Chapter 3

Review of literature on measuring the economic impacts of climate change on agriculture

3.0 Introduction

This chapter discusses the various approaches and methods that have been used to measure economic impacts of climate change on agriculture. Particular empirical studies that have measured economic impacts of climate change on agriculture are reviewed. The chapter concludes with a discussion of the approach chosen to implement the empirical economic analyses of this study and to yield its expected contributions.

3.1 Approaches to measuring economic impacts of climate change

Impacts of climate change on agriculture have been estimated using two main approaches: (a) *structural modelling* of crop and farmer response – this approach combines crop agronomic response with economic/farmer management decisions and practices; and (b) *spatial analogue models* that measure observed spatial differences in agricultural production (Adams, Hurd, Lenhart & Leary, 1998a; Schimmelpfenning, Lewandrowski, Reilly, Tsigas & Parry, 1996). Other impact assessment methods that have been used are the integrated impact assessment method and the agro-ecological zone (AEZ) method (Mendelsohn, 2000). All these approaches are discussed in more detail in the following sub-sections.

3.1.1 Structural approaches

Structural approaches (agronomic-economic models) start by using crop simulation models such as the CERES family of models (see Ritchie, Singh, Goodwin & Hunt, 1989 for a description of the CERES models), CROPWAT (FAO, 1993) or EPIC models (see Schneider, Easterling & Mearns, 2000). These models are based on detailed experiments to determine the response of specific crops and crop varieties to different climatic and other conditions. Farm management practices can be included in structural models, for example, modelling the impacts of changing timing of field operations, crop choices, adding irrigation etc. (Adams, 1999; Adams et al., 1998a; Schimmelpfenning et al., 1996). Economic impacts (e.g. changes in acreage, supply by crop and region, as well as resulting changes in prices) are then estimated by incorporating yield estimation results from crop simulation models e.g. from General Circulation Model (GCM) forecasts into economic models of the agricultural sector (Adams, 1999; Adams et al., 1998a). The objective of the economic model component is to optimise consumer and producer welfare, subject to climatic and other factors imposed in the model (Adams, 1999; Adams et al., 1998a). Examples of studies that have applied this approach include: Kaiser, Riha, Wilks, Rossier & Sampath (1993) at the farm-level; Adams and others (1998b; 1995; 1990) at the national level, and Easterling et al. (1993) at the regional level.

The types of economic models that have been used with agronomic models include: (a) computable general equilibrium (CGE) models that simulate economic wide impacts of climate change taking into account interactions between many economic agents and activities (e.g. Yates & Strzepek, 1996, 1998; Darwin, Lewandrowski, McDonald & Tsigas, 1994); (b) partial equilibrium models that include mathematical programming (e.g. Chang, 2002; Kumar & Parikh, 2001) and spatial equilibrium models of the agricultural sector (e.g. Adams et al., 1998b; Iglesias, Rosenzweig & Pereira, 1999); and (c) the basic linked system approach – an applied general equilibrium model for analysing global impacts of agricultural policies and food systems (e.g. Rosenzweig & Parry, 1994; Parry, Rosenzweig, Iglesias, Fischer & Livermore, 1999).

The strength of using *structural* approaches is that they allow for detailed understanding of the biophysical responses, as well as adjustments that farmers can make in response to changing climatic and other conditions (Adams, 1999; Adams et al., 1998a; Schimmelpfenning et al., 1996). In addition, economic models can estimate changes in clearing prices that can be translated into aggregate changes in well-being for consumers and producers (Adams, 1999; Adams et al., 1998a). This enables identification of the gainers and losers from changing climate conditions, as well as the distribution of the impacts. Such information might be important for focused policy and adaptation planning in identifying which group of people to target and in which ways they should be supported. Another strength of *structural* models compared to reduced form *statistical* (cross-sectional) models, is that they indicate the various technological and adaptation options that would offset the negative effects of climate change and positively increase yields.

One of the disadvantages of *structural* approaches is that adaptations included in agronomic models fail to account for economic considerations and limitations in human capital and other resources that affect actual farm-level decisions (Mendelsohn, 2000). In addition, if the economist fails to correctly anticipate the potential farmer adjustments and adaptations, the estimates might be biased (either overestimating the damages or underestimating the potential benefits of climate change) (Adams, 1999).

Furthermore, the problem of using such approaches is that in aggregate studies, inferences need to be made based on results from very few laboratory and experimental sites and crops analyses, to large areas and diverse agricultural production systems (Schimmelpfenning et al., 1996). Crop simulations models fail to account for the diversity of factors that affect production in the field (Adams et al., 1998a). Furthermore, *structural* models are usually associated with very high cost implications (Mendelsohn, 2000; Adams, 1999). This makes it difficult to implement them in poor and developing countries, implying that such countries need to rely on experiments conducted in developed countries.

