant at least at the one percent level of probability. All coefficients of the included variables carry the expected signs, except that of farm yard manure (fym) which is negative and significant. The parameter estimate of cultivated area (lnca) is 0.16[49] having a positive sign and significant at the 1 percent level of probability implies that 1 percent increase in area under cultivation would raise farm production by 0.16 percent. This result is consistent with the findings of Ali and Chaudhry (2008), Parikh, Ali and Shah (1994), Coelli and Battese (1996), and Battese and Broca (1997). The labor variable has partial output elasticity of 0.25. This magnitude implies that 1 percent allocation of more labor would increase farm production by 0.25 percent. The elasticity of labor is relatively large may be due to the reason that labor in peak agricultural seasons becomes short and is not available at proper time and may result in late sowing and harvesting leading losses in farm output[50]. Therefore, additional labor availability at the peak season would have greater output response. The partial output elasticity of fertilizer is 0.07 carrying a positive sign and is statistically significant. The parameter estimate of tractor use (hours) is 0.16, which is positive and statistically significant. The seed variable has a partial output elasticity of 0.14, which is also positive and statistically significant. This result is consistent with the finding of Ahmad*, et al.* (2002). The coefficient of herbicides and pesticides use came out to be 0.11, which is positive and statistically significant. The coefficient of farmyard manure is unexpectedly negative and statistically significant at the 5% level of significance. To get the benefit of organic fertilizer (fym) it is necessary that it must be applied in proper timing and amount in combination with inorganic fertilizers—various empirical studies found similar result (e.g. Ahmad 2000; Battese, *et al.* 1993; Ahmad, *et al.* 2002; Ahmad 2003 and Hassan and Ahmad 2005). The coefficient of irrigation variables is 0.41 which is positive and statically significant at the 5% level—this estimate is higher than the coefficients of all other inputs variables. This result implies that reduced availability of irrigation water

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[49] The parameter estimates of the inputs variables in CD function are elasticities of production.
[50] This is particularly true in cases of rice crop sowing, wheat and sugarcane harvesting, and cotton, fruits and vegetable pickings.

under the changing climate—characterized as higher temperature and lower rainfall, would badly hurt the agriculture in Punjab. This result compares well with the outcomes of Hassan and Ahmad (2005), Ahmad (2003) and Ahmad, *et al.* (2002). The parameter of dummy variable of irrigation representing production regime with no irrigation is positive and statistically significant at the 1% level indicating higher initial productivity on farm fields where no application of irrigation water was observed. Finally, the parameter estimate of fertilizer (NP) nutrients used carries positive sign and is significant at the 10% level. The coefficient of dummy variable of no fertilizer use (dNP) is also significant and positive implying that initial production in case of no fertilizer use has been higher than those farms where the fertilizer is being used. It could be due to the reason that such plots may be more fertile than those where chemical fertilizer has been applied. The results of zone level dummy variables show that farm level production on average is significantly higher in rice-wheat zone than that of in the other zones— cotton-wheat and mixed crops. This is an unexpected outcome, since this system has the highest cropping intensity by continuous cultivation of wheat crop after rice, year after year caused depletion of soil nutrients. Both of these crops are shallow-rooted and heavily extract nutrients from the same layer soil. The present study however takes whole farm approach (considers all crops grown on the farm), while the focus of previous work has been on wheat crop grown in rotation with rice (e.g. Ashraf 1984-85; Cassman and Pingali 1993; Byerlee and Siddiq 1994; Pingali, Hussain and Gerpacio 1997; Ahmad, Ahmad and Gill 1998 and Ahmad and Qureshi 1999). The positive result implies that though wheat productivity declines if grown continuously in rotation with rice, but the farm system as a whole is still more productive than the other cropping systems in Punjab. The significance of coefficients of these dummy variables indicates that zone specific characteristics do have played a significant role in the production of crop.

Among climatic variables, the coefficient of the temperature normal during the first quarter (April-June) is statistically significant and carries a positive sign. The magnitude of the coefficient (0.36) implies that 1℃ increase in long run average temperature would cause 36 percent increase in production. This is due to the fact that *kharif* (summer) season crops are heat loving plants and for most of them the stage of vegetative growth is observed during April-June. An increase in temperature coupled with irrigation application[51] enhances vegetative growth resulting in higher yields of these crops. The parameter estimates of July-Sept are negative and statistically significant. Their magnitudes indicate that 1℃ increase in temperature would discourage farm production by 16 percent in each quarter. The temperature coefficients during the third (Oct-Dec) and fourth quarter (January-March) are however insignificant. Farmer's perception survey highlighted the fact that temperature has generally increased and frost incidence has declined during these months in most of the areas of Pakistan therefore warming up of temperature helped enhance production during this period particularly of wheat in cooler areas. Moreover, this trend encouraged offseason vegetable growing and early sowing of Bt. cotton (Ahmed, *et al.*2014). However, the rise and fall in temperature has become very uncertain overtime since frost may occur in winter months in some areas impacting the production adversely (Ahmed, *et al*. 2013).

In general, higher precipitation positively affects the production in arid and semi-arid regions. However, in regions with already high rainfall, more precipitation can reduce production by nutrient percolating and water logging (Ludwig and Asseng 2006). Further, continued wet conditions during vegetative growth stage increase the occurrence of diseases (ICARDA 2011). Our results have shown that the parameter

[51] most of crops are grown under irrigated conditions in the study area.

estimates of precipitation normal during the first and second quarter precipitation impacted growth negatively but the magnitude of the impact of incremental rains came out to be very low. The third quarter precipitation is non-significant while fourth quarter precipitation (January-March) is positive and significant. These results imply that in the presence of relatively high temperature, increased rainfall during January to March turned out to be beneficial for the farming system on the whole.

5.2.1 Analysis of the Determinants of Technical Inefficiency

Equation 4.2 was used to obtain technical efficiency estimates. The results show that the technical inefficiencies exist at the farm level. The parameter estimates of the factors affecting the (in)efficiency are reported in lower panel of Table 5.2. The data used in this study allowed us to use variables like age and educational level of the farmer, farm size and tenancy status of the farm operator. Furthermore, the climatic related shock variables—season wise precipitation and temperature deviations from long-term means, have also been introduced in the inefficiency model. The results show that age, education and tenancy status variables have no influence on the farm level inefficiency since their coefficient are statistically highly non-significant. The results further show that there exists a positive association between farm size and technical efficiency. This result is consistent with the findings of Ahmad and Ahmad (1998) and Ahmad, *et al.* (2002) and Ahmad (2003). The reason for this result could be that the larger farmers due to their better off financial and social position have greater access to information, farm machinery as well as extension services and can perform agricultural operations with greater precision and more timely. Further, the scale of farm operations can enable them to use inputs more efficiently (Ahmad, *et al.* 2002).

As mentioned earlier, the climate shock variables—temperature and rainfall, jointly play a significant role in explaining the variations in technical efficiency of sampled farmers. The individual parameters of the temperature deviations show that April-June (DV_{t1}) and January-March (DV_{t4}) carry positive signs and are statistically significant at least at one percent level of probability. These results imply that significant deviations from the long term mean temperature during January-June months would have negative impact on technical efficiency of the sampled farmers. The period from April to June is start of *kharif* season (summer) crop in Pakistan—major crops like rice and cotton are sown while wheat is harvested in April. They all require higher temperature. As mentioned earlier, most of the famers in Pakistan are small, poor and illiterate. The changing patterns of climate change require resources and knowledge to quickly respond to vagaries of nature, while the farming community is ill prepared. Further to this, January-March period is a second half of *rabi* season where wheat—a major crop, is grown which requires cold temperature in early period—for vegetative growth, and warm at the end—for maturity of the crop. Two other major crops that are sugarcane and maize are mainly sown in this season and both require a mild temperature (warm) at this stage. As winter is warming up due to climate change phenomenon, early sowing of cotton (Bt in particular), spring maize and offseason vegetable growing (in tunnels) are becoming more popular in Punjab province (Ahmad, *et al.* 2014). These dynamics are relatively new in the farming system of Punjab, and therefore it may have negatively influenced the farm level technical efficiency. Our data shows that average temperature deviations from long term means for the period from January to March is positive (see Table 5.2) indicating rise in temperature that actually is the main driver of changing cropping pattern.

The parameter estimate of temperature deviation for the period of July-September (DV_{t2}) is negative and statistically significant at the 10 percent probability level implying that above normal temperature would increase technical efficiency of the sampled farmers. This period in fact represents mainly the vegetative growth stages of the two major crops of the season that are rice and cotton—both are heat loving plants; therefore, rise in temperature above the mean deviation would benefit farm level efficiency and thus help achieve output closer to frontier—but to a certain extent. Since the mean of deviations from the long term average temperature is negative (Table 5.2), therefore in reality it had potentially reduced the technical efficiency of the sampled farmers. Temperature deviations during the period of October-December (DV_{t3}) did not have any significant impact on farm level efficiency.

The parameter estimates of two rainfall deviation variables, April-June (DV_{p1}) and October-December (DV_{p3}) carry positive signs and are statistically significant at the one percent level of probability implying that excessive rains had potential to reduce farm level technical efficiency during these periods. However, our data shows average deviations are positive and negative during DV_{p1} and DV_{p3} period, respectively. This implies that average precipitation during the months October-December is below normal same as observed in case of average temperature deviations; therefore, lower precipitation in the presence of lower temperature did help achieve greater output closer to the frontier. The other two deviation variables DV_{p2} and DV_{p4} did not significantly influence the farm level (in)efficiency.

5.2.2 Technical Efficiency Distribution

The average technical efficiency scores presented in Table 5.3 show mean technical efficiency score of 0.82 implying that the average farm production could be increased by about 18 percent by using the existing technology more efficiently—with a minimum efficiency score of 0.15 to a maximum of 0.95. Table 5.4 shows that about 11 percent of the farmers are having technical efficiency score of less than 80 percent, while the remaining 89 percent are having efficiency score of more than 80 percent during the first year. During the second year, the respective figures are 26 percent of the farmers falling in the range of 50-80 percent technical efficiency, while the remaining 74 fall in the efficiency levels of 80-100 percent during the second year. During the third year, 40 percent of the farmers lie between efficiency score of 50-80 percent, while the remaining 60 percent fall between 80-100 percent. A careful observation indicates that with the passage of time, number of farmers in highest efficiency group (90-100) declined over the time period. However, the number of farmers in the lower efficiency group slightly increased with the passage of time. Majority of the farmers are concentrated in efficiency range of 70 to 90 percent. The overall efficiency trend however highlights the fact that efficiency score declined over time making the farmers less technically efficient.

