Chapter 3: Review of Relevant Literature

3.1 Introduction

It has long been recognized that climate change has an impact on agriculture. Researchers from different disciplines have been investigating the potential harmful effects of climate change on agriculture using different models. Those models were in general used to predict changes in climate associated with different economic activities, assess and quantify the level of damage caused so that corrective measures can be taken through policy intervention for mitigation. This chapter reviews approaches and models developed to predict the level of climate change, assess and quantify the sensitivity of different economic sectors in general and agriculture in particular to climate change. The detailed theoretical background, strengths and weaknesses of each model are presented. The chapter also provides detailed review of literature on climate change impact studies on different sectors of South African economy with special emphasis on agriculture. Review of the state of current literature on climate impact in South Africa will help identifying existing knowledge gaps and the needs for further research.

3.2 Climate Prediction Models

Human activities such as the burning of fossil fuels and deforestation increase the concentration of carbon dioxide (CO_2) and other trace gasses in the atmosphere, which in turn alters the energy balance of the earth (Rosenzweig, 1989). These gasses affect the energy balance of the earth through absorbing long wave radiations emitted by the earth to balance the incoming short wave solar radiation. Over the long run, if the absorbed solar radiation is not balanced by out-going thermal radiation, global warming will occur. The warming caused by trapping of the long wave radiation is known as 'green house effect' and the trace gasses responsible are known as ' green house gasses' (Rosenzweig, 1989).

The behavior of a climate system, its components and their interactions are studied and simulated using climate prediction models. These models are designed mainly for studying climate processes and natural climate variability, and for projecting the response of climate to human induced forces. The most complex climate prediction models developed and used are called the global climate models or general circulation models (GCMs). They are mathematical representations of the atmosphere, ocean, and land surface processes involving mass, momentum, energy and water and their interactions. These models are based on physical laws describing the dynamics of atmosphere and ocean expressed in mathematical equations. The equations in the models incorporate numerical representations of the physical processes of radiation, turbulent transfers at the ground atmosphere boundary, cloud formations, condensation of rain and transport of heat by ocean currents (Barron, 1995).

Through mathematical simulations GCMs enable prediction of what should happen to climate around the world in response to wide variety of changes in the concentrations of green house gasses in the atmosphere (Barron, 1995; IPCC, 2001). Two different strategies are applied to make projections of future climate changes using GCMs. These are the equilibrium and the transient methods (IPCC, 2001).

Equilibrium models (as the case in comparative statics) are not dynamic, e.g. do not trace changes over time but compare two points of equilibrium. In these models, first, the base-line climate is simulated under present conditions (emission levels) to determine the current equilibrium. Then, climate is simulated under a new scenario, such as the doubling of CO_2, which leads to a new equilibrium. The differences between the climate levels of the two simulations provide an estimate of the climate change corresponding to the doubling of CO_2. While this method is relatively cheap and easy to apply, it does not provide insight into the time dependence of climate change (IPCC, 2001).

Transient models trace changes over time at various points of disequilibria or paths to new equilibrium. These models project climate change based on different emission levels, which are developed based on assumptions concerning future socio-economic and demographic changes such as the growth of world population, energy intensity and efficiency, and economic growth, which lead to different emissions scenarios. The difference between the simulated climate change under different emission scenarios and the original base-line simulation provides a time dependent projection of climate change. Thus, these methods are more realistic ways of projecting future climate than forcing the GCMs with an abruptly doubled concentration of atmospheric carbon dioxide as in the case of the equilibrium method (Rosenzweig *et al.*, 1998).

Though very crucial in climate research, the GCMs have limitations. Important limitations include poorly understood ocean circulation processes, lack of knowledge on cloud formation and feedbacks, crudely formulated hydrological processes, coarse spatial resolution, and inability to simulate current regional climate accurately (Rosezwieg, 1989; Dinnar and Beach, 1998). In addition, Barron (1995) indicated that predictions of future climate using climate models are imperfect as they are limited by significant uncertainties that stem from: 1) the natural variability of climate; 2) our inability to predict accurately future green house gases and aerosol emissions; 3) the potential for unpredicted or unrecognized factors, such as volcanic eruptions or new unknown human influences, to perturb atmospheric conditions and 4) our as-yet incomplete understanding of the total climate system.