Another disadvantage of agronomic models is that they have historically ignored the adoption of new technologies and most of them impose climate change scenarios on *current* agricultural systems (Mendelsohn, 2000). The problem with this is that the impact of climate change does not materialise for decades and by the time the climate actually changes, the farming systems could have changed from their current form. Including technical change in farming systems is important in assessing the damages that will be caused by climate change when it occurs (Mendelsohn, 2000). Adams et al. (1998) cited by Mendelsohn (2000), made attempts to capture technical change in the farming system by explicitly forecasting how farming would change in the United States by 2060. Modelling the adoption of new technologies and the transition from low input labour-intensive agriculture to high input modern farming is particularly important for developing countries. The sensitivity of climate change results to assumptions about baseline scenarios can be assessed through examining a range of assumptions concerning the speed of this transition.

The other disadvantages of *structural* approaches are the same as those for the cross-sectional approach. For instance, uncertainties surrounding economic development and political stability affect predictions of the nature of the future agricultural sector. Technical progress is often difficult to predict and very few agronomic efforts have considered the implications of projecting impacts into the future (Mendelsohn, 2000).

Generally as discussed above, the literature review reveals that agronomic models are associated with high cost implications (for data collection) and historical non-use of new technologies. However, more recent agronomic approaches make use of new global databases, do not have to rely on farm-level experiments, and have no problem with using advanced technologies. Furthermore, *structural* models, when combined with agricultural sector models, can present some types of autonomous adaptation triggered by price changes.

3.1.2 The Spatial analogue approach

The *spatial analogue* approach uses cross-sectional evidence to undertake statistical (econometric) estimations of how changes in climate would affect agricultural production across different climatic zones. Statistical and programming analyses across different geographic areas make it possible to make a comparative assessment of factors affecting production across different regions. In addition, this approach gives evidence of changes in farmer management practices and decisions in response to changing climatic conditions. Another advantage of the *spatial analogue* approach is that other factors that affect crop production, such as soil type and quality, are taken into account in statistical estimation. This cannot be done using the *structural* approach, since it depends on the quality of the data and how representative it is, as well as on the ability of the statistical analysis to separate the confounding effects (Adams et al., 1998a; Schimmelpfenning et al., 1996).

Two main *spatial analogue* methods have been developed to account for adaptation in response to changes in climate: (a) the Future Agricultural Resources Model (FARM) by Darwin et al. (1994, 1995); and (b) the Ricardian approach by Mendelsohn, Nordhaus and Shaw (1994). The basic underlying assumption for both the FARM and Ricardian methods is that similar climates mean similar production practices. This allows the two approaches to implicitly capture changes in crop or livestock outputs, production inputs or management practices that farmers are likely to take in response to changing climatic and other conditions (Darwin, 1999). Each of these approaches is discussed in more detail below.

3.1.2.1 The Future Agricultural Resources Model (FARM)

The FARM was developed by Darwin et al. (1994, 1995) to estimate the potential impacts of climate change on US agriculture, considering at the same time interactions with non-agricultural sectors and other global regions. The estimates in the FARM fully account for all responses by economic agents under global climate change, including estimates of Ricardian rents[4].

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[4] Ricardian rent refers to the estimates of land values from the 'Ricardian' approach named after David Ricardo (1772–1823), which relies upon the standard theory of land rent, as a way of identifying the impacts of changes on net economic welfare (Mendelsohn & Nordhaus, 1996).

The FARM makes use of geographic information systems (GIS) to link climatically derived land classes with other inputs and agricultural outputs in a computable general equilibrium (CGE) model of the world. The GIS component characterises regional differences in land, climate, water and agricultural suitability. Changes in climate are assumed to alter agricultural potentials of a given area by shifting regional land class and water characteristics. The resulting economic changes and effects on regional and global production and prices are then estimated in the CGE model (Adams et al., 1998a). The FARM's GIS is a *spatial analogue* model and the FARM's CGE is *structural* model (Darwin, 1999). Simulations using the FARM's CGE model capture further interactions that are likely to occur under climate change between farmers and downstream consumers (both domestic and foreign) of agricultural products (Darwin, 1999).

One of the limitations of the FARM is that the sensitivity of the Ricardian rents to changes in climate variables at grid levels is affected by the aggregation of climatic information into six land classes. In addition, it may be difficult to downscale the analysis to country level as some countries may be only one or two grids. Another limitation of the FARM is that it fails to capture some seasonal variations in climatic variables such as temperature, precipitation and coldness. Failure to include these variations might lead to biased estimates (Darwin, 1999).

