Chapter 4: Approach and Methods of the Study

As explained earlier, this study will use the Ricardian model as it allows for the incorporation of farmers' adaptation in measuring the impact of climate change on agriculture. The study applied the Ricardian model to the analysis of the impact of climate change on sugarcane production in various regions of South Africa. The rest of this chapter discusses the Ricardian approach, sampling procedures, data and the empirical model adopted.

4.1 The Ricardian Approach

Ricardian method, adopted by this study is an empirical approach developed by Mendelson *et al.* (1994) to measure the value of climate in the United States agriculture. The technique has been named the Ricardian method because it is based on the observation made by Ricardo (1817), that land values would reflect land productivity at a site under perfect competition. It is possible to account for the direct impact of climate on yields of different crops as well as the indirect substitution among different inputs including the introduction of different activities by directly measuring farm prices or revenues by using the Ricardian model.

The value of land reflects the sum of discounted future profits, which may be derived from its use. Any factor, which influences the productivity of land, will be reflected in land values or net revenue. Therefore the value of land or net revenue contains information on the value of climate as one attribute of land productivity. By regressing land values on a set of environmental inputs, the Ricardian approach enables measuring the marginal contribution of each input to farm income as capitalized in land value.

4.2 The Analytical Model

The model used in this study is based on a set of well- behaved production function of the form:

$$Q_i = Q_i(K_i, E) \tag{4.1}$$

Where, Q_i is quantity produced of good i, $K_i = (K_{i1}, K_{i2} \dots K_{iJ})$ is a vector of purchased inputs such that K_{ij} is the input j $(j = 1 \dots J)$ used in the production of good i, and;
$E = (E_1, E_2 \dots E_k)$ is a vector of exogenous environmental inputs such as temperature, precipitation, and soil, which are common to production sites.

Given a set of factor prices w_j, E and Q, cost minimization gives the cost function:

$$C_i = C_i(Q_i, W, E) \tag{4.2}$$

Where C_i is the cost of production of good i and $W(w_1, w_2 \dots w_n)$ is the vector of factor prices. Using the cost function C_i at given market prices, profit maximization by farmers on a given site can be specified as:

$$Max.\ \pi = [P_i Q_i - C_i(Q_i, W, E) - P_L L_i] \tag{4.3}$$

Where P_L is annual cost or rent of land at that site.

Perfect competition in the land market will derive profit to zero:

$$P_i Q_i^* - C_i^*(Q_i^*, W, E) - P_L L_i^* = 0 \tag{4.4}$$

If the production of good i is the best use of the land given E, the observed market rent on the land will be equal to the annual net profits from the production of the good. Solving for P_L from the above equation gives land rent per hectare to be equal to net revenue per hectare.

$$P_L = (P_i Q_i^* - C_i(Q_i^*, W, E)) / L_i \tag{4.5}$$

The present value of the stream of current and future revenues gives the land value V_L:

$$V_L = \int_0^\infty P_L e^{-rt} dt = \int_0^\infty \left[(P_i Q^*_i - C_i(Q_i^*, W, E) / L_i \right] e^{-rt} dt \tag{4.6}$$

The issue to be analyzed is the impact of exogenous changes in environmental variables on net economic welfare (ΔW). Consider an environmental change from the environmental state *A* to *B*, which causes environmental inputs to change from E_A to E_B. The change in annual welfare from this environmental change is given by:

$$\Delta W = W(E_B) - W(E_A) = \int_0^{Q_B} [(P_i Q_i - C_i(Q_i, W, E_B) / L_i] e^{-rt} dQ - \int_0^{Q_A} [(P_i Q_i - C_i(Q_i, W, E_A) / L_i] e^{-rt} dQ$$

If market prices do not change as a result of the change in E, then the above equation reduces to:

$$\Delta W = W(E_B) - W(E_A) = \left[PQ_B - \sum_{i=1}^{n} C_i(Q_i, W, E_B) \right] - \left[PQ_A - \sum_{i=1}^{n} C_i(Q_i, W, E_A) \right] \tag{4.7}$$

Substituting for $P_L L_i = P_i Q_i^* - C_i (Q_i^*, W, E)$ from (4.5)

$$\Delta W = W(E_B) - W(E_A) = \sum_{i=1}^{n} (P_{LB} L_{Bi} - p_{LA} L_{Ai}) \tag{4.8}$$

Where P_{LA} and L_A are at E_A and P_{LB} and L_B are at E_B

The present value of the welfare change is thus:

$$\int_0^\infty \Delta W e^{-rt} dt = \sum_{i=1}^{n} (V_{LB} L_{Bi} - V_{LA} L_{Ai}) \tag{4.9}$$

The Ricardian model takes either (4.8) or (4.9) depending on whether the dependent variable is annual net revenues or capitalized net revenues (land values V_L). The model in (4.8) was employed for this research, as data on land prices for the selected samples were not available. This is the same approach followed by Sanghi *et al.* (1998) and Kumar and Parikh (1998) for India.