3.3 Economic Impact Assessment Models

There are two main types of economic impact assessment models in the literature: economy-wide (general equilibrium) and partial equilibrium models. Economy-wide models are analytical models, which look at the economy as a complete system of interdependent components (industries, factors of production, institutions, and the rest of the world). Partial equilibrium models on the other hand, are based on the analysis of part of the overall economy such as a single market (single commodity) or subsets of markets or sectors (Sadoulet and De Janvry, 1995).

3.3.1 Economy-Wide Models of Climate Change

Computable general equilibrium (CGE) models are one of the economy-wide policy impact assessment models. Currently economic analysis of environmental issues and policies is a principal area of CGE model applications (Oladosu *et al.*, 1999). This class of economic modes is suitable for environmental issues because it is capable of capturing complex economy-wide effects of exogenous changes while at the same time providing insights into micro level impacts on producers, consumers and institutions (Mabugu, 2002; Oladosu *et al.*, 1999).

As climate change directly or indirectly affects different sectors of the economy, the use of economy-wide models, which incorporate the complex interactions among different sectors, is required. Accordingly, the use of these models is growing in the areas of climate change impact assessment studies. For instance, Winters *et al.* (1996) studied the impact of global climate change on the less developed countries using a CGE model for three economies representing the poor cereal importing countries of Africa, Asia and Latin America. The said study showed that all these countries would lose and that their agricultural outputs would fall as a result of climate change and Africa to be the most severely affected. Yates and Strezepek (1996) also applied a dynamic CGE model to assess the impact of climate change on the Egyptian economy, which concluded that the net effects of climate change on per capita GDP was not significant.

Nodrhaus *et al.* (1996) used a dynamic general equilibrium model to analyze different national strategies in climate change policies such as, pure market solutions, efficient cooperative outcomes, and non- cooperative equilibra. This study revealed that there are substantial differences in the levels of controls in both the cooperative and the non-cooperative policies among different countries and that the high-income countries may be the major losers from cooperation. In addition to these, Deke *et al.* (2001) used the CGE model approach in a regionally and sectorally disaggregated framework to analyze adaptation to climate change in different regions of the world. The study result showed that vulnerability to climate impact differs significantly across regions and that the overall adjustment of the economic system quite reduces the direct economic impacts.

Although CGE models can analyze the economy-wide impacts of climate change, there are some drawbacks in using them. Key limitations include difficulties with model selection, parameter specification, and functional forms, data consistency or calibration problems, the absence of statistical test for the model specification and the complexity and requirement of high skill to develop and use CGE models (Gillig and Mc Carl, 2002).

3.3.2 Partial Equilibrium Models of Climate Change Impacts

One can classify the partial equilibrium models available in the literature into two approaches to the analysis of the sensitivity of agriculture to climate change. The first approach is based on crop growth simulation models and the second uses econometric procedures. The approaches are compared and discussed in further detail in the following sub-sections.

3.3.2.1 Crop Growth Simulation Models

The two approaches commonly used for analyzing the impact of climate change on agriculture under this group of models are discussed here under.

3.3.2.1.1 Crop Suitability Approach

This approach is also referred to as the agro-ecological zoning (AEZ) approach, which is used to assess the suitability of various land and biophysical attributes for crop production. In this approach, crop characteristics, existing technology, and soil and climate factors, as determinants of suitability for crop production, are included (FAO, 1996). By combing these variables, the model enabled the identification of and distribution of potential crop producing lands. As the model includes climate as one determinant of agricultural land suitability for crop production, it can be used to predict the impact of changing climatic variables on potential agricultural outputs and cropping patterns (Schulze *et al.*, 1993; Du Toit, 2001; FAO, 2002; Xio *et al.*, 2002).