3.1.2.2 Ricardian cross-sectional approach

Cross-sectional models measure farm performances across climatic zones (Dinar et al., 2008; Mendelsohn et al., 1994; 1996; Sanghi, Mendelsohn & Dinar, 1998; Mendelsohn, 2000, Mendelsohn & Dinar, 1999, 2003). The Ricardian approach is the cross-sectional method commonly used to measure the impact of climate change on agriculture. The Ricardian approach measures the performance of farmers, households and firms across spatial scales with different climates. Measured changes in farm performance are used to estimate long-run sensitivity of farm performance to climate (Dinar et al., 2008; Mendelsohn & Dinar, 1999, 2003, 2005; Mendelsohn et al., 1994, 1996). The technique draws heavily on the underlying observation by Ricardo that under competition, land values reflect the productivity of the land. The Ricardian approach has been applied in the United States (Mendelsohn et al., 1994, 1996) and in some developing countries: India (Sanghi et al., 1998; Kumar & Parikh, 1998) (using district level data), South Africa, (Gbetibouo & Hassan, 2005; Deressa et al., 2005) and eleven African countries[5] under the GEF/WB/CEEPA project (Dinar et al., 2008) using district level data to examine the economic impacts of climate change on agriculture.

The Ricardian approach regresses farmland values against climate, economic and other factors to estimate the economic impacts of climate change and other factors on farm performance (Mendelsohn & Dinar, 1999, 2003; Mendelsohn, 2000; Mendelsohn et al., 1994, 1996; Adams et al., 1998a). In a well-functioning market system, the value of a parcel of land should reflect its potential profitability, implying that spatial variations in climate derive spatial variations in land use, which in turn affects land values (Polsky, 2004). With this background, it should be possible to estimate a meaningful climate–land value relationship by specifying a multivariate regression model. The estimated coefficients for the climate variables would reflect the economic value of climate in agriculture, holding other factors constant.

The Ricardian cross-sectional approach automatically incorporates farmer adaptation by including decision making changes that farmers would make to tailor their operations to a changing climate. An important example of farmer adaptation strategies is crop choice, where a particular crop will become the optimal choice depending on the effects of a warmer climate. Optimal crop switching is therefore an important component of measuring the agricultural impact of climate change (Mendelsohn et al., 1994, 1996; Mendelsohn & Dinar, 1999). The Ricardian approach provides a framework to make comparative assessments of with and without adaptation scenarios, giving a valuable view of how adaptation measures may help to reduce the impact of climate change on agriculture.

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[5] Burkina Faso; Cameroon; Egypt; Ethiopia; Ghana; Kenya; Niger; Senegal; South Africa; Zambia and Zimbabwe.

Farmer adaptations that are implicit in the Ricardian model results are projected to largely offset the economic costs associated with climate change (Polsky, 2004). Farmers use available information to their maximum economic benefit in adapting to climatic shocks in any economy at equilibrium. For instance, a standard Ricardian model would imply that if growing citrus crops is more profitable than growing wheat, and if the climate becomes more suitable for citrus than for wheat, then farmers will adapt to the changed climate by drawing on the experiences of citrus farmers elsewhere and switching from wheat to citrus (Polsky, 2004).

The advantage of the *cross-sectional* approach is that it fully incorporates farmer adaptations. The first round adaptations by farmers are captured in the estimates of climate-induced changes that represent the economic value of climate change on agriculture (Mendelsohn et al., 1994, 1996). Measurement of long-term impacts of climate change considers the costs and benefits associated with changes in management decisions and practices taken by farmers in response to changes in local climate, as well as the effect of other explanatory variables such as soils, infrastructure, agricultural services and other socio-economic variables (Mendelsohn & Dinar, 2005; Mendelsohn et al., 1994, 1996). The underlying assumption is that farmers will automatically make adjustments in their management practices and respond to changes in climate (Mendelsohn & Dinar, 2003; Mendelsohn et al., 1994, 1996; Adams, 1999; Adams et al., 1998a). The assumption of implicit structural changes and farmer adaptations frees one from the burden of estimating the impacts of climate change on region-specific crops and farmer adaptations (Adams, 1999; Adams et al., 1998).

One limitation of the *cross-sectional* approach is the scarcity of good and reliable data, particularly in developing countries (Mendelsohn & Dinar, 2005; Adams, 1999). It is difficult to control for all variables that might affect the estimated relationship between climate and agricultural production using evidence from cross section data. For example, some variables might be included in the model but poorly measured, or might be excluded for lack of data (Reilly, 1999). The GEF/WB/CEEPA African climate and agriculture project provided a dataset that is very useful in addressing data limitation in developing countries (see Dinar et al., 2008). The empirical estimation for this study is based on this rich dataset that has not been fully utilised in country and regional studies for the GEF/WB/CEEPA African climate and agriculture project. The dataset contains detailed farm information across agro-climatic zones and farming systems in eleven Africa countries and provides an important source of information for assessing the effects of climate change on farm performance. In addition, the data contains useful information on farmer perceptions on changes in climate, and various farm-level adaptations they have made in response to changes in climate (e.g. planting different crops, changing planting and harvesting dates, changing livestock practices and using irrigation technologies).

Another limiting factor of the *cross-sectional* approach is trying to control for spatial variations in other physical (e.g. variations in soils across landscape), economic (e.g. proximity to markets, labour and technology) and policy variables (e.g. trade restrictions, subsidies and taxes) (Mendelsohn & Dinar, 2005). Making policy recommendations from estimations that fail to take these factors into account will produce biased estimates of impacts of and adaptation to climate change. Policy recommendations made based on such results will be inaccurate and might lead to misdirection and mismanagement of limited resources (Mendelsohn & Dinar, 2005). This study does control for these other factors, in order to ensure improved accuracy of estimation results and policy recommendations based on the results. A detailed description is provided in the section that discusses the independent variables used in the estimation.

