1. Introduction

This book examines the impact of climate change on agriculture and what farmers do to adapt to climate. Agriculture and grazing currently occupy 40 percent of the earth’s land surface (Easterling and Aggarwal et al., 2007). Overall, agriculture is responsible for 6 percent of the world’s GDP. In many developing countries, agriculture is a primary sector of the economy and is the primary source of livelihood for about 70 percent of the rural population (Easterling and Aggarwal et al., 2007). Climate changes are expected to affect farmers throughout the world. This book examines the magnitude of the impacts to farmers, where these impacts will occur, and how farmers can adapt.

Although climate change is expected to have many impacts on various sectors, few sectors are as important as agriculture. If future climate scenarios lead to a widespread reduction in food supply, there could be massive problems with hunger and starvation (Rosenzweig and Parry, 1994; Reilly, 1996). Global analyses of the total impacts of rising greenhouse gases have consistently raised concerns about agricultural impacts (Cline, 1992; Pearce et al., 1996; Reilly et al., 1996; Gitay et al., 2001; Easterling and Aggarwal et al., 2007). Virtually all developed countries are concerned about whether climate change will damage their agricultural sectors. However, several authors are concerned that agricultural losses will be especially harmful to developing countries (Pearce et al., 1996; Rosenzweig and Parry, 1994; Mendelsohn and Williams, 2004; Cline, 2007).

CLIMATE CHANGE

In order to understand climate impacts, it is first necessary to discuss climate change itself. It is now widely agreed that changes in land use and especially burning fossil fuels have already caused and will continue to cause substantial releases of greenhouse gases into the atmosphere (IPCC, 2007). These emissions stay in the atmosphere for long periods of time so that the concentrations of greenhouse gases have been rising steadily (IPCC, 2007). As greenhouse gas concentrations rise, they are expected to trap heat in the lower atmosphere. This excess heat is expected to warm
Climate change and agriculture

The oceans over several decades. The warmer oceans in turn lead to a long-term change in climate. Because it takes oceans so long to warm, there is a lag between emissions and temperature changes.

There is evidence that temperatures have warmed about 0.5°C over the past century (IPCC, 2007). The climate change of concern, however, is not past warming but rather warming in the future. If there is no mitigation of greenhouse gas emissions over the next century, global temperatures are expected to rise between 2°C and 4°C depending on the emissions scenario (IPCC, 2007). However, even these estimates are uncertain, so the range of actual warming by 2100 may be even broader. One reason why the range is so wide is that it is not clear how much greenhouse gas the future economy will emit. A second reason is that it is not clear how much CO₂ will be absorbed by the biosphere and the ocean. A third reason is that it is not clear whether other forces such as sea ice and clouds in the earth-climate system will dampen or enhance the greenhouse effect.

Table 1.1 examines a number of likely scenarios for the next century if there is no mitigation. It is quite clear that the higher the concentrations, the greater the warming. However, even with a known level of greenhouse gas concentrations, there is still uncertainty about the magnitude of warming. The direct effect of man-made greenhouse gas emissions on solar radiation is reasonably well understood and calibrated. This direct effect is small and leads to the lower estimates in the range. In addition, climate scientists expect that there are positive feedbacks. Once climate changes, these positive feedbacks can amplify the change in climate from

Table 1.1  Projected global average surface warming at the end of the 21st century

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Temperature change (change in °C in 2090–2099 compared to 1980–1999)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Best estimate</td>
</tr>
<tr>
<td>A1T (600 ppm)</td>
<td>+2.4</td>
</tr>
<tr>
<td>A1B (800 ppm)</td>
<td>+2.8</td>
</tr>
<tr>
<td>A2 (1250 ppm)</td>
<td>+3.4</td>
</tr>
<tr>
<td>A1F1 (1550 ppm)</td>
<td>+4.0</td>
</tr>
</tbody>
</table>

Notes:
a. The scenarios listed above reflect likely outcomes in the absence of mitigation over the next century.
b. To express the temperature changes relative to pre-industrial times add 0.5°C.

Source: Adapted from IPCC (2007, Table SPM3).
man-made emissions (IPCC, 2007). For example, warming will increase the speed of the hydrological cycle and there is likely to be increased cloud. These clouds could themselves act as greenhouse gases. However, depending on the height at which they form, the clouds may act as a cooling force. Sea ice will melt as temperatures rise and this will change the albedo of the earth’s surface so that it absorbs more heat. However, it is not clear how powerful this effect will be at the poles where such an effect will occur. The albedo of other parts of the earth’s surface may also change as ecosystems shift. There may also be releases of carbon from the biosphere as it warms. All these effects have the potential to amplify man-made emissions into much larger changes in temperature, but they are uncertain.