Table 5.3: Mean of Technical Efficiency Estimates for Each Year

TE	Year 1	Year 2	Year 3	Overall
Average	0.86	0.81	0.79	0.82
Min	0.19	0.15	0.22	0.18
Max	0.95	0.96	0.95	0.95

Source: Author's own calculation

Table 5.4: Technical Efficiency Distribution Using CD- SFA Model

Technical Efficiency (%)	Percent of Farms Year 1	Percent of Farms Year 2	Percent of Farms Year 3
<50	3	5	5
50-60	1	2	4
60-70	2	3	8
70-80	5	16	23
80-90	53	56	48
90-100	36	18	12
Total	100	100	100

Source: Author's own calculation

5.3 Stochastic Profit Frontier: Empirical Results

Equation 4.3 was estimated using R-Frontier Package. This statistical package provides maximum-likelihood estimates (MLE). The results of the profit frontier function incorporating inefficiency effects in the model are reported in Table 5.5.

Table 5.5: The Maximum Likelihood Estimates for Cobb-Douglas Profit Frontier

	Variables	Parameters	Coefficients	Std. Error
Profit Function				
	Constant		0.69	1.05
Log of Cultivated Area	lnCA	β_1	0.51***	0.03
Log of permanent family labour	LnPFL	β_2	0.00	0.03
Log of present value of farm implement	LnFI	β_3	0.02***	0.01
Log of seed value index	Lnseed	β_4	0.31***	0.02
Log of material price index	Lnmat	β_5	-0.08***	0.01
Log of wage rate of hired labour	Lnwag	β_6	-0.04***	0.01
Log of irrigation rate	Lnirri	β_7	-0.05**	0.02
Dummy variable for cotton wheat zone	Dcw	β_8	0.77***	0.07
Dummy variable for rice wheat zone	Drw	β_9	0.97***	0.06
Dummy variable for mixed zone	Dmw	β_{10}	0.65***	0.05
Dummy variable for year 2006-07	dt1	β_{11}	0.20***	0.04
Dummy variable for year 2007-08	dt2	β_{12}	0.66***	0.06
Precipitation normal for April-June	P_1	β_{13}	0.00*	0.00
Precipitation normal for July-Sept	P_2	β_{14}	0.00	0.00
Precipitation normal for Oct-Dec	P_3	β_{15}	-0.01*	0.01
Precipitation normal for Jan-March	P_4	β_{16}	0.04***	0.02
Temperature normal for April-June	T_1	β_{17}	-0.10**	0.05
Temperature normal for July-Sept	T_2	β_{18}	0.03	0.07
Temperature normal for Oct-Dec	T_3	β_{19}	-0.04	0.09
Temperature normal for Jan-March	T_4	β_{20}	0.29***	0.07
Profit Inefficiency Model				
	Constant	$d_\circ$	-2143.20**	880.35
Age of household head	Age	d_1	-2.04**	0.82
Education of household head	Edu	d_2	20.06**	8.27
Total area of farm in acres.	Farm size	d_3	1.30**	0.53
Dummy variable if the farm is rented in	Dtenants	d_4	126.74**	52.83
Deviation of first quarter average rainfall	DVp1	d_5	-3.49**	1.42
Deviation of second quarter average rainfall.	DVp2	d_6	-2.15**	0.93
Deviation of third quarter average rainfall	DVp3	d_7	1.71**	0.69
Deviation of fourth quarter average rainfall	DVp4	d_8	21.30**	8.70
Deviation of first quarter average temperature.	DVt1	d_9	-316.19**	128.98
Deviation of second quarter average temperature	DVt2	d_{10}	-111.46**	45.10
Deviation of third quarter average temperature.	DVt3	d_{11}	-36.42**	16.39
Deviation of fourth quarter average temperature.	DVt4	d_{12}	-169.05**	69.19
	Variance Parameters			
	Sigma sq	σ^2	579.03**	238.90
	Gamma	Γ	0.99***	0.00
	log likelihood value		-1458.531	

Note: ***, **, * indicate significance at 0.01, 0.05 and 0.1 probability levels

Source: Author's estimation

The results of tests of hypotheses are reported in Table 5.6. The first null hypothesis which was tested relates to $H_0 : \gamma = 0$ specifying that the inefficiency effects do not exists in the model. The value of key parameter, $\gamma,$ which is defined as $\frac{\delta_{\mu}^2}{\delta_u^2+\delta_v^2}$, ranges between 0 and 1; 0 implies no inefficiency, and 1 indicates no random noise[52]. The null hypothesis was rejected implying that there exists profit inefficiencies at the sampled farms. The magnitude of γ is close to 1 and is significantly different from 0 shows the existence of high level of inefficiencies at the sampled farms. Moreover, the corresponding variance-ratio parameter implies that 99% of the differences between observed and the maximum frontier profits are due to the existing differences in efficiency levels among farmers. The second null hypothesis $H_\circ$: $\gamma = d_\circ = \dots d_n = 0$, which specifies that the inefficiency effects are not present in the model, was also rejected at the 5% level of significance. This result confirms the above finding that a significant part of the variability in profits among farms is explained by the existing differences in the level of technical inefficiencies. The third null hypothesis,$H_\circ$: $d_1 = \dots\dots d_n = 0$, was again rejected. This result implies that the variables included in the inefficiency model significantly explain the variation in profit inefficiency. The fourth null hypothesis is $H_\circ$: $d_5 = \dots\dots d_{12} = 0$ which specifies that climatic deviations jointly have no impact on profit inefficiency. This hypothesis was also rejected implying that climatic shocks do explain the variations in farm profit inefficiencies statistically significantly.

Table 5.6: Generalized Likelihood-Ratio Tests of Hypothesis for the Profit Frontier Model

Null Hypothesis	LR	DF	Critical Value	Decision
$H_\circ$: $\gamma = 0$	164	1	3	Reject $H_\circ$
$H_\circ$: $\gamma = d_\circ .. = d_n = 0$	291	14	23	Reject $H_\circ$
$H_\circ$: $d_1 = \dots\dots d_n = 0$	137	13	21	Reject $H_\circ$
$H_\circ$: $d_5 = \dots\dots d_{12} = 0$	58	8	14	Reject $H_\circ$

These critical values are taken from Table 1 of Kodde and Palm (1986) at 5% level of significance.

52 "If γ is not significantly different from 0, the variance of the inefficiency effects is 0 and the model reduces to a mean response function in which the inefficiency variables enter directly (Battese and Coelli, 1995)".

Based on the estimates of the profit frontier function, we computed basic features of the production structure, namely, profit elasticities with respect to changes in variable input cost and fixed factors. The material price index, wage and irrigation rate are significant and carry expected signs that are negative. The incremental contribution of farm capital, land, permanent family labor and seeds contributed positively to farm profit. Results of the model also demonstrate that all estimated coefficients of zone specific dummy variables are statistically significant and carry positive signs indicating higher profitability in irrigated areas relative to the rain-fed zone.

The results of climate variables show that precipitation normal significantly contribute towards farm profit, except that of the October-December which is affected negatively and significant—implying that better precipitation helps crop productivity if the temperature stays at the historical mean. Also increased precipitation results in high humidity that can cause high pests and diseases of crop and ineffectiveness of weed control measures (ICARDA 2011). The parameter estimates of first and fourth quarter temperature variables are statistically significant at least at the 5 percent level of significance. The rise in temperature normal during April-June contributed negatively and January-March contributed positively towards farm profit while July-September and October –December temperature are insignificant.

5.3.1 Analysis of the Determinants of Profit Inefficiency

The impact of the socio-economic factors accounting for farm inefficiency is listed in the lower panel of Table 5.5. The results show that education of head of the household has significant positive impact on profit inefficiency—implying that more educated farmer are less involve in farm production due to off farm jobs and realizes less profit. The farm size also affects inefficiency significantly positively. The impact of farm size on inefficiency is mystifying. The large farm area positively contributed efficiency on the one hand and negatively on the other hand because having larger planting area, enhance the ability of the farmers to apply modern technologies such as tractors and irrigation while other group of researchers is arguing that small farmers are more efficient in managing limited available resources for their survival because of economic pressure. Therefore, farmers with large farm size could be more efficient or less inefficient. The parameter estimate of tenancy variable shows that the tenants are inefficient relative to the owner and owner-cum-tenants.

Variations in temperature and precipitation from their respective long term means have also been used to examine the impacts of climatic shocks. All parameter estimates of climate related shock variables—temperature and precipitation deviations, are significant at least at the 5 percent probability level. The parameter estimates of rainfall deviation variables, April-June (DV_{p1}) and July-Sept (DV_{p2}), carry negative signs implying that excessive rains had potential to reduce farm level technical inefficiency during these periods that mostly covers summer crops. However, our data shows average rainfall deviations for third quarter DV_{p3} and fourth quarters DV_{p4} months (Oct-Dec and Jan-March) are positive. These months cover winter crops season *(rabi)* and the results imply that positive rain shocks (positive deviations from the long term trends) would reduce farm efficiency.

All parameter estimates of temperature deviation variables are statistically significant and negatively contribute to inefficiency levels. Our data show that average temperature deviations in fact are negative for DV_{t1}, DV_{t2}, DV_{t3} and DV_{t4} from long term means which imply that the lower temperature from long-term means has reduced the level of technical inefficiency pushing farmers further close the profit frontier. The impact of temperature deviations during the period of October-December (DV_{t3}) was though positive on efficiency and found statistically significant. The deviations of January-February (DV_{t4}) also contributed positively to profit efficiency. (DV_{t3}) and (DV_{t4}) period represents mainly the sowing and vegetative growth stages of winter crops i.e. wheat, peas and gram therefore the negative temperature shocks have potential to reduce farm inefficiency. The mean of the deviations during this period is negative implying negative temperature shocks (cooling up weather compared to historical trends) leading us to conclude that low temperature than the historical mean helps raise farm efficiency. This result is consistent with the findings of Ahmed, *et al.* (2014).