A further limiting factor of the *cross-sectional* approach is that estimations of climate change impacts on farm performance are based on incremental changes in crop prices. Estimates would be inaccurate if large and widespread changes in climate result in long-term sustained changes in crop prices. Changes in prices would determine the magnitude and direction of error (Schimmelpfenning et al., 1996).

The statistical and programming methods used in the *spatial analogue* approach assume that farmers and other agents make costless structural adjustments and adaptations. Adaptation is however associated with costs, for example, research and development costs associated with changes in technologies, as well as costs of farm-level adoption and possible physical and human capital investments (Adams, 1999; Adams et al., 1998a).

Another limitation of using *cross-sectional* evidence is that it represents at best a long-run equilibrium response. Reilly (1999) argues that the cross-sectional Ricardian method and other similar reduced form approaches fail to explicitly define/describe how one gets from point A (current climate and current production activities) to point B (new climate and new production activities). Darwin et al. (1995), as cited by Reilly (1999), attempted to provide more information on possible ways of adaptation by dividing the response to climate change into three options: (a) on farm changes, (b) in the market changes and (c) land use changes. Despite being artificial, these categories provide more insight on the ways farmers respond to changes in climate and adapt. Using these categories, Darwin et al. were able to show that farmers can adjust their decisions even without much market response and without moving agricultural production to completely new areas (Reilly, 1999).

3.1.3 Integrated assessment models

Integrated assessment models of climate change impacts predict a range of impacts and climate sensitivity, starting with greenhouse gas emissions to final impacts. Using projections of economic development over the next century, global warming integrated assessment models can make predictions of future greenhouse gas concentrations. Changes in greenhouse gas concentrations are expected to lead to increasing global temperatures and hence global warming. Changing global temperatures will have differential effects on patterns of climate change and climate sensitivity across climatic regions (Mendelsohn, 2000).

Future agricultural impacts are predicted based on projected changes in climate and climate sensitivity. Impacts from global warming are expected to be evident as the climate changes. Changes in temperature, precipitation and carbon dioxide concentrations are all expected to affect agricultural production (Mendelsohn, 2000). Studies that have used integrated assessment methods in estimating climate change impacts on agriculture include: the Egyptian study (Yates & Strzepek, 1998); the MINK study on Minnesota, Iowa, Nebraska and Kansas (Crosson & Rosenburg, 1993); the US agriculture study (Adams et al., 1990, 1995); and the world food trade study (Rosenweig & Parry, 1993).

3.1.4 Agro-ecological zone (AEZ) method

The agro-ecological zone (AEZ) model uses detailed information about climate and soil conditions, crops and technologies to measure climate sensitivity of simulated crop yields. The AEZ model relies heavily on natural science relationships and develops a detailed eco-physiological process model. The model predicts Land Utilisation Types (LUT) based on combinations of existing technology, soil and climate to determine which crops are suitable for each cell. The AEZ model can simulate the impacts of changes in temperature and precipitation on potential agricultural output and cropping patterns on a global scale (Güther, van Velthuizen, Shah & Naehtergaele, 2002; Mendelsohn, 2000).

The AEZ model can be used to assess the impact of various aspects of climate change on potential crop production over wide geographic areas, although it was not created to model climate change. An important strength of the AEZ model is the widespread coverage of developing countries, where little climate research has been done, and where data constraints may make the use of other methods difficult. The AEZ model can simulate the impacts of changing precipitation and cloud cover on potential crop production and to a lesser extent, the impacts of temperature changes. Another advantage of the AEZ model is that with full knowledge of the potential impacts of future technology and genetic strains on specific parameters, modelling of future climate sensitivities can be done based on detailed eco-physiological relationships (Güther et al., 2002; Mendelsohn, 2000).

The main disadvantage of this method is that it is not possible to predict final outcomes without explicitly modelling all relevant components. It is also difficult to build a general model that will predict actual yields across locations, even with relatively simple agronomic systems. To address this problem the AEZ method compares simulated yields against reported yields and substitutes field data where there are major differences (Güther et al., 2002; Mendelsohn, 2000).

3.2 Empirical studies assessing impacts of climate change on agriculture

3.2.1 Empirical studies based on structural approaches

Chang (2002) adapted the *structural* approach to incorporate the yield effects of climate change directly into a sector-wide economic model with various levels of farm adaptation possibilities. He used a two-step procedure to estimate the impacts of climate change on the agricultural sector of Taiwan: (a) yield regression models were used to investigate the impact of climate change on sixty crops; and (b) an agricultural sector model was used to evaluate the impacts of crop yield changes (based on estimates from the regression models) on agricultural production, land use, welfare distribution, as well as the potential of agricultural adaptation in response to climate change.