The AEZ framework contains three basic elements (FAO, 2002). The first is land utilization types (LUTs), which refer to selected agricultural production systems with defined input and management relationships, and crop specific environmental requirements and adaptability characteristics. The second is agro-referenced climate, soil, and terrain data, which are combined into a land resource database. The third element is the procedure for calculating potential yields by matching crop/LUT environmental requirements with the environmental characteristics captured in the database. These models were developed to look at potential production capacity across various ecological zones by using a simulation of crop yields rather than measured crop yields (Mendelson, 2000).

Xia *et al.* (2002) used the AEZ approach to estimate the area and spatial distribution of global potential croplands under contemporary and different climate change predictions. The Xia *et al.* (2002) study indicated that the area of global potential croplands is about $32.91*10^6$ km^2 under contemporary climate, with a tendency to increase substantially over the period of 1977 - 2100 as a result of global warming. In the said analysis, developed countries accounted for most of the increase in global potential croplands, while developing countries showed little change in area of cropland. A similar, FAO study (FAO, 2002) showed that a temperature increase of 3°C, paired with a 10 % increase in rainfall, would lead to about 4% more cultivable rain-fed land. The cultivable land in developed countries would grow by 25 % whereas it drops by 11% in developing countries, clearly indicating the uneven distribution of climate benefits.

Adoption and adaptation to changing climatic conditions can be addressed within this model by generating comparative static scenarios with changes in technological parameters (Mendelson, 2000). The disadvantage of the AEZ methodology is that it is not possible to predict final outcomes without explicitly modeling all relevant components and thus the omission of one major factor would substantially affect the prediction of the model (Mendelson, 2000).

3.3.2.1.2 The Production Function Approach

The production function approach to analyzing impacts of climate change on agriculture is based on an empirical or experimental production function measuring the relationship between agricultural production and climate change (Mendelson, 1994). In this approach, a production function, which includes environmental variables such as temperature, rainfall and carbon dioxide as inputs into production, is estimated. Based on the estimated production function, changes in yield induced by changes in environmental variables are measured and analyzed at testing sites (Adams, 1989; Kaiser *et al.*, 1993; Lal *et al.*, 1999; Olsen, 2000; Southworth *et al.*, 2000; Alexandra, 2000). The estimated changes in yield caused by changes in environmental variables are aggregated to reflect the overall national impact (Olson, 2000) or incorporated into an economic model to simulate the welfare impacts of yield changes under various climate change scenarios (Adams, 1989; Kumar and Parikh, 1996; Chang, 2002).

Production as a function of yield and area can be presented by,

$$Q_i = y_i * A_i \tag{3.1}$$

$$y_i = F_i(K_i, E) \tag{3.2}$$

$$A_i = f_i(E, Z, y_i) \tag{3.3}$$

Where Q_i is production, y_i is yield and A_i is area,

$\mathbf{K}_i = [\, K_{i1}, \ldots K_{ij}, \ldots K_{iJ} \,]$

Where K_{ij} is the purchased input j (j = 1,… J) in the production of product i, and:

$\mathbf{E} = [E_1, \ldots E_m \ldots E_M]$ is a vector of exogenous environmental inputs such as temperature, precipitation, and soils, which are common to the production site. Z is access to market (distance to market, infrastructure like roads and the availability of transportation).

A is commonly expressed in terms of share of land area H_i and hence a land share equation rather than area in hectares is generally employed:

$$H_i = h_i(\mathbf{E}, \mathbf{Z}, y_i) \tag{3.4}$$

Where H_i measures the share of crop i in total land area.

The production function approach assumes that firms seek to maximize total profit from a mix of crops on a piece of land:

$$\max N = \sum_{i=1}^{n} H_i . \left[P_i Q_i - \sum_{j=1}^{m} w_j . k_{ij} \right] \tag{3.5}$$

Subject to the physical conditions facing the farm (soil, climate and water).

Where N is net income per unit of land, i.e. per hectare

P_i is market price of crop i,

k_{ij} is amount of input j used to produce units of crop i, and

w_j is unit cost of input j.