5.3.2 Profit Efficiency Distribution

The average profit efficiency scores presented in Table 5.7 show that average profit efficiency score is 0.72; the average farm could increase profits up to 28 percent by improving their technical efficiency. Results show that there exist a widespread in profit inefficiency ranging from 95 percent to less than 0.02 percent. The observed results are not unexpected; similar results were found by previous empirical studies in Pakistan, e.g. Ali and Flinn (1989) stated mean profit efficiency level of 0.69 (ranging between 13–95%) in Punjab while Ali, *et al*. (1994) reported 0.75 (ranging between 4–90%) in KPK province for rice producers. However, the results shows that a substantial amount of unexploited profit exists in agriculture that can be realized by using even the existing technologies more efficiently in production.

The distribution of profit efficiency of sampled farmers is presented in Table 5.8 that indicate that the proportion of famers having efficiency score below 0.80 slightly decreased in second year and increases in third year, while the proportion of farmers having efficiency score of above 0.80 have declined. However, the overall trend of profit efficiency measures slightly decreased overtime. And most of the farmers are concentrated in efficiency range of 60 to 90 percent.

Table 5.7: Mean of Profit Efficiency Estimates for Each Year

Year	Efficiency Scores
Year 1	0.77
Year 2	0.65
Year 3	0.74
Mean Profit Efficiency	0.72

Source: Author's own calculations

Table 5.8: Profit Efficiency Estimates Distribution Using CD -SFA Model

PE Range	Percent of Farms Year 1	Percent of Farms Year 2	Percent of Farms Year 3
<50	2	16	5
50-60	3	10	6
60-70	8	19	10
70-80	34	34	36
80-90	52	20	41
90-100	1	1	2
Total	100	100	100

Source: Author's own calculations

According to Kumbhakar (2001), profit efficiency (PE) depends on output technical efficiency. Our results do not however fully support this argument, since both are weakly associated: The Spearman rank correlation coefficients were found to be +0.10, 0.01 and 0.40 for the data years 2005-06, 2006-07 and 2007-08, respectively, while the correlation coefficient for the full period (2005-2008) was 0.21. The first two years show almost no association, while the correlation coefficient for the year 2007-08 is not only reasonably high but also statistically highly significant. Overall association between TE and PE is weak but found statistically significant. The major reason for this trend could be the extraordinary rise in food prices (world over) in the third year of the data incentivized the farming community to use resources more efficiently. Both TE and PE measures were found higher than the previous year. The overall situation, however, highlights the fact that higher technical efficiency does not always transform into higher profit and thus profit efficiency (see Xiang, Shamsuddin and Worthington, 2011, Jayaraman and Srinivasan, 2014 in the banking sector).

5.4 Food Security Analysis

This section describes the construction of household food security index by incorporating technical efficiency as an indicator of food availability component of FSI and profit efficiency as an indicator of accessibility component based on their definition. To improve households and community's food security situation, the efficiency of existing utilization of resources may need to be improved. It will enhance the productive capacity of resources to ensure long run sustainability (Bokeloh 2009). In addition to this, efficient use of agricultural resources can help in achieving certain desirable welfare indicators which are related ultimately with the goal of food security (Alene and Manyong 2006). The pathways through which efficiency gain can lead to sustainable development are complex and interrelated (Schneider and Gugerty 2011). Technical efficiency and profit efficiency growth may lead to increased output and enhanced farm income that may translate into improving the livelihood of households.

We also incorporate weather shocks along with other socioeconomic characteristics in the model to evaluate their impacts on household food security status over time. Analytical tools employed in this section include Principle component analysis (PCA), descriptive statistics, logistic regression that has been described in some detail in the previous chapters. We start from descriptive analysis, after that the findings from empirical results will be interpreted and discussed.

5.4.1 Food Security Index

Following the procedure described in previous chapter, we apply PCA on food security indicators to construct FSI at the household level.

The results of the PCA reported in Table 5.10 indicate that loading in the first component for the indicators are positive as expected. The first factor explained 23 percent of the total variation in the data. The second factor explains 14 percent of the variance and the third explains 14 percent and so on. The loading components exhibiting positive signs indicated positive contribution of indicators in FSI such as increase in technical efficiency will result in higher per capita output with the given cultivated area through increased overall food availability/supply and dietary diversity that positively contributed to profit efficiency. These are important components of food security index. Based on the first principle component, FSI is constructed. It is worth mentioning here that the value of Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy turned out to be 0.62 on average, which implies that compact patterns of correlations between the variables and hence justifies the use of PCA for our purpose (Dunteman 1994).

Table 5.9: Food Security Indicators Loading Component Statistics

	Variables	Eigenvalue	Component loading	Proportion of Variation	KMO test Statistics
1	Cereal prod/cap	1.82	0.49	0.23	0.59
2	TE score	1.11	0.06	0.14	0.48
3	PE score	1.03	0.02	0.13	0.49
4	No of food crops	0.99	0.23	0.12	0.64
5	Health expenditure	0.93	0.21	0.12	0.63
6	Cultivated area	0.86	0.50	0.11	0.63
7	PV of assets	0.70	0.53	0.09	0.65
8	Animal adult units	0.56	0.36	0.07	0.62

Source: Author's own calculations

5.4.2 Food Security Status

The food security index was constructed by using Equation 3.23. The descriptive statistics of the outcome are reported in Table 5.11. The results show that food security index for three years vary from -1.63 to 8.15 with a cut-off point at zero (see Table 5.11). The households having FSI ≤ 0 are considered food insecure and having value greater than zero (FSI ≥ 0) are considered food secure. Based on this assumption, 301(56%) households were found food insecure and the rest 236(44%) were food secure in 2005-06. During 2006-07, 268(50%) households were found as food insecure, while the remaining 269(50%) were food secure. For the year 2007-08, 243(45%) household were food insecure and 294(55%) were food secure. The overall average shows that 50 percent of the households were food insecure during the study period, while the remaining 50 percent were found food secure. A paired t-test analysis shows that there is statistically significant difference in relative food security status measured by using FSI during the data period.

Table 5.100: Descriptive Statistics Food Security Index FSI

Year	Mean	Standard deviation	Min	Max	Food insecure #HH	Food secure #HH	Total HH
Year one	0.10	1.13	-1.62	7.84	301(56%)	236(44%)	537
Year two	0.22	1.19	-1.63	8.15	268(50%)	269(50%)	537
Year three	0.25	1.05	-1.47	7.93	243(45%)	294(55%)	537
Total Obs					812(50%)	799(50%)	1611

Source: Author's own calculations

5.4.3 Factors Explaining Food Security

This section focuses on examining the impact of socio-economic and weather shocks variables on food security. For this purpose, logistic regression technique is used and the results are reported in Table 5.12. The χ^2 statistics suggests that the overall model is significant and fits the data well. The results show that most of the explanatory variables are statistically significant at least at the 5 percent level of probability, and carry expected signs. The value of Pseudo R^2 (0.36) is also indicative of that model is reasonably well specified[53].

Dependent variable is binary—1/0 where 0 represents food insecure and 1 denotes food secure household. The results are also presented in the form of 'Odds Ratio' (OR). "*This is the ratio of the odds of an event occurring in one group to the odds of it occurring in another group*" and can be computed as $exp^{(\text{logit coeff})}$ (Grimes and Schulz 2008). The magnitude of OR shows marginal effect of on unit change in explanatory variable.

The parameter estimates of the estimated logistic regression reported in Table 5.12 show that 15 out of the total 21 estimates are statistically significant at least at the 5 percent level of probability. The constant term (intercept) shows the average production of rainfed (*barani*) and partial rainfed (*barani*) zone taken as a base for the three cropping zone included in the model whereas their coefficients show deviations from this mean production. The coefficient of rice-wheat and mixed zone are positive and significant indicating that farm households of these zones are likely to be more food secure than that of those living in other zones. Households living in cotton-wheat zone are more food insecure. The previous studies analyzing the poverty measures endorse these results (Malik 1992; Gazder, et al. 1994; and Arif and Ahmad 2001). These studies concluded that poverty was lowest in the rainfed (barani) areas of Punjab because of better access to employment in other sectors—services sector as well as overseas migration, as compared to other ecological zones of Pakistan. These studies further pointed out the presence of high incidence of poverty in irrigated areas of the

[53] Nonetheless, the pseudo R^2 has not been considered an appropriate measure of goodness of fit of the model because it take into account various comparisons of the predictive values from the fitted model (Hosmer and Lemeshow 2000).

country particularly in Southern Punjab (cotton-wheat system) where feudal system still prevails, and off-farm job opportunities are limited as well as migration within country and overseas is not very common in these areas.

Table 5.11: Logistic Regression Results
(Dependent variable is 1/0 variable: Foods secure =1 and Food insecure=0)

	Logistic Regression Results			
Dependent variable	1/0 variable: Foods secure =1 and Food insecure=0			
Explanatory	Coefficient	Std. Err.	Odd-Ratio	Std. Err.
Age	-0.01**	0.00	0.99	0.00
Education	0.04**	0.01	1.04	0.02
Farm size	0.08**	0.00	1.08	0.01
Dtenant	-0.28*	0.38	0.76	0.29
Dependency ratio	-0.12*	0.09	0.88	0.08
Cotton-wheat zone	-0.61**	0.28	0.54	0.15
Rice-wheat zone	0.64**	0.32	1.90	0.60
Mixed wheat zone	0.50**	0.23	1.65	0.37
dvt1	0.09*	0.27	1.09	0.30
dvt2	-0.07	0.15	0.93	0.14
dvt3	-0.03	0.18	0.97	0.18
dvt4	-0.31**	0.17	0.74	0.13
dvp1	-0.01	0.01	0.99	0.01
dvp2	0.01**	0.00	1.01	0.00
dvp3	0.00	0.01	1.00	0.01
dvp4	0.01*	0.01	1.01	0.01
Dcantub	0.11	0.22	1.11	0.25
Dcanal	-0.05	0.26	0.95	0.25
Dtub	0.50**	0.22	1.64	0.36
dt2	-0.57	0.49	0.56	0.28
dt3	1.19**	0.57	3.28	1.86
Constant	-2.15**	0.45	0.12	0.05
LR chi^2(21)	806.40			
Prob > chi2	0.00			
Log likelihood	-713.40			
Pseudo R2	0.36			

Sig code: **significant at $p < 0.05$, and * at $p < 0.10$,
Source: Authors' estimation

The results further show that the households having aged heads are likely to be more food insecure than those which are headed by the relatively younger heads. This result is consistent with the finding of Bashir, *et al.* (2010 and 2012).The variable of educated head is also statistically significant and is positive which implies that the farm households whose heads are educated are more likely to be food secure. The coefficient of dummy for tenure status carries not only negative sign but it is also highly significant. This result implies that the tenant households are likely to be more food insecure relative to owner cultivators. The dependency ratio also influences food security negatively and this result very well matches with the findings of Bashir, *et al.* (2010 and 2012), Sindhu, *et al.* (2008) and Omotesho, *et al.* (2007). The farm size has a positive association with the household food security status. The OR suggests that one acre increase in farm size would raises the chances of household to becoming food secure by about 8 percent—this result is consistent with the finding of Omotesho, *et al.* (2007). Households having access to irrigation water from tub-well/dug-well/check dams,is positive and significant. These are likely to be significantly more food secure than those households who do not have access to such facilities while coefficient of other sources—canal, canal plus tube-well are insignificant. It is pertinent to mention here that installation of tube-wells, dug-wells and use of check dams are becoming very popular in the rainfed areas of Punjab (Ahmad, *et al*. 2014).