The regression models for crop yields integrated the physical and social determinants of yield. Welfare results showed that an increase in temperature is not stressful for Taiwan's farmers, and may even be beneficial when adaptation is taken into account. However, the upward shift in rainfall intensity was found to have potentially devastating impacts on farmers' welfare. The welfare effects were shown to be different for producers and consumers, with producers expected to benefit from changes in climate. Variations in climate were shown to be significant in influencing crop yields and Chang (2002) highlighted the importance of incorporating these variations in impact assessment studies in sub-tropical and tropical regions.

In another study, the impact of climate change was estimated using an integrated modelling approach that included a crop simulation model and an applied general equilibrium model (Kumar & Parikh, 2001). The crop simulation model was used to estimate the impacts of changing climatic conditions on crop yields of wheat and rice. To estimate the economic and welfare implications of climate change, the authors integrated the predicted yield changes from the crop simulation model as supply shocks into an applied general equilibrium model (Agriculture, Growth and Redistribution of Income Model - AGRIM). Results from the study show that predicted changes in climate are expected to adversely affect crop yields and agricultural production. In addition, climate change will negatively affect welfare and the poor will be most affected.

Schneider et al. (2000) used an Erosion Productivity Impact Calculator (EPIC) crop model to examine the effects of natural variability on how farmers in the US Great Plains respond to changes in climate. The EPIC model, driven by a $2\times CO_2$ regional climate model scenario, was used to calculate changes in crop yields for three groups of farmers in terms of their adaptation practices: no adaptation; perfect adaptation; and 20-year lagged adaptation. The latter group was included to mimic the masking effects of natural variability on the ability of farmers to notice changes in climate. Adaptation options tested in the EPIC crop model included: varying planting dates, changing crop varieties, and regulating crop growth period. The results show that warmer temperatures enabled farmers to plant early in the spring so that critical reproductive periods avoided the risk of damage from high heat levels in mid-summer. In addition, with a longer growing period, farmers were able to grow long maturity varieties with longer grain filling periods and hence higher yields. The results from the EPIC crop model show that adaptation improves crop yields relative to the no adaptation case. These results support findings from other studies that adaptation serves to reduce potential negative effects from changes in climate.

Iglesias et al. (1999) estimated the impacts of climate change across spatial scales (seven sites) in major wheat growing regions in Spain, using CERES-Wheat, a dynamic process crop growth model. Using results from the crop model, the authors examined response of yield to changes in irrigation water, temperature, precipitation and CO_2 concentration. Results from the spatial analysis showed similar results to the CERES-Wheat crop growth model. An important finding from the empirical results is that crop water (both precipitation and irrigation) and temperature during the growing season significantly affect variability in simulated crop yields.

Yates and Strzepek (1998) assessed the integrated impacts of climate change on the Egyptian agricultural sector using a quadratic programming sector model. These authors used a forward-linkage sector approach to impact assessment that applied two economic models: (a) an Egyptian specific CGE sub-model (the Standard National Model-SNM) of the Basic Linked System to estimate impacts of climate change on crop yields, crop water use, water supply and land resources; and (b) results from the SNM were entered as inputs into the Egyptian Agricultural Sector Model (EASM) for assessing climate change impacts.

Simulations of the partial equilibrium, quadratic programming EASM model capture changes in water, land, crop, livestock, labour and other components at the sub-national scale. The results show that consumers and producers will be affected differently by changes in climate, with producers likely to experience more losses. Another important finding is that climate change impacts, coupled with changes in world markets as well as local and regional biophysical factors, would be more harmful to smaller food importing countries. Based on these findings, agricultural production will be vulnerable to changes in climate in African countries, most of which are net small food importers. This will impact negatively on national and regional food security efforts to support the fast growing populations.

The findings by Yates and Strzepek (1998) on climate change impacts on Egyptian farmers differ from those of Chang (2002) in terms of Taiwanese farmers. Although both studies used the structural approach and different methods, the latter study showed that farmers in Taiwan are likely to benefit from increases in temperature, while in Egypt (the former study), farmers will suffer from further warming. A possible explanation for this difference is the fact that Taiwan is already wetter and has cooler conditions compared to Egypt. Furthermore, Egypt is entirely dependent on irrigated crops because the climate is too dry to support crops without irrigation (Kurukulasuriya et al., 2006).

Kaiser et al. (1993) examined the potential economic and agronomic impacts of climate change and farm-level adaptation using three models of the relevant climatic, agronomic and economic processes based on a case study of a grain farm in southern Minnesota in the United States. The study simulated the sensitivity of crop yields, crop mix and farm revenue to climate change, based on a number of scenarios with different severity. The study simulated climate change in a dynamic way rather than the comparative static way of comparing a ‘doubled CO_2’ induced climate change with the current climate, which is important for analysing farm-level adaptations. The empirical estimation of climate change impacts included variability in climate variables as a way of capturing impact on agriculture performance.