One advantage of this model is that it has more dependable prediction of how climate affects yield because the impact of climate change on crop yields is determined through controlled experiments. However, one problem with this model is that its estimates do not control for adaptation (Mendelson *et al.*, 1994). Farmers are likely to respond to changing climate and other environmental factors by varying among other things, the crop mix, planting and harvesting dates, irrigation scheduling and application of fertilizers and pesticides to mitigate the potential harmful effects of climate change. Moreover, this model does not consider the introduction of new crops, technological changes and changes in land use, and thus the main bias or weakness of the model is in its failure to allow for economic substitution as conditions change (Mendelson *et al.*, 1994).

In order to properly apply the production function approach, farmers' adaptations should be included in the model (Dinar *et al.*, 1998). Moreover, simulations should be run with a variety of different farm methods such as varying planting dates, crop variety, date of harvesting and tilling and irrigation methods. This allows identifying activities, which maximize profit under changing climatic conditions. A successful introduction of adaptation to the production function approach is found in Kaiser *et al.* (1993), who altered crop mix, crop varieties, sowing times, harvesting dates and water saving technologies (tillage) for farms in the United States and found that these adaptation activities reduce the damages from climate change. Although this model included adaptation, it was restricted to limited test sites and general conclusions about climate change and agriculture at the national level could not be made.

In addition to the failure to consider farmers' adaptations, each crop considered under this model, in general required extensive experimentation (high cost). Due to this fact, the use of this methodology has been restricted to the most important crops and few test locations and hence limited value for generalization of the results.

3.3.2.2 Econometric Approaches: The Ricardian Model

The Ricardian model analyses a cross-section of farms under different climatic conditions and examines the relationship between the value of land or net revenue and agro climatic factors (Mendelson *et al.*, 1994; Sanghi *et al.*, 1998; Kumar and Parikh, 1998; Polsky *et al.*, 2001). The model has been applied to value the contribution that environmental factors make to farm income by regressing land values on a set of environmental inputs thereby measuring the marginal contribution that each input makes to farm income. Net revenue or price of land can be used to represent farm income. Mendelson *et al.* (1994) used both net revenue and land value where as Polsky *et al.* (2001) used only land value as the dependent variable in the studies of the impact of climate change on the United States agriculture. Additionally, Sanghi *et al.* (1998) used land value for Brazil, while Kumar and Parikh (1998) used net revenue as the dependent variable in analyzing the impact of climate change on Indian agriculture.

The most important advantage of the Ricardian model is its ability to incorporate private adaptations (Mendelson, 2000). Farmers adapt to climate change to maximize profit by changing the crop mix, planting and harvesting dates, and a host of agronomic practices. The response of farmers induces costs causing economic damages that are reflected in net revenue. Thus to fully account for the cost or benefit of adaptation the relevant dependent variable should be net revenue or land value (capitalized net revenues) not yield. Accordingly, the Ricardian approach takes into account adaptation by measuring economic damages as reductions in net revenue or land value induced by climatic factors. The other advantage of the model is that it is cost effective since secondary data on cross-sectional sites can be relatively easy to collect on climatic, production and socio-economic factors.

One of the weaknesses of the Ricardian approach is that it is not based on controlled the experiments across farms. Farmers' responses vary across space not only due to climatic factors, but also due to many socio-economic conditions. Such non-climatic factors are seldom fully included in the model. Attempts were made to include soil quality, market access and solar radiation to control for such effects (Mendelson *et al.*, 1994; Kumar and Parikh, 1998). In general however, it is often not possible to get perfect measures of such variables and thus all of them may not be taken into account in the analysis using this method (Mendelson, 2000).

The other weakness of the Ricardian model is that it does not include price effects (Cline, 1996). If relative prices change due to the impact of climate change on aggregate supply, the method underestimates or overestimates the impact depending on whether the supply of a commodity increases or decreases. Overlooking of price changes in response to changing aggregate supply leads to a bias in the calculations of producer and consumer surplus and hence lead to biased welfare calculations (Cline, 1996).