The results further show that the climatic shocks do influence the food security status of the farm households. The first quarter temperature deviation carries a positive sign and is statistically significant implying that above the historical mean temperature would likely to have positive influence on household food security. The OR suggests that one $1C^{\circ}$ increase in temperature would raises the chances of household to becoming food secure by about 9 percent. The fourth quarter deviation shows a negative impact on household food security status. The data show that the mean of temperature deviations during fourth quarter period is negative implying that the negative temperature shocks have been influencing the household food security negatively. However, second and third quarters' temperature deviations have not proved to be having any significant direct impact on household food security.

First quarter (April-June) and third quarter (Oct-Dec) deviations impacts were not found significantly different from zero. The excessive precipitation during the second quarter (July-Sept) positively impacts food security. The fourth quarter (Jan-March) precipitation deviations also show a positive and statistically significant association with the household food security status.

5.5 Summary

In this chapter, farm level technical and profit efficiencies were estimated by using Stochastic Frontier Approach. Farm level panel data from Punjab for the period of 2005-08 was used for the analysis. The results from production frontier analysis indicated that wide range of technical inefficiencies existed at farm level in all sample districts. Mean technical efficiency was found to be 82 percent indicating significant room for improvement in farm productivity. The climatic variables were found to be significantly affecting farm production as well as farm level technical efficiencies.

The profit frontier results are suggestive of the existence of wide range profit inefficiencies. The average profit efficiency was found to be 72 percent. The correlation between technical efficiency measures (using production frontier) and profit efficiency (using variable profit function) revealed weak association—though the relation was statistically significant. This result is indicative of the fact that technical efficiency does not necessarily promote profit efficiency. However, the results do support the notion that the farmers who were technically inefficient were also unable to operate at the profit frontier—rather found more inefficient in realizing the maximum achievable profit using the given level of technology. The results further show that the climatic variables—long-term normals and short term climatic shocks, significantly influence farm production, profits and efficiencies which have serious implications for the agriculture sector of Pakistan.

This chapter has also constructed food security index (FSI) by using different indicators like per capita cereals production, cultivated area, number of food crops grown, animal adult units owned, assets value, health expenditures, and technical and profit efficiencies which represent all four aspects for food security including availability, accessibility and utilization. The results revealed high level of food insecurity in the sampled districts that varies across cropping zones—cotton-wheat the least and rice-wheat crops zone the most food secure. Tenants and households headed by aged members were found more food insecure. Households having access to irrigation from tube-well water were found more food secure than those who do not have this facility.

Climatic variables—precipitation and temperature deviations (shocks) do play significant role in determining the household food security status. The results are suggestive of the fact that fighting the climate change through mitigation and adaptation strategies and enhancing farm level production efficiencies shall be the key elements to improve the performance of the agriculture sector as well as the farm household food security.

Chapter 6

CONCLUSIONS, POLICY SUGGESTIONS AND WAY FORWARD

At the close of this study we summarize our findings drawn from the analyses presented in the foregoing chapters, highlight policy implications in respect of meeting the challenges of climate change, and suggest possible extensions of this study for future research. Finally, the limitations of the study and the ways how these could be tackled have been suggested.

6.1 Summary and Conclusion

This thesis sought to fill the gap in economic literature by exploring the linkages between climate change, farm production and profits, production efficiencies, and household food security. The study provides extensive review of literature—both theoretical and empirical, dealing with the measurement of farm efficiency covering wide range of developments over time in parametric and non-parametric analytical techniques. In parametric techniques the review dealt with deterministic models to stochastic frontier approaches (SFA). Based on the review and merits and demerits of the different methodologies used to assess the performance of the farm sector, this study opted for SFA to achieve the objectives. We used SFA incorporating technical inefficiency effects in the model proposed by Battese and Coelli (1995). This technique allows estimation of the parameters of the production/profit frontiers and the inefficiency model in a single step. In this study we used a modified Cobb-Douglas functional form in estimating both production and profit frontiers.

The dependent variable in production frontier was output quantity index. The independent variables included land, labor and capital material services along with climatic variables—20 years moving averages of temperature and precipitation, in the main production function, while the inefficiency model included socio-economic variables besides climatic shocks—deviations of temperature and precipitation of current quarter from their respective long term means. The results suggest that there exist significant levels of technical inefficiencies at the sampled farms. The results further imply that the climate related variables play significant role in determining the variations in farm production and technical efficiencies. The average technical efficiency was found to be 82 percent and maximum efficiency was 96 percent among the sample farmers so leaving room for average farmer to make an improvement in farm productivity by 14 percentage points by improving managerial capacity of the farming community at the same level of inputs used and technology. The results also imply that technical efficiency declined over the period under study.

The study also estimated the variable profit function applying the SFA incorporating the profit inefficiency model. The results show the existence of wide range profit inefficiencies with an average score of 72 percent—highest efficiency score was 95 percent leaving room for improvement in farm profits by 23 percentage points by using farm resources more efficiently. The correlation between technical efficiency estimates (using production frontier) and profit efficiency (using profit frontier) reveal a weak association—though the relation was statistically significant. This result is indicative of the fact that technical efficiency does not necessarily promote profit efficiency. However, the results do support the notion that the farmers who were technically inefficient were also unable to operate at the profit frontier—rather found more inefficient in realizing the maximum achievable profit using the given level of technology. The results further show that the climatic variables—long-term normal and short term climatic shocks, significantly influence farm production, profits and efficiencies which have serious implications for the agriculture sector of Pakistan.

The study takes a step further to establish association between climate change and household food security—while the latter itself is influenced by the technical and profit inefficiencies. Food Security Index (FSI) was constructed using Principal Component Analysis as a first step in this regard. Different indicators of food security used for the construction of FSI including cereal production per capita, cultivated area, number of food crop grown, animal adult units owned, assets value, health expenditures, and technical and profit efficiencies which represent all three aspects for food security including availability, accessibility and utilization. In the second step, FSI was regress against various socioeconomic variables. The results reveal a high level of food insecurity in the sampled districts that varies across cropping zones—cotton-wheat being the least and rice-wheat cropping zone being the most food secure cropping zone. Tenants as well as households headed by aged members were found more food insecure. Households having access to irrigation from tube-well water were found more food secure than those who lack the access. Climatic variables—precipitation and temperature deviations (shocks) do play significant role in determining the food security status of household.

The results are suggestive of the fact that fighting climate change through promotion of mitigation and adaptation strategies and enhancing farm level production efficiencies with provision of formal education, facilitating consolidation of lands, and securing tenancy, shall be the key elements to improve the performance of the agriculture sector as well as the farm household food security.

6.2 Policy Suggestions

The major objectives of the study were to quantify the impact of changes in climate on the performance of farm production, profitability and household food security. To this end the study confirms the premises that climate change affects agricultural production and profitability considerably. The results further indicated that production efficiencies—technical and profit, besides the climate change indicators play crucial role in determining the levels of farm household food security. Therefore, there is a need to take steps:

- to handle the adverse effects of climate change on crop production, efficiency and food security through devising and promoting mitigation and adaptation strategies;
- to enhance off-farm employment and investment opportunities in order to facilitate the exit of extremely inefficient farmers.
- to improve the educational system in rural areas making it more accessible to the general public—particularly for those living in far flung areas;
- to re-orient the agricultural extension system to meet the challenges of climate change, since extension agents are the one who could better train the farming communities to improve their management skills under the changing scenarios of the environment; and
- to modernize the weather information and forecasting system that could cope with the information gap spurred by the vagaries of nature.

In addition to above, it is generally believed that the changing climatic conditions would further worsen the shortages of irrigation water in the country. The crops are already being grown under water stress and rise in temperature would result in enhance water requirements by the plants. Therefore, it is crucial to enhance water storage capacity in the country in order to ensure sustainability in agricultural production system and food security status of household.The results of the study are further suggestive of the fact that maximizing output does not always maximize farm profits. Therefore, there is need to increase input and output market efficiencies through better infrastructure and farmers friendly policies that in turn would reduce the cost of production and make the sector more competitive.

6.3 Way Forward

Our results and policy implications suggest additional research and analyses related to the following topics:

- The main shortcoming of this study is that it only considers two climatic variables—precipitation and temperature, and ignores other important climatic factors like fog, growing degree days, cumulative precipitation, minimum and maximum of climatic indicators (nights and days times), frost, and humidity etc. Incorporation of these variables in the models may provide different implications.
- The effect of soil fertility and moisture status, as well as possible adoption of new crop varieties and production technologies also need to be accounted for in such studies.
- Studies show that input and output prices have significant impact on farm profitability. Additional research is required to evaluate the impact of climate change on input and output prices.
- Climatic factors may affect crops productivity differently at various stages of crop growth as each growth stage has a specific range of optimum values of climatic variables (temperature and moister etc.). Therefore, deeper understanding and separate analysis by crops at different developmental stages will be another improvement.
- Further, the model developed here can further be extended to incorporate adaptation strategies to climate change to see their impacts on farm production, efficiency and profitability as well as on food security.