The results by Kaiser et al (1993) show that climate change will affect growth and yield of agricultural crops, as well as length and timing of growing periods, all of which will contribute to reduction in the productivity of the agricultural sector of the southern Minnesota of the United States. The study also shows that farmers will adjust their management practices to reflect changes in the agricultural ecosystem due to climate change and other factors. The ‘tactical’ farm-level adaptation decisions included: changing crop varieties, changing planting and harvesting dates (to take advantage of a longer growing season due to climate change) and crop mix. These adaptation measures, even if they lag behind the evolution of climate change, were shown to be effective in helping reduce the negative effects of climate change on agriculture. Adaptation is therefore important in helping farmers to reduce the potential impacts of climate change, while at the same time achieving their farming goals (e.g. food security and higher incomes).

Empirical agronomic studies in Zimbabwe have revealed that climate change has a negative effect on the agricultural performance of major crops. Muchena (1994) and

Magadza (1994) showed that a 2º C rise in ambient temperature and a 4º C rise in mean temperature significantly lowered yields. In another study, Makadho (1996) assessed the potential effects of climate change on corn, using a Global Circulation Model (GCM) and the dynamic crop growth model CERES-Maize. The results indicated that maize production is expected to decrease significantly by approximately 11–17%, under conditions of both irrigation and non-irrigation. The above studies found that a reduced crop growth period due to increases in temperature, particularly during the grain filling and ripening stages, is the main factor contributing to decreased yields.

Schulze, Kiker and Kunz (1993), and Du Toit, Prinsloo, Durand and Kiker (2002) applied a CERES-Maize simulation model to estimate the impacts of climate change on maize production in South Africa. The former study considered the effects of increasing carbon dioxide concentrations and subsequent increases in temperature and did not consider changes in precipitation due to uncertainty of predicted changes. The results show that potential maize production increased with varied intensity across geographic areas. Increases in temperature and carbon dioxide strongly increased yields in low yielding areas (below 4 tonnes per hectare), and had less impact in high yielding areas (at least 8 tonnes per hectare). The latter study showed that seasonal changes in precipitation strongly affected maize yields. Simulation results showed that under current management practices, some parts of South Africa, such as the marginal western region, may become unsuitable for maize production, whereas the eastern region may remain unchanged or increase production.

New research and knowledge since the Third Assessment Report (TAR) show that many studies have estimated climate change impacts on agriculture (e.g. agricultural productivity, food security etc) at regional and global scales (IPCC, 2007). Examples include: Fischer and others (2002; 2005); Parry (2004); Parry et al., (2005); and Tubiello & Fischer (2006). The methodologies applied were based on agro-ecological zone data and/or dynamic crop models and socio-economic models. These studies first estimate climate change impacts on agronomic production potentials, followed by estimations of the effects on food supply, demand and consumption at regional to global levels that take into account different socio-economic future scenarios (typically SRES) (IPCC, 2007).

Further highlights of new research and knowledge since the TAR confirm that developing countries will suffer from potentially large negative impacts, while developed regions will experience small changes (IPCC, 2007). The studies cited in the IPCC (2007) report show that the aggregate impacts on world food production would be small based on the projected impacts of climate change in developing and developed countries (Fisher et al. 2002, 2005; Parry, 2004; Parry et al., 2005). However, contrasting findings from regional studies (e.g. Reilly et al. 2003; Olesen & Bindi, 2002) cited by the IPCC report show that the impacts of climate change could be significantly negative in key production regions even in developed countries.

Furthermore, the IPPC (2007) reports that climate change (especially increased frequency of extreme events) is projected to have adverse impacts on long-term agricultural yields (e.g. Antle, Capalbo, Elliott & Paustian, 2004; Porter & Semenov, 2005). These losses are expected crop damages at specific developmental stages (e.g. temperature thresholds during flowering) and reduced efficiency of farm inputs as timing of field applications becomes more difficult.

Despite some limitations and uncertainties associated with these studies, they are reported to provide fairly robust findings for policy formulation. The projections from the studies show that the number of people at risk of hunger is likely to increase with climate change, compared to reference scenarios with no climate change. For example, climate change is projected to increase the number of undernourished people in 2080 by 5-26% relative to the no climate change case, or by between 5 and 10 million people (SRES B1) and 120-170 million people (SRES A2) (Fischer et al. 2002, 2005).

3.2.2 Empirical studies based on the cross-sectional (Ricardian) approach

Polsky (2004) explored the variations in human-environment relationships associated with climate change in the US Great Plains from 1969 to 1992 using spatial Ricardian econometric models. The study included effects of spatial and temporal scales in the estimation of variations in human-environment interactions. The estimation results show that climate sensitivities are significantly influenced by spatial effects such as extra-local communication processes and proximity to and regulation of irrigation water. These results indicate the importance of accounting for spatial and temporal scales in estimating the impacts of climate change on agriculture.