Mendelson (2000) argues that it is difficult to include price effects carefully using any method for a number of reasons. First, for most crops prices are determined in global markets and the prediction of what would happen to each crop needs global crop models. But global crop models are poorly calibrated so that it is difficult to predict what will happen to the global supply of any single crop in a new world climate. Second the few global analyses completed so far (Reilly *et al.*, 1994) predicted that the range of warming expected for the next century have a small effect on aggregate supply. Third, if aggregate supply changes by only a moderate amount, the bias from assuming constant prices is relatively small. Thus based on the above points Mendelson (2000) justifies that keeping prices constant does not pose a serious problem in using the model.

The fact that the model does not take into account the fertilization effect of carbon dioxide concentrations (higher CO_2 concentration can enhance crop yield by increasing photosynthesis and allowing more efficient use of water) is another weakness of the model (Cline, 1996; Mendelson, 2000). In spite of these weaknesses, the model can be used to analyze the impact of climate change on agriculture by fully considering adaptations farmers make to mitigate the harmful impact of changing climate.

Climate models such as the GCMs enable the prediction of climatic levels based on the levels of different economic activities (like CO_2 emission). Impact assessment models rely on predictions from GCMs and analyse the impacts of the predicted climate levels on the economic system.

3.4 Climate Impact Studies in South Africa

3.4.1 Studies of Impact on Agriculture

Some studies have been conducted to assess the impact of climate change on South African Agriculture. For instance, Schulze *et al.* (1993) assessed the potential production of maize under different climatic conditions and concluded that under elevated carbon dioxide and temperature conditions, there is an overall increase in potential maize production even though there are places in which yield of maize decreases. In contrast, result the study by Du Toit *et al.* (2001) was pessimistic in explaining the vulnerability of maize production to climate change in South Africa. The Du Toit *et al.* (2001) study indicated that South African maize production is characterized by high variation in yield due mainly to fluctuations in seasonal precipitation. The results of crop model simulation showed that maize yields would either remain at current levels or decrease by ten to twenty percent according to the climate scenarios used. Some of the marginal western areas may become unsuitable for maize production under current management strategies while some of the eastern production areas may remain unchanged or increase production levels. It was additionally indicated that specially crops grown in specific environmentally favorable areas may also be at risk as both rainfall and temperature effects may cause changes in areas suitable for specialized production.

Erasmus *et al.* (2000) studied the effects of climate change on the Western Cape farm sector using a GCM. A sectoral mathematical programming model was employed to incorporate predicted climate change specifically rainfall from GCM for determining the effects on key variables of the regional farm economy. The results indicated that there would be a negative overall effect on the western cape farm economy and it was further shown that producers would switch to extensive farming. The said study also showed that the total decline in welfare falls disproportionately on the poor.

Poonyth *et al.* (2002) studied the impact of climate change on South African agriculture by using the Ricardian method and found that an increase of 2^0C in average temperature decreases net revenue per hectare by 25 %. Although Poonyth *et al.* (2002) applied a methodology that allows for integrating farmers' adaptations, the data used in the study were aggregated to provincial levels and cost of production data by each of the crops considered for the study were not available. Thus, the study failed to fully capture the costly adaptations that farmers situated at different agro-ecological places in South Africa and producing different crops make to mitigate the potential harmful impact of climate change.

Kiker (2002) and Kiker *et al.* (2002) developed sugarcane growth models to simulate growth factors and sucrose yields and indicated that climatic factors (rainfall and temperature) affect different sites differently across the sugarcane producing regions. In addition to the failure to present the level of damage induced by climate change across production regions, the methodology adopted for the cited studies (the production function approach) did not include farmers' adaptations.