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APPENDIX

Table: A1 Food Security Results using Continuous Data of Food Security Index (FSI)

	OLS	
Dependent variable	FSI continuous data	
Explanatory Variables	Coefficient	Std. Err.
Age	0.01**	0.00
Education	0.01**	0.00
Farm size	0.01**	0.01
Dtenant	-0.15*	0.11
Dependency ratio	-0.08**	0.02
Cotton-wheat zone	-0.12*	0.08
Rice-wheat zone	0.28**	0.09
Mixed wheat zone	0.03*	0.06
dvt1	-0.07	0.07
dvt2	-0.09**	0.04
dvt3	0.07	0.05
dvt4	-0.11**	0.05
dvp1	-0.01**	0.00
dvp2	0.00**	0.00
dvp3	0.00	0.00
dvp4	0.01**	0.00
Dcantub	0.05	0.06
Dcanal	-0.01	0.08
Dtub	0.11**	0.06
dt2	-0.02	0.14
dt3	0.28**	0.17
Constant	-0.35**	0.13
F(21, 1589)	93.33	
Prob > chi2	0.00	
R-squared	0.55	

Sig code: **significant at p < 0.05, and * at p < 0.10,
Source: Authors' estimation

Table: A2 Technical Efficiency Scores

Household	year1	year2	year3
1	0.78	0.71	0.69
2	0.83	0.57	0.57
3	0.92	0.89	0.87
4	0.91	0.82	0.84
5	0.90	0.78	0.80
6	0.92	0.84	0.82
7	0.93	0.90	0.90
8	0.93	0.86	0.84
9	0.92	0.82	0.82
10	0.90	0.81	0.74
11	0.87	0.82	0.82
12	0.89	0.82	0.80

Technical Efficiency Scores Table: A2 Continue ….

Household	year1	year2	year3
13	0.84	0.72	0.43
14	0.89	0.71	0.81
15	0.88	0.78	0.77
16	0.89	0.67	0.81
17	0.87	0.50	0.70
18	0.90	0.79	0.79
19	0.88	0.77	0.75
20	0.91	0.67	0.63
21	0.84	0.76	0.76
22	0.82	0.73	0.86
23	0.34	0.33	0.28
24	0.69	0.56	0.56
25	0.27	0.15	0.26
26	0.29	0.27	0.28
27	0.49	0.53	0.62
28	0.48	0.28	0.32
29	0.31	0.20	0.25
30	0.56	0.41	0.45
31	0.34	0.19	0.23
32	0.82	0.85	0.79
33	0.51	0.26	0.54
34	0.33	0.30	0.22
35	0.51	0.30	0.32
36	0.65	0.56	0.64
37	0.60	0.50	0.53
38	0.34	0.29	0.33
39	0.31	0.24	0.41
40	0.88	0.91	0.81
41	0.88	0.85	0.78
42	0.88	0.75	0.70
43	0.88	0.89	0.76
44	0.91	0.87	0.81
45	0.83	0.73	0.73
46	0.91	0.78	0.77
47	0.82	0.88	0.29
48	0.83	0.88	0.58
49	0.91	0.82	0.75
50	0.90	0.78	0.79
51	0.94	0.90	0.90
52	0.93	0.88	0.76
53	0.88	0.65	0.84
54	0.95	0.92	0.87

Technical Efficiency Scores			Table: A2 Continue….
Household	year1	year2	year3
55	0.85	0.84	0.77
56	0.91	0.86	0.77
57	0.75	0.88	0.87
58	0.78	0.89	0.85
59	0.88	0.93	0.91
60	0.69	0.87	0.75
61	0.71	0.89	0.87
62	0.82	0.88	0.85
63	0.19	0.48	0.33
64	0.71	0.84	0.84
65	0.88	0.93	0.90
66	0.79	0.85	0.83
67	0.60	0.72	0.79
68	0.60	0.82	0.72
69	0.39	0.56	0.78
70	0.50	0.82	0.81
71	0.77	0.78	0.73
72	0.52	0.71	0.73
73	0.68	0.56	0.78
74	0.86	0.85	0.64
75	0.73	0.71	0.75
76	0.55	0.53	0.64
77	0.78	0.77	0.78
78	0.80	0.75	0.83
79	0.73	0.79	0.82
80	0.47	0.37	0.74
81	0.84	0.86	0.91
82	0.45	0.36	0.37
83	0.83	0.78	0.78
84	0.75	0.48	0.79
85	0.85	0.80	0.79
86	0.72	0.60	0.62
87	0.79	0.83	0.76
88	0.74	0.64	0.77
89	0.78	0.83	0.81
90	0.94	0.91	0.84
91	0.89	0.84	0.85
92	0.88	0.71	0.82
93	0.92	0.83	0.76
94	0.85	0.72	0.83
95	0.92	0.89	0.73
96	0.86	0.71	0.82
97	0.86	0.73	0.73

Technical Efficiency Scores Table: A2 Continue….

Household	year1	year2	year3
98	0.87	0.60	0.74
99	0.88	0.75	0.68
100	0.92	0.92	0.86
101	0.91	0.71	0.87
102	0.85	0.68	0.72
103	0.88	0.82	0.72
104	0.95	0.94	0.92
105	0.93	0.94	0.94
106	0.92	0.91	0.91
107	0.89	0.86	0.79
108	0.85	0.86	0.80
109	0.93	0.90	0.89
110	0.87	0.89	0.88
111	0.91	0.89	0.94
112	0.88	0.81	0.74
113	0.88	0.84	0.81
114	0.93	0.89	0.86
115	0.89	0.89	0.86
116	0.89	0.90	0.84
117	0.92	0.90	0.94
118	0.90	0.90	0.90
119	0.87	0.89	0.84
120	0.84	0.86	0.70
121	0.90	0.90	0.86
122	0.90	0.90	0.84
123	0.84	0.85	0.73
124	0.89	0.89	0.86
125	0.86	0.87	0.84
126	0.93	0.94	0.93
127	0.90	0.89	0.89
128	0.84	0.74	0.71
129	0.90	0.92	0.90
130	0.96	0.96	0.91
131	0.92	0.90	0.96
132	0.94	0.94	0.89
133	0.85	0.86	0.76
134	0.89	0.88	0.77
135	0.90	0.90	0.88
136	0.91	0.86	0.78
137	0.96	0.95	0.95
138	0.92	0.91	0.89
139	0.87	0.75	0.60
140	0.89	0.91	0.72

Technical Efficiency Scores Table: A2 Continue….

Household	year1	year2	year3
141	0.84	0.83	0.56
142	0.84	0.82	0.58
143	0.87	0.84	0.54
144	0.85	0.78	0.49
145	0.89	0.82	0.65
146	0.82	0.69	0.51
147	0.67	0.72	0.46
148	0.87	0.84	0.55
149	0.83	0.83	0.63
150	0.84	0.71	0.51
151	0.84	0.84	0.50
152	0.87	0.86	0.54
153	0.86	0.85	0.74
154	0.88	0.80	0.69
155	0.82	0.65	0.57
156	0.63	0.40	0.39
157	0.81	0.83	0.55
158	0.78	0.59	0.62
159	0.83	0.84	0.48
160	0.88	0.89	0.73
161	0.86	0.88	0.54
162	0.85	0.76	0.46
163	0.90	0.83	0.71
164	0.88	0.90	0.65
165	0.89	0.88	0.67
166	0.88	0.90	0.69
167	0.87	0.86	0.62
168	0.82	0.84	0.67
169	0.82	0.75	0.76
170	0.75	0.69	0.48
171	0.82	0.79	0.60
172	0.84	0.81	0.68
173	0.89	0.90	0.83
174	0.91	0.91	0.82
175	0.90	0.92	0.86
176	0.92	0.93	0.86
177	0.92	0.94	0.81
178	0.93	0.93	0.88
179	0.92	0.90	0.83
180	0.82	0.93	0.83
181	0.91	0.90	0.86
182	0.91	0.90	0.86
183	0.90	0.90	0.78

Technical Efficiency Scores			Table: A2 Continue….
Household	year1	year2	year3
184	0.92	0.90	0.83
185	0.92	0.90	0.83
186	0.91	0.90	0.86
187	0.89	0.90	0.71
188	0.85	0.85	0.70
189	0.92	0.88	0.88
190	0.92	0.86	0.91
191	0.84	0.82	0.81
192	0.91	0.89	0.84
193	0.93	0.81	0.76
194	0.92	0.90	0.88
195	0.93	0.79	0.82
196	0.92	0.90	0.90
197	0.90	0.91	0.83
198	0.81	0.82	0.63
199	0.82	0.79	0.53
200	0.80	0.71	0.56
201	0.87	0.79	0.76
202	0.86	0.82	0.85
203	0.86	0.77	0.70
204	0.89	0.83	0.77
205	0.86	0.86	0.81
206	0.89	0.87	0.86
207	0.85	0.77	0.69
208	0.90	0.86	0.80
209	0.89	0.77	0.71
210	0.91	0.86	0.85
211	0.87	0.74	0.69
212	0.73	0.45	0.76
213	0.89	0.80	0.74
214	0.89	0.88	0.83
215	0.89	0.90	0.67
216	0.91	0.85	0.56
217	0.92	0.85	0.67
218	0.92	0.86	0.85
219	0.91	0.89	0.82
220	0.91	0.90	0.83
221	0.91	0.89	0.86
222	0.90	0.87	0.84
223	0.92	0.91	0.80
224	0.90	0.86	0.83
225	0.92	0.89	0.82
226	0.91	0.61	0.82

Technical Efficiency Scores			Table: A2 Continue….
Household	year1	year2	year3
227	0.88	0.86	0.79
228	0.92	0.85	0.83
229	0.93	0.90	0.89
230	0.93	0.86	0.81
231	0.92	0.91	0.88
232	0.93	0.91	0.91
233	0.95	0.90	0.90
234	0.92	0.87	0.89
235	0.93	0.89	0.89
236	0.94	0.89	0.89
237	0.93	0.79	0.88
238	0.90	0.77	0.92
239	0.94	0.86	0.86
240	0.86	0.74	0.75
241	0.93	0.74	0.89
242	0.86	0.52	0.73
243	0.94	0.90	0.91
244	0.93	0.82	0.89
245	0.92	0.83	0.89
246	0.92	0.66	0.61
247	0.92	0.86	0.94
248	0.92	0.66	0.77
249	0.93	0.80	0.81
250	0.92	0.87	0.92
251	0.94	0.87	0.90
252	0.90	0.82	0.84
253	0.91	0.75	0.76
254	0.94	0.88	0.90
255	0.89	0.77	0.80
256	0.89	0.86	0.83
257	0.90	0.83	0.89
258	0.89	0.86	0.82
259	0.88	0.84	0.80
260	0.88	0.83	0.74
261	0.90	0.82	0.84
262	0.88	0.81	0.71
263	0.81	0.80	0.75
264	0.86	0.81	0.81
265	0.88	0.80	0.77
266	0.87	0.78	0.82
267	0.89	0.85	0.88
268	0.88	0.90	0.86
269	0.86	0.82	0.72

Technical Efficiency Scores Table: A2 Continue….