4.3 Specification of the Empirical Model Variables and Data

As seen in chapter two, the South African sugarcane producing regions extend from the Eastern Cape province through Mpumalanga province in the north. Over these areas, sugarcane is produced under two main climatic conditions: the stepped (arid) zones in the irrigated northern parts and the sub-tropical wet climate in the dryland farming areas of Kwazulunatal.

A total of 11 districts were selected for this study. Two districts (Malelane and Pongola) were selected from the northern irrigated region; nine districts (Umfolozi, Entumeni, Amatikulu, Noodsbureg, Union Coop, Sezela, Darnall, Gledhow, and Maidstone) from the sub-tropical wet climate in KwazuluNatal (the dryland farming region).

Data on farm-level net-revenue were obtained from the South African Sugar Producers Association. Those included, price per tone, production per hectare, cost of labor, chemicals, fertilizer, fuels and lubricants, mechanical and fixture maintenance, and irrigation per tone of sugarcane produced. The net revenue per hectare was deflated using the agricultural GDP deflator and is in 1995 prices.

Data on climatic (rainfall & temperature) and geographic (altitude and latitude) variables were collected from experiment stations, which compile data for each of the cane producing districts. The soil data were collected from the Institute for Soil, Climate and Water of the CSIR.

The climatic variables included were the monthly average temperature and rainfall for each district over the periods 1976/77 to 1997/98. As the net revenue per hectare is expected to be influenced by factors other than climatic variables, control variables like soil type and altitude were also included. The soil type, which varies across the sample districts, was included as it affects yield. Altitude was included to proxy solar energy. In addition, the irrigation dummies for irrigated and dryland farming were included to compare the impact of climatic variables on irrigated and dryland farming. Finally, time trends were included for both irrigated and dryland farming to observe the net revenue per hectare over time for both regions. Table 4.1 gives a description of the variables included in the empirical model.

Table 4. 1: Description of model variables

Variable name	Definition and data (measurement)
Net revenue (NR_i)	Net revenue for district *i* measured in R/ha
Winter temperature (WT_i)	Average of the winter growing temperature (May to August) for district *i* measured in degree centigrade
Winter temperature square ($WTSQ_i$)	
Summer temperature (ST_i)	Average of the summer growing temperature (September to January) for district *i* measured in degree centigrade
Summer temperature square ($STSQ_i$)	
Harvesting temperature (HT_i)	Average of the harvesting season temperature (May to September of the second cropping year) for district i measured in degree centigrade
Harvesting temperature square ($HTSQ_i$)	
Winter precipitation (WP_i)	Average of the winter growing precipitation (May to August) for district *i* measured in millimeters
Winter precipitation Square ($WPSQ_i$)	
Summer precipitation (SP_i)	Average of the summer growing precipitation (September to January) for district *i* measured in millimeters
Summer precipitation square ($SPSQ_i$)	
Harvesting precipitation (HP_i)	Average of the harvesting season precipitation (May to September of the second cropping year) for district i measured in millimeters.
Harvesting precipitation squared ($HPSQ_i$)	
Winter temperature * winter precipitation (WTP_i)	
Summer temperature * summer precipitation ($STSP_i$)	
Harvesting temperature * harvesting precipitation ($HTHP_i$)	
Soil dummy 1 (SD_1)	The type of soil in the sample district. This variable takes the value of one if the soil is red, excessively drained sandy soil and zero other wise.
Altitude (ALT_i)	The distance above sea level measured in meters.
Irrigation dummy (ID_1)	The irrigation dummy, takes the value of one if irrigated and zero if dryland.
Dryland dummy (ID_2)	The dryland dummy, takes the value of one if dryland and zero if irrigated
Trend (ID_1T)	Time trend for irrigated farming.
Trend (ID_2T)	Time trend for dryland farming