Mendelsohn and Dinar (2003) explored the interaction between climate, water and agriculture. The study tested the impacts of surface water withdrawal on the variation of farm values across the United States, as well as the impact of adding these variables to the standard Ricardian model on climate sensitivity of agriculture. The results of the study show that the value of irrigated cropland is not sensitive to precipitation, but increases in value with temperature. A key recommendation from the study is that irrigation is an important potential adaptation measure for agriculture.

Mendelsohn et al. (1996) measured the economic impact of climate change on land prices. An important contribution of the study is that it developed the Ricardian approach for measuring the economic impacts of climate change on agriculture. The study was based on cross-sectional data on climate, farmland prices and other economic and geographical data, for almost 3000 counties in the United States. The results show that seasonal temperatures in all seasons except autumn reduced average farm values, while more precipitation outside autumn increased farm values. Another key result from the study was that estimated impacts of global warming on US agriculture were significantly lower than estimates from the traditional production-function approach.

Polsky and Easterling (2001) modelled the influences of factors from multiple spatial scales on climate sensitivity of the Ricardian estimates in the US Great Plains. The study extended the Ricardian approach to take into account social factors at large scales that condition farm-level responses to changes in climate. An important contribution of the study is that it included the large-scale social context missing from most impact assessment studies. The Ricardian climate sensitivity results show that social factors associated with large scale agro-climatic zones significantly affect local level climate sensitivity. The study also showed that farmers and institutions in highly variable climates have adapted and are more resistant, compared to those in relatively stable climates. An important recommendation from this study is the necessity to investigate the precise forms of local and other adaptations and their effects on sustainability of the agricultural system.

Gbetibouo and Hassan (2005) applied the Ricardian approach to measure the impact of climate change on South Africa's field crops. The study regressed farm net revenue on climate, soil and other socio-economic variables based on agricultural data for seven field crops (maize, wheat, sorghum, sugarcane, groundnuts, sunflowers and soy beans), across 300 districts in South Africa. The results of the study show that production of field crops is sensitive to marginal changes in temperature compared to changes in precipitation. Increases in temperature were shown to be beneficial as they increased net farm revenues, while reductions in precipitation were shown to be detrimental to crop production as they led to reductions in net farm revenues. Potential adaptation options identified in the study to respond to further changes in climate include: shifts in crop calendars and growing seasons, and switching between crops to the extent of the possible complete disappearance of some field crops in some regions.

In another study, Deressa, Hassan and Poonyth (2005) used a Ricardian model to estimate climate change impacts on sugarcane production in South Africa. The study was based on a time series data set for the period 1977-1998. The results show that predicted changes in temperature strongly affected net revenue from sugarcane production compared to changes in precipitation.

Kurukulasuriya et al. (2006) used a Ricardian method to estimate the likely impacts of climate change on net farm revenues in African agriculture using farm-level data collected for the GEF/WB African climate project coordinated by CEEPA. The study measured total net farm revenue as the sum of three main activities: (a) dryland crops that rely on natural rainfall; (b) irrigated crops that depend at least on some irrigated water; and (c) livestock. Net farm revenues for both dryland and irrigated crops were measured per hectare as the area planted could be accurately measured. This was difficult for the livestock which is based largely on common grazing lands and had to be measured on a per farm basis. The study estimated separately the impacts on dryland crops, irrigated crops and livestock. The results show that dryland crops and livestock will experience more adverse impacts from increases in temperature and decreases in precipitation, compared to irrigated crops which will benefit from warming in terms of irrigation. Using the same approach and dataset, Kurukulasuriya and Mendelsohn (2007a) also found that dryland crops suffered more from increased warming compared to irrigated crops. In both studies irrigation offered an important adaptation option for buffering the negative impacts associated with warming.

Seo and Mendelsohn (2007a) used the cross-sectional Ricardian approach to estimate the impacts of climate change on large and small livestock farms. The results show that large specialised farms were more vulnerable to changes in temperature and precipitation, compared to small farms. The reason for this is that large farms tend to rely on commercial beef and other species that are not tolerant to high temperatures, compared to small farms that have more traditional livestock species such as goats and sheep that can do well in dry and warm environments.

Studies using the Ricardian approach in southern African countries also found that dryland crops will be more affected by changes in temperature and precipitation (Mano & Nhemachena (2007) in Zimbabwe; Benhin (2006) in South Africa). Jain (2007) found that crop production is adversely affected by increases in temperature in November and December and reduction of rainfall in January and February, which coincide with the crop maturing stage. The above studies identified the following important adaptation measures in the region: use of different crop varieties, crop diversification, different planting dates (given the high perception that the timing of rains is changing), diversifying from farming to non–farming activities, increased use of irrigation, increased use of water and soil conservation techniques.

A study by Molua and Lambi (2007) in West Africa found that agriculture in Cameroon is adversely affected by decreases in precipitation and increases in temperature. Future climate scenarios predicted declines in farm net revenues due to increased warming and decreased precipitation. In Senegal, small rain-fed farms were found to be highly vulnerable to changes in climate variables (temperature and precipitation) (Sene, Diop & Dieng, 2006). The study also identified some adaptation strategies being used by farmers, such as crop diversification and growing short season crops.