Household	year1	year2	year3
270	0.88	0.19	0.85
271	0.89	0.87	0.86
272	0.90	0.91	0.89
273	0.91	0.92	0.90
274	0.92	0.88	0.88
275	0.92	0.92	0.91
276	0.93	0.90	0.91
277	0.93	0.91	0.91
278	0.92	0.90	0.84
279	0.90	0.88	0.88
280	0.90	0.92	0.87
281	0.90	0.88	0.91
282	0.93	0.88	0.90
283	0.85	0.81	0.80
284	0.92	0.86	0.87
285	0.91	0.85	0.85
286	0.91	0.85	0.87
287	0.89	0.77	0.81
288	0.90	0.86	0.90
289	0.95	0.92	0.92
290	0.90	0.85	0.86
291	0.89	0.83	0.79
292	0.85	0.80	0.87
293	0.92	0.87	0.87
294	0.91	0.85	0.87
295	0.93	0.92	0.91
296	0.91	0.91	0.90
297	0.89	0.88	0.85
298	0.86	0.86	0.86
299	0.92	0.91	0.92
300	0.85	0.87	0.86
301	0.89	0.89	0.91
302	0.83	0.92	0.91
303	0.92	0.90	0.91
304	0.91	0.85	0.88
305	0.93	0.87	0.90
306	0.86	0.90	0.89
307	0.93	0.81	0.88
308	0.86	0.81	0.87
309	0.91	0.88	0.73
310	0.92	0.92	0.83
311	0.87	0.79	0.88
312	0.90	0.81	0.90

Technical Efficiency Scores			Table: A2 Continue….
Household	year1	year2	year3
313	0.90	0.87	0.89
314	0.87	0.85	0.85
315	0.87	0.89	0.92
316	0.65	0.41	0.67
317	0.87	0.82	0.91
318	0.90	0.89	0.84
319	0.87	0.81	0.84
320	0.81	0.56	0.82
321	0.91	0.88	0.93
322	0.90	0.91	0.92
323	0.85	0.80	0.80
324	0.92	0.89	0.94
325	0.90	0.75	0.84
326	0.89	0.88	0.90
327	0.86	0.34	0.85
328	0.90	0.88	0.93
329	0.81	0.90	0.90
330	0.91	0.87	0.90
331	0.89	0.87	0.90
332	0.88	0.79	0.90
333	0.89	0.81	0.85
334	0.88	0.85	0.85
335	0.88	0.77	0.89
336	0.89	0.84	0.93
337	0.92	0.80	0.88
338	0.85	0.87	0.87
339	0.88	0.83	0.91
340	0.89	0.84	0.90
341	0.84	0.79	0.87
342	0.83	0.85	0.81
343	0.90	0.87	0.89
344	0.91	0.89	0.54
345	0.90	0.87	0.75
346	0.91	0.85	0.82
347	0.92	0.86	0.83
348	0.93	0.86	0.88
349	0.91	0.87	0.84
350	0.88	0.90	0.87
351	0.91	0.85	0.82
352	0.90	0.84	0.76
353	0.91	0.88	0.85
354	0.92	0.83	0.84
355	0.89	0.92	0.90

Technical Efficiency Scores Table: A2 Continue….

Household	year1	year2	year3
356	0.87	0.81	0.89
357	0.88	0.85	0.82
358	0.87	0.88	0.87
359	0.89	0.90	0.83
360	0.89	0.87	0.83
361	0.84	0.26	0.61
362	0.89	0.87	0.74
363	0.88	0.85	0.85
364	0.78	0.77	0.74
365	0.85	0.79	0.74
366	0.89	0.85	0.90
367	0.90	0.89	0.90
368	0.90	0.87	0.91
369	0.86	0.85	0.81
370	0.90	0.87	0.34
371	0.89	0.90	0.90
372	0.86	0.85	0.87
373	0.86	0.85	0.91
374	0.89	0.81	0.89
375	0.86	0.84	0.89
376	0.89	0.91	0.88
377	0.89	0.89	0.89
378	0.88	0.87	0.85
379	0.87	0.93	0.91
380	0.88	0.90	0.95
381	0.95	0.93	0.95
382	0.93	0.88	0.92
383	0.94	0.86	0.88
384	0.94	0.87	0.88
385	0.94	0.84	0.86
386	0.94	0.83	0.88
387	0.94	0.85	0.88
388	0.95	0.89	0.92
389	0.94	0.84	0.88
390	0.94	0.87	0.89
391	0.94	0.87	0.89
392	0.93	0.83	0.85
393	0.95	0.89	0.91
394	0.95	0.87	0.91
395	0.95	0.87	0.91
396	0.94	0.88	0.92
397	0.95	0.91	0.91
398	0.84	0.85	0.88

Technical Efficiency Scores		Table: A2 Continue….	
Household	year1	year2	year3
399	0.91	0.90	0.92
400	0.92	0.91	0.93
401	0.88	0.89	0.89
402	0.91	0.91	0.90
403	0.90	0.89	0.91
404	0.85	0.88	0.87
405	0.81	0.71	0.72
406	0.90	0.89	0.89
407	0.84	0.86	0.90
408	0.87	0.86	0.89
409	0.88	0.90	0.96
410	0.96	0.96	0.94
411	0.94	0.93	0.89
412	0.80	0.76	0.83
413	0.92	0.93	0.89
414	0.90	0.86	0.86
415	0.90	0.91	0.84
416	0.89	0.96	0.85
417	0.86	0.90	0.77
418	0.91	0.92	0.89
419	0.78	0.86	0.80
420	0.91	0.91	0.84
421	0.89	0.91	0.81
422	0.84	0.88	0.83
423	0.88	0.89	0.83
424	0.88	0.91	0.82
425	0.90	0.91	0.76
426	0.87	0.89	0.85
427	0.83	0.83	0.86
428	0.88	0.89	0.83
429	0.89	0.43	0.76
430	0.87	0.91	0.81
431	0.85	0.91	0.80
432	0.93	0.92	0.85
433	0.88	0.89	0.87
434	0.89	0.94	0.82
435	0.88	0.91	0.78
436	0.87	0.89	0.78
437	0.88	0.91	0.80
438	0.87	0.88	0.75
439	0.89	0.91	0.70
440	0.90	0.91	0.81
441	0.89	0.89	0.80

Technical Efficiency Scores — Table: A2 Continue….

Household	year1	year2	year3
442	0.87	0.84	0.81
443	0.88	0.91	0.81
444	0.90	0.92	0.84
445	0.87	0.91	0.76
446	0.88	0.87	0.79
447	0.87	0.90	0.83
448	0.84	0.88	0.77
449	0.90	0.86	0.73
450	0.85	0.83	0.80
451	0.91	0.90	0.88
452	0.83	0.79	0.75
453	0.89	0.88	0.80
454	0.88	0.87	0.83
455	0.90	0.86	0.78
456	0.83	0.87	0.73
457	0.89	0.87	0.68
458	0.90	0.91	0.87
459	0.89	0.86	0.75
460	0.90	0.84	0.73
461	0.87	0.87	0.69
462	0.91	0.88	0.84
463	0.89	0.87	0.72
464	0.90	0.88	0.76
465	0.89	0.88	0.85
466	0.90	0.88	0.79
467	0.85	0.86	0.79
468	0.87	0.72	0.76
469	0.90	0.73	0.75
470	0.87	0.83	0.49
471	0.82	0.77	0.65
472	0.91	0.79	0.78
473	0.90	0.87	0.87
474	0.82	0.78	0.71
475	0.81	0.78	0.61
476	0.89	0.89	0.83
477	0.79	0.79	0.67
478	0.85	0.88	0.87
479	0.93	0.90	0.88
480	0.87	0.80	0.70
481	0.86	0.76	0.74
482	0.88	0.84	0.77
483	0.78	0.77	0.76
484	0.87	0.80	0.81

Technical Efficiency Scores			Table: A2 Continue….
Household	year1	year2	year3
485	0.88	0.82	0.71
486	0.78	0.78	0.78
487	0.86	0.77	0.64
488	0.89	0.85	0.86
489	0.86	0.78	0.79
490	0.88	0.82	0.83
491	0.91	0.87	0.78
492	0.88	0.83	0.79
493	0.87	0.79	0.83
494	0.84	0.54	0.68
495	0.92	0.75	0.88
496	0.89	0.77	0.85
497	0.82	0.83	0.67
498	0.88	0.84	0.80
499	0.84	0.83	0.70
500	0.88	0.88	0.84
501	0.89	0.82	0.75
502	0.91	0.88	0.86
503	0.84	0.71	0.70
504	0.87	0.81	0.82
505	0.90	0.85	0.87
506	0.89	0.87	0.80
507	0.90	0.94	0.86
508	0.91	0.85	0.83
509	0.84	0.83	0.75
510	0.92	0.87	0.84
511	0.89	0.84	0.87
512	0.87	0.88	0.77
513	0.90	0.88	0.87
514	0.90	0.83	0.81
515	0.91	0.91	0.82
516	0.89	0.87	0.83
517	0.88	0.84	0.88
518	0.90	0.84	0.85
519	0.90	0.86	0.90
520	0.91	0.86	0.89
521	0.90	0.91	0.90
522	0.88	0.86	0.78
523	0.91	0.89	0.85
524	0.91	0.89	0.89
525	0.91	0.86	0.88
526	0.89	0.85	0.84
527	0.87	0.90	0.84