3.4.2 Other Climate Change Impact Studies

Efforts are also increasing in studying the impact of climate change on non-agricultural sectors in South Africa. For example, van Jaarsveld and Chown (2001) summarized the studies conducted on climate change and its impacts on South Africa. According to van Jaarsveld and Chown (2001), the arid interior and moister northeastern regions of South Africa are likely to be subject to elevated evapo-transpiration rates, increased stress, and more frequent flood events compared to the southwestern regions, which are most likely to experience increased early winter frontal and orographic rainfall. Additionally, it was indicated that the grassland component of rangelands would be least affected by this change compared to the savannah component of rangelands, which appear to be more sensitive. Moreover, livestock production was reported to remain relatively unaffected with marginal impacts on cattle production.

Fecher and Moodly (2002) reported an initial economic valuation of the increased incidence of malaria due to projected changes in the climate of South Africa. Fecher and Moody (2002) showed that, by 2010 the costs of increased malaria due to climate change could reach at least R1.2 billion or almost 0.2 % of the total GDP. Although a good indication of the economic impact of climate change is provided, costs and benefits of prevention and adaptation have not been included in the said study.

Turpie (2002) estimated the existence value of biodiversity threatened by climate change by using a contingent valuation method (CVM) in which 814 residents of the Western Cape province were interviewed. The study indicated that most of the respondents were willing to pay towards biodiversity conservation in South Africa, favouring the policy to reduce the impacts of climate change by passing external costs on to consumers of products such as fuel. This study estimated the potential loss of existence value to South Africa to be R 2.63 billion per year. Moreover, in another study based on the analysis of estuarine fishery production data, Turpie *et al.* (2002) showed that 35 % of natural estuarine catch might be reduced by 2050, under increasing warming conditions.

3.5 Summary

In general, two approaches are found in the literature on measuring the sensitivity of agriculture to climate change. These are the general equilibrium and partial equilibrium models. The general equilibrium models look at all sectors of the economy and analyse the impact of a shock from a policy change of one sector on the rest of the economy. While, very useful for policy simulation these models were not adopted for this study due to high data requirements and methodological complexity.

The partial equilibrium models look at single or multiple market or commodity in part of the economy. These models are divided in two main sub-divisions to the analysis of climate change on agriculture: the crop growth simulation and the econometric approaches. The crop growth simulation models have two sub-divisions, which are the crop suitability and the production function approaches. The crop suitability/agro-ecological zoning approach relies on crop models and land resource inventory to determine potential yields. The disadvantage of this model is that it is not possible to predict final outcomes without explicitly modelling all relevant components. Using this model can capture adaptation to climate change but it requires a high level of effort in data collection and it is therefore costly. The production function approach is based on experimental or empirical analysis of the relationships between yield and environmental factors. It has the advantage of reliable results in terms of the relationship between yield and climatic variables, but it does not take adaptation into account, and it is also costly.

The econometric / Ricardian approach regresses net revenue over a set of climatic and social variables, and enables capturing adaptations farmers make in response to climate change. One of the weaknesses of the Ricardian studies is the assumption of constant prices, but it is practically difficult to include price effects carefully by using any of the other methods (Mendelson, 2000). The Ricardian method is successfully adopted and used to analyse the climate sensitivity of agriculture in different countries (Brazil, India, and USA). It can be used with lesser cost than the other methods and equally important information can be gained for policy purpose in countries where time series data on climate, price of land and production data are found. The sugar cane producing regions of South Africa are one of the places where these kinds of data can be obtained from the well-organised database of the South African Sugarcane Producers Association (SASPA).

The above reviewed literature indicates that studies on the impacts of climate change in South Africa are growing. In spite of these increasing scientific investigations, so far there has been no attempt to analyse the economic impact of climate change on different crops in different regions in the country. Impacts of climate change on different crops and different production systems are different. Also socio-economic groups and geographical regions involved are different, and hence climate change is expected to have different implications for different crops, regions and social groups involved. Moreover, none of the cited studies controlled for adaptation by farmers. Thus, this study uses the Ricardian approach which accounts for farmers' adaptations in analysing the impact of climate change on agriculture as applied to climate change impact studies in the United States, Brazilian and Indian agriculture.