In East Africa, Kabubo-Mariara and Karanga (2007) applied the Ricardian approach to measure the economic impacts of climate change in Kenya. The results show that changes in temperature are harmful to agricultural productivity. Predicted future impacts indicate that agriculture production will be adversely affected by expected warming in temperatures. The study also identified some important adaptation strategies being used by farmers to help reduce the negative impacts of climate change: crop diversification, water conservation, irrigation and shading. Poverty and lack of information were identified as the major limiting factors in using different adaptation measures. Other East African studies by Deressa (2007) in Ethiopia, and Eid, El-Marsafawy and Ouda (2007) in Egypt, show that increases in temperature and decreases in precipitation are generally detrimental to agricultural production in Ethiopia. Net farm revenues were reported to fall due to increases in temperatures and decreases in precipitation.

3.3 Summary

The various approaches and methods that have been used to measure economic impacts of climate change on agriculture were discussed in this chapter, as well as empirical studies that applied the reviewed approaches. Two main approaches have been used in the literature to measure climate change impacts on agriculture: (a) *structural modelling* of crop and farmer response, which combines crop agronomic response with economic/ farmer management decisions and practices; and (b) *spatial analogue models* that measure observed spatial differences in agricultural production. Other impact assessment methods that have been used are the integrated impact assessment method and the agro-ecological zone method.

The review of empirical studies shows that the various approaches have been applied at different levels (district, national and regional). For example, the structural approach has been applied at the farm-level (e.g. Kaiser et al., 1993; Muchena, 1994; Magadza, 1994); the national level (e.g. Adams et al., 1990, 1995, 1998b) and the regional level (e.g. Easterling et al., 1993). Similarly the Ricardian approach has been applied at different levels: regional (e.g. Kurukulasuriya et al., 2006; Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a), and national and farm level (e.g. Dinar et al., 2008; Gbetibouo & Hassan, 2005).

The results of the various studies exhibit similar findings on the general impacts of temperature and precipitation. For example, studies based on structural approaches in Zimbabwe (e.g. Muchena, 1994; Magadza, 1994) show that warming and drying will result in significantly low yields for maize. Similarly, Mano and Nhemachena (2007), using a cross-sectional Ricardian approach, found that net farm revenues will be adversely affected by further warming and decreases in precipitation. However, the magnitude of the estimated impacts from studies using different approaches varies, possibly due to the underlying assumptions of the studies. For example, structural approaches tend to overestimate the impacts of climate change, as they do not include adaptation mechanisms, as opposed to the cross-sectional Ricardian approach which does.

This study applies the Ricardian approach to measure the impact of changes in climate attributes (rainfall and temperature levels) on net revenue from crop and livestock farming, controlling for other production factors. The justification of this choice over other models is that it helps to achieve the stated objectives of this study, and has several advantages over other models (as discussed above), such as the incorporation of farmer adaptations. Furthermore, measuring economic impacts of climate change in African agriculture is limited by the scarcity of reliable data. The available data from the GEF/WB/CEEPA African Climate and Agriculture Project provided a very useful cross-sectional dataset that addresses typical limitations in developing countries, for estimation of the Ricardian model (see Dinar et al., 2008).

Recent efforts have measured the impacts of climate change in Africa. Other studies based on the Global Environmental Facility (GEF) African Climate Project estimated the economic impacts of climate change on African agriculture (Dinar et al., 2008), using district level data. Before the GEF/WB/CEEPA African climate study, other studies applied the same approach: Gbetibouo and Hassan (2005) on South African field crops and Deressa et al. (2005) on sugarcane production in South Africa.

However, these studies analysed impacts on dryland crops, irrigated crops and livestock separately. This represents an important limitation of the cited studies, since the choice between crop and livestock production, or the combination of both (mixed systems), is an endogenous decision made by agricultural producers in response to varying climates and other circumstances. The decision as to what to produce is motivated by climate and other determinants and is accordingly an important adaptation mechanism of farmers. It is therefore considered appropriate not to separate choices and responses of crop and livestock farmers, but to analyse them jointly and to compare adaptive capacities of such choices (the degree of vulnerability to climate change). This is of special importance for Africa, where the majority of poor small-scale farmers practise mixed crop–livestock agriculture and few depend on livestock only.

This study therefore measures the aggregate impact of climate change on income from all agricultural production systems (crop, livestock and mixed) in Africa and predicts future impacts under various climate scenarios. In addition to estimating impacts on mixed crop–livestock farms, the study also measures and compares impacts on specialised crop and livestock farms. The results are contrasted with findings of other regional studies using the same data but generating different climate response functions for crop and livestock farming separately (Kurukulasuriya et al., 2007; Kurukulasuriya & Mendelsohn, 2007a; Seo & Mendelsohn, 2007a). In this study, the responses of different production systems are analysed under irrigation and dryland conditions.