Technical Efficiency Scores			Table: A2 Continue….
Household	year1	year2	year3
528	0.91	0.68	0.88
529	0.91	0.88	0.88
530	0.92	0.92	0.90
531	0.89	0.88	0.86
532	0.90	0.88	0.85
533	0.92	0.91	0.91
534	0.79	0.71	0.83
535	0.78	0.75	0.70
536	0.75	0.69	0.69
537	0.70	0.69	0.66

Table: A3 Profit Efficiency Scores

Household	year1	year2	year3
1	0.77	0.61	0.54
2	0.62	0.54	0.50
3	0.85	0.87	0.84
4	0.85	0.78	0.78
5	0.84	0.79	0.79
6	0.82	0.76	0.69
7	0.84	0.83	0.81
8	0.87	0.16	0.81
9	0.85	0.74	0.71
10	0.83	0.81	0.75
11	0.79	0.78	0.77
12	0.79	0.74	0.71
13	0.86	0.65	0.43
14	0.81	0.77	0.79
15	0.68	0.66	0.61
16	0.77	0.42	0.74
17	0.75	0.68	0.64
18	0.83	0.79	0.78
19	0.73	0.71	0.64
20	0.84	0.82	0.82
21	0.85	0.81	0.82
22	0.85	0.80	0.89
23	0.81	0.79	0.30
24	0.83	0.80	0.78
25	0.68	0.39	0.36
26	0.78	0.77	0.54
27	0.74	0.79	0.82
28	0.73	0.52	0.56
29	0.82	0.77	0.50
30	0.77	0.71	0.72

Profit Efficiency Scores Table: A3 Continue….

Household	year1	year2	year3
31	0.83	0.78	0.38
32	0.84	0.88	0.84
33	0.81	0.72	0.81
34	0.62	0.77	0.80
35	0.71	0.78	0.51
36	0.81	0.81	0.77
37	0.80	0.81	0.74
38	0.80	0.80	0.61
39	0.78	0.73	0.71
40	0.76	0.59	0.75
41	0.80	0.77	0.70
42	0.81	0.82	0.77
43	0.80	0.83	0.73
44	0.66	0.51	0.63
45	0.78	0.78	0.78
46	0.80	0.69	0.74
47	0.81	0.80	0.61
48	0.63	0.67	0.62
49	0.83	0.75	0.78
50	0.81	0.68	0.83
51	0.87	0.83	0.84
52	0.84	0.79	0.44
53	0.76	0.84	0.80
54	0.83	0.81	0.73
55	0.80	0.81	0.81
56	0.84	0.85	0.75
57	0.78	0.75	0.73
58	0.81	0.76	0.74
59	0.81	0.75	0.77
60	0.71	0.62	0.62
61	0.79	0.71	0.74
62	0.84	0.64	0.80
63	0.85	0.75	0.57
64	0.84	0.78	0.82
65	0.83	0.81	0.79
66	0.82	0.73	0.75
67	0.84	0.82	0.83
68	0.81	0.87	0.75
69	0.72	0.68	0.76
70	0.77	0.74	0.70
71	0.78	0.67	0.55
72	0.70	0.78	0.74
73	0.71	0.76	0.50

Profit Efficiency Scores			Table: A3 Continue….
Household	year1	year2	year3
74	0.82	0.87	0.87
75	0.84	0.80	0.72
76	0.70	0.77	0.69
77	0.73	0.52	0.76
78	0.78	0.61	0.77
79	0.78	0.83	0.75
80	0.72	0.56	0.65
81	0.86	0.80	0.73
82	0.84	0.75	0.81
83	0.76	0.40	0.76
84	0.82	0.56	0.74
85	0.84	0.63	0.60
86	0.73	0.62	0.60
87	0.79	0.74	0.76
88	0.77	0.72	0.79
89	0.78	0.72	0.73
90	0.80	0.70	0.81
91	0.52	0.52	0.56
92	0.80	0.23	0.78
93	0.80	0.78	0.76
94	0.75	0.66	0.84
95	0.65	0.73	0.78
96	0.82	0.84	0.79
97	0.68	0.51	0.78
98	0.80	0.69	0.84
99	0.74	0.63	0.50
100	0.76	0.68	0.74
101	0.76	0.42	0.62
102	0.78	0.69	0.66
103	0.88	0.77	0.54
104	0.80	0.69	0.77
105	0.79	0.89	0.89
106	0.78	0.77	0.85
107	0.76	0.73	0.35
108	0.87	0.75	0.60
109	0.79	0.77	0.85
110	0.80	0.78	0.79
111	0.74	0.71	0.80
112	0.73	0.63	0.28
113	0.75	0.70	0.42
114	0.80	0.72	0.79
115	0.87	0.81	0.86
116	0.84	0.86	0.81

Profit Efficiency Scores			Table: A3 Continue….
Household	year1	year2	year3
117	0.81	0.77	0.78
118	0.82	0.74	0.78
119	0.82	0.82	0.78
120	0.88	0.75	0.69
121	0.84	0.80	0.80
122	0.82	0.81	0.72
123	0.74	0.75	0.74
124	0.77	0.77	0.84
125	0.83	0.80	0.89
126	0.83	0.89	0.92
127	0.79	0.83	0.88
128	0.73	0.82	0.68
129	0.82	0.78	0.87
130	0.78	0.65	0.82
131	0.86	0.83	0.87
132	0.84	0.78	0.85
133	0.79	0.78	0.43
134	0.76	0.80	0.86
135	0.88	0.86	0.86
136	0.78	0.84	0.76
137	0.85	0.78	0.81
138	0.76	0.57	0.80
139	0.81	0.72	0.81
140	0.84	0.83	0.81
141	0.85	0.86	0.83
142	0.80	0.86	0.84
143	0.82	0.84	0.71
144	0.82	0.68	0.80
145	0.84	0.88	0.81
146	0.76	0.66	0.67
147	0.77	0.81	0.82
148	0.85	0.83	0.70
149	0.83	0.86	0.84
150	0.71	0.72	0.75
151	0.82	0.79	0.78
152	0.80	0.84	0.76
153	0.84	0.83	0.88
154	0.81	0.65	0.61
155	0.88	0.72	0.82
156	0.88	0.79	0.77
157	0.81	0.80	0.75
158	0.79	0.57	0.66
159	0.85	0.77	0.78

Profit Efficiency Scores			Table: A3 Continue….
Household	year1	year2	year3
160	0.85	0.83	0.83
161	0.83	0.80	0.76
162	0.86	0.76	0.74
163	0.87	0.77	0.76
164	0.85	0.84	0.81
165	0.83	0.82	0.81
166	0.82	0.85	0.75
167	0.84	0.81	0.82
168	0.85	0.76	0.83
169	0.84	0.73	0.80
170	0.84	0.73	0.80
171	0.82	0.69	0.76
172	0.86	0.78	0.82
173	0.79	0.51	0.79
174	0.78	0.50	0.83
175	0.80	0.48	0.88
176	0.69	0.60	0.77
177	0.79	0.31	0.73
178	0.70	0.26	0.76
179	0.71	0.42	0.79
180	0.66	0.77	0.76
181	0.66	0.20	0.69
182	0.80	0.42	0.85
183	0.76	0.38	0.75
184	0.65	0.58	0.67
185	0.76	0.08	0.71
186	0.76	0.09	0.82
187	0.71	0.44	0.78
188	0.74	0.38	0.69
189	0.83	0.03	0.83
190	0.84	0.71	0.82
191	0.77	0.32	0.50
192	0.75	0.46	0.53
193	0.81	0.69	0.67
194	0.85	0.78	0.72
195	0.84	0.78	0.79
196	0.82	0.77	0.76
197	0.83	0.10	0.81
198	0.81	0.51	0.70
199	0.82	0.34	0.74
200	0.80	0.67	0.80
201	0.80	0.06	0.85
202	0.78	0.12	0.86

Profit Efficiency Scores Table: A3 Continue….

Household	year1	year2	year3
203	0.80	0.04	0.78
204	0.80	0.03	0.68
205	0.82	0.29	0.86
206	0.86	0.80	0.80
207	0.48	0.31	0.21
208	0.86	0.79	0.79
209	0.73	0.27	0.55
210	0.81	0.76	0.83
211	0.66	0.59	0.78
212	0.40	0.63	0.86
213	0.72	0.63	0.45
214	0.72	0.55	0.61
215	0.85	0.26	0.45
216	0.86	0.67	0.28
217	0.78	0.58	0.55
218	0.84	0.82	0.84
219	0.84	0.86	0.78
220	0.85	0.77	0.75
221	0.83	0.78	0.77
222	0.81	0.72	0.79
223	0.84	0.82	0.77
224	0.85	0.56	0.82
225	0.84	0.45	0.78
226	0.86	0.82	0.81
227	0.82	0.42	0.76
228	0.70	0.72	0.67
229	0.71	0.85	0.82
230	0.75	0.83	0.72
231	0.43	0.82	0.57
232	0.71	0.78	0.79
233	0.80	0.71	0.88
234	0.82	0.79	0.82
235	0.81	0.70	0.82
236	0.76	0.71	0.66
237	0.79	0.83	0.85
238	0.62	0.54	0.84
239	0.81	0.58	0.58
240	0.60	0.23	0.26
241	0.78	0.66	0.80
242	0.84	0.77	0.79
243	0.78	0.67	0.77
244	0.76	0.75	0.68
245	0.76	0.72	0.77

Profit Efficiency Scores			Table: A3 Continue….
Household	year1	year2	year3
246	0.79	0.79	0.77
247	0.84	0.72	0.90
248	0.82	0.81	0.78
249	0.83	0.83	0.81
250	0.77	0.77	0.49
251	0.85	0.90	0.86
252	0.84	0.80	0.83
253	0.87	0.86	0.85
254	0.77	0.70	0.72
255	0.84	0.80	0.82
256	0.73	0.42	0.60
257	0.79	0.63	0.79
258	0.72	0.54	0.53
259	0.79	0.60	0.71
260	0.71	0.62	0.44
261	0.66	0.29	0.54
262	0.64	0.44	0.41
263	0.84	0.79	0.78
264	0.62	0.55	0.65
265	0.79	0.69	0.70
266	0.79	0.55	0.69
267	0.69	0.55	0.60
268	0.62	0.39	0.50
269	0.79	0.53	0.81
270	0.82	0.77	0.81
271	0.75	0.65	0.81
272	0.86	0.70	0.81
273	0.85	0.67	0.83
274	0.90	0.77	0.78
275	0.79	0.73	0.73
276	0.87	0.84	0.79
277	0.84	0.77	0.59
278	0.85	0.81	0.76
279	0.81	0.77	0.78
280	0.86	0.69	0.80
281	0.81	0.79	0.75
282	0.88	0.65	0.75
283	0.82	0.80	0.79
284	0.86	0.80	0.82
285	0.85	0.64	0.77
286	0.86	0.83	0.74
287	0.84	0.75	0.70
288	0.73	0.78	0.76

Profit Efficiency Scores			Table: A3 Continue….
Household	year1	year2	year3
289	0.87	0.07	0.93
290	0.86	0.82	0.55
291	0.86	0.78	0.31
292	0.79	0.71	0.73
293	0.87	0.79	0.86
294	0.86	0.79	0.74
295	0.85	0.78	0.82
296	0.82	0.77	0.89
297	0.74	0.65	0.84
298	0.79	0.67	0.73
299	0.83	0.79	0.85
300	0.77	0.64	0.87
301	0.81	0.77	0.82
302	0.83	0.31	0.80
303	0.80	0.58	0.91
304	0.82	0.46	0.89
305	0.83	0.83	0.82
306	0.79	0.50	0.72
307	0.38	0.01	0.35
308	0.78	0.21	0.80
309	0.11	0.53	0.05
310	0.42	0.58	0.12
311	0.81	0.34	0.57
312	0.77	0.13	0.86
313	0.73	0.69	0.82
314	0.83	0.51	0.83
315	0.67	0.47	0.81
316	0.75	0.52	0.58
317	0.82	0.73	0.88
318	0.69	0.56	0.64
319	0.23	0.39	0.75
320	0.46	0.36	0.32
321	0.73	0.69	0.89
322	0.86	0.72	0.90
323	0.51	0.81	0.44
324	0.73	0.65	0.68
325	0.85	0.80	0.81
326	0.78	0.66	0.88
327	0.81	0.72	0.82
328	0.69	0.47	0.76
329	0.79	0.61	0.83
330	0.79	0.66	0.82
331	0.77	0.67	0.83

Profit Efficiency Scores Table: A3 Continue….

Household	year1	year2	year3
332	0.80	0.67	0.86
333	0.84	0.73	0.78
334	0.83	0.72	0.85
335	0.86	0.79	0.71
336	0.84	0.73	0.72
337	0.71	0.58	0.74
338	0.84	0.41	0.83
339	0.81	0.69	0.88
340	0.85	0.78	0.88
341	0.79	0.63	0.85
342	0.81	0.73	0.69
343	0.81	0.67	0.84
344	0.66	0.54	0.89
345	0.81	0.18	0.81
346	0.77	0.63	0.72
347	0.77	0.62	0.78
348	0.56	0.36	0.90
349	0.81	0.68	0.86
350	0.81	0.64	0.91
351	0.81	0.64	0.86
352	0.74	0.67	0.81
353	0.78	0.62	0.89
354	0.78	0.30	0.30
355	0.76	0.10	0.87
356	0.79	0.61	0.87
357	0.61	0.35	0.33
358	0.72	0.68	0.80
359	0.80	0.53	0.86
360	0.77	0.58	0.85
361	0.50	0.66	0.67
362	0.74	0.41	0.86
363	0.60	0.39	0.72
364	0.75	0.41	0.66
365	0.73	0.43	0.80
366	0.76	0.80	0.86
367	0.72	0.22	0.85
368	0.77	0.22	0.86
369	0.76	0.16	0.86
370	0.77	0.37	0.89
371	0.79	0.17	0.85
372	0.76	0.27	0.89
373	0.57	0.40	0.87
374	0.81	0.19	0.88

Profit Efficiency Scores			Table: A3 Continue….
Household	year1	year2	year3
375	0.79	0.16	0.89
376	0.79	0.52	0.86
377	0.72	0.28	0.87
378	0.82	0.30	0.83
379	0.53	0.24	0.88
380	0.75	0.49	0.86
381	0.82	0.50	0.95
382	0.78	0.40	0.92
383	0.72	0.69	0.88
384	0.70	0.66	0.86
385	0.66	0.56	0.82
386	0.62	0.71	0.85
387	0.63	0.60	0.84
388	0.76	0.71	0.90
389	0.56	0.50	0.87
390	0.56	0.65	0.86
391	0.69	0.66	0.87
392	0.63	0.66	0.81
393	0.82	0.76	0.89
394	0.72	0.62	0.89
395	0.56	0.45	0.89
396	0.59	0.64	0.91
397	0.71	0.80	0.90
398	0.72	0.68	0.84
399	0.82	0.72	0.88
400	0.80	0.79	0.87
401	0.78	0.84	0.50
402	0.76	0.70	0.76
403	0.86	0.81	0.88
404	0.76	0.78	0.75
405	0.59	0.38	0.60
406	0.85	0.81	0.83
407	0.70	0.78	0.75
408	0.69	0.50	0.80
409	0.66	0.62	0.69
410	0.02	0.00	0.63
411	0.83	0.76	0.82
412	0.52	0.63	0.62
413	0.80	0.80	0.80
414	0.83	0.66	0.80
415	0.80	0.80	0.80
416	0.80	0.77	0.76
417	0.76	0.67	0.79

Profit Efficiency Scores			Table: A3 Continue….
Household	year1	year2	year3
418	0.81	0.64	0.78
419	0.04	0.34	0.67
420	0.29	0.55	0.53
421	0.82	0.77	0.79
422	0.70	0.55	0.77
423	0.68	0.64	0.67
424	0.70	0.46	0.76
425	0.86	0.82	0.74
426	0.82	0.69	0.83
427	0.81	0.64	0.81
428	0.66	0.55	0.54
429	0.79	0.85	0.78
430	0.78	0.43	0.82
431	0.75	0.86	0.78
432	0.82	0.84	0.86
433	0.84	0.80	0.84
434	0.82	0.81	0.80
435	0.78	0.77	0.76
436	0.80	0.68	0.76
437	0.68	0.65	0.74
438	0.75	0.72	0.74
439	0.83	0.73	0.74
440	0.83	0.80	0.78
441	0.80	0.78	0.76
442	0.79	0.78	0.81
443	0.81	0.69	0.77
444	0.86	0.78	0.89
445	0.75	0.72	0.80
446	0.78	0.69	0.79
447	0.75	0.90	0.82
448	0.62	0.45	0.77
449	0.65	0.50	0.77
450	0.64	0.84	0.84
451	0.85	0.80	0.85
452	0.79	0.74	0.81
453	0.69	0.52	0.55
454	0.81	0.64	0.76
455	0.84	0.78	0.81
456	0.79	0.65	0.62
457	0.79	0.90	0.80
458	0.63	0.52	0.67
459	0.80	0.74	0.76
460	0.84	0.72	0.83

Profit Efficiency Scores			Table: A3 Continue….
Household	year1	year2	year3
461	0.82	0.69	0.73
462	0.86	0.84	0.79
463	0.74	0.64	0.83
464	0.85	0.86	0.81
465	0.82	0.76	0.78
466	0.83	0.72	0.76
467	0.86	0.77	0.78
468	0.82	0.75	0.80
469	0.85	0.82	0.82
470	0.82	0.72	0.68
471	0.82	0.77	0.81
472	0.85	0.80	0.81
473	0.81	0.74	0.76
474	0.79	0.72	0.76
475	0.82	0.82	0.81
476	0.79	0.78	0.76
477	0.80	0.71	0.82
478	0.82	0.90	0.80
479	0.91	0.88	0.91
480	0.77	0.70	0.72
481	0.72	0.58	0.65
482	0.78	0.66	0.69
483	0.79	0.76	0.78
484	0.78	0.68	0.76
485	0.77	0.62	0.63
486	0.73	0.44	0.73
487	0.78	0.64	0.68
488	0.77	0.72	0.62
489	0.84	0.70	0.82
490	0.85	0.74	0.79
491	0.88	0.88	0.87
492	0.83	0.74	0.79
493	0.72	0.72	0.84
494	0.78	0.29	0.83
495	0.84	0.86	0.88
496	0.81	0.70	0.81
497	0.81	0.51	0.56
498	0.60	0.59	0.64
499	0.79	0.70	0.77
500	0.77	0.72	0.71
501	0.82	0.60	0.70
502	0.81	0.76	0.82
503	0.75	0.50	0.72

Profit Efficiency Scores			Table: A3 Continue….
Household	year1	year2	year3
504	0.83	0.71	0.73
505	0.87	0.82	0.80
506	0.84	0.10	0.83
507	0.84	0.68	0.74
508	0.85	0.72	0.77
509	0.61	0.63	0.70
510	0.81	0.59	0.76
511	0.84	0.77	0.82
512	0.83	0.79	0.67
513	0.83	0.74	0.79
514	0.86	0.77	0.78
515	0.84	0.79	0.85
516	0.84	0.75	0.81
517	0.85	0.61	0.83
518	0.84	0.61	0.85
519	0.87	0.77	0.78
520	0.89	0.67	0.84
521	0.84	0.80	0.80
522	0.80	0.55	0.72
523	0.82	0.77	0.83
524	0.83	0.77	0.82
525	0.85	0.73	0.85
526	0.88	0.77	0.80
527	0.80	0.78	0.76
528	0.83	0.76	0.83
529	0.66	0.65	0.79
530	0.75	0.66	0.41
531	0.78	0.05	0.74
532	0.80	0.70	0.84
533	0.64	0.68	0.72
534	0.80	0.82	0.64
535	0.82	0.81	0.78
536	0.78	0.80	0.76
537	0.78	0.78	0.79