It is also important to note that the anticipated temperature increases are likely to be greater near the poles and lower near the equator. The temperature changes will not be uniform across the planet. Further, the changes in temperature are likely to increase the energy in the hydrological cycle, leading to more clouds, more rain and more evaporation. These changes can be as important as the change in temperature. How precipitation changes will be distributed across the planet is not clear as meteorological processes are likely to change, leading to weather patterns shifting from place to place. Some areas may get a lot more rain and others a lot less. These changes are poorly understood at the moment and there is little agreement about the distribution of precipitation changes across the planet across climate models.

In conclusion, there is a great deal of uncertainty about future climate change scenarios. The question is not whether greenhouse gases might warm the planet; the answer to this question is clearly that they will. The issue is how much will the planet warm, how much will precipitation change, and how will these changes be distributed across the planet? This book does not answer these questions. These answers lie in climate science.

The focus of this book is upon measuring the consequences of climate changes for agriculture. In order to capture the uncertainty in climate outcomes, the book examines the range of climate changes currently considered plausible. In particular, the book contrasts a relatively mild warming scenario with a relatively harsh scenario. The mild scenario predicts a small increase in temperature (of about 2.5°C) and a small increase in precipitation (of about 7 percent). The harsh scenario predicts a large increase in temperature of about 5°C and no increase in precipitation. There is a myriad of possible climate scenarios but examining these two provides a reader with a sense of the consequences of the range of possible climate outcomes.

Although climate change is sometimes discussed as though it is a discrete event (before or after), it is actually a continuous process that evolves
over time. If emissions are not curbed, temperatures will continue to increase for centuries. Just looking over the rest of this century indicates a clear dynamic process. Figure 1.1 illustrates how temperature might evolve over the rest of this century, depending on whether the outcome is relatively mild or severe. The differences between the two scenarios are not that large at first. However, after 2050, the high and low scenarios become more distinct. By 2100, the two scenarios lead to very different temperature outcomes.

Climate scientists predict that there may be other changes to climate in addition to just a gradual increase in annual temperature or precipitation. Warming may change seasonal distributions. Warming may reduce diurnal range by reducing heat loss at night. Warming may lead to an increase in interannual variance. Although not every study examined each of these elements, at least some studies were able to address them all. The changes above are covered as part of the analysis of climate change impacts on agriculture in this book.

In addition to the climate changes listed above, scientists also predict that greenhouse gas emissions will lead to sea level rise, which will inundate coastal properties. Warming may also increase the severity or frequency of hurricanes and other storms. These latter two effects are
not covered in this book. That is not to say that these impacts are not important, but that they are quantified as separate studies of impacts. For example, there is a whole collection of literature on sea level rise (Bosello et al., 2007; Yohe et al., 1999; Neumann and Livesay, 2001; Ng and Mendelsohn, 2005; 2006). In addition, there is a small but important body of literature on hurricane and storm damages (West and Dowlatabadi, 1998; Nordhaus, 2006).

**ORGANIZATION OF THE BOOK**

Chapter 2 establishes the scientific relationship between climate and agricultural production, explaining why plants and animals are sensitive to climate. The chapter explains why agricultural production is affected by climate. However, it also discusses the fact that agricultural performance is also sensitive to soils, technology, institutions and market access.

Chapter 3 reviews the economic literature that has examined climate change impacts on agriculture. A wide range of techniques have been developed including (1) crop modeling; (2) mathematical programming; (3) Ricardian cross-sectional analysis; (4) analysis of panel data; and (5) other econometric approaches. The advantages and disadvantages of each of these approaches are discussed, including how well each approach deals with adaptation. Although there are now many available approaches to studying impacts on agriculture, the bulk of the work has focused on the United States. There has been surprisingly little empirical economic research given the importance of agricultural impacts and especially the importance of agricultural impacts in developing countries.

The remainder of the book reviews a new set of economic studies that measure the impact of climate change and adaptation on agriculture, specifically focusing on developing countries. Chapter 4 develops in detail the impact methodology, the Ricardian approach, used in many of these studies. The Ricardian approach is at the heart of the seven studies funded by the World Bank in four continents, covering 22 countries. The chapter discusses how the Ricardian approach has evolved over time to address different situations and circumstances. The chapter reviews various modifications and adjustments that have been made in data collection and analytical methods.

Chapter 5 examines methodologies for measuring adaptation. Although many authors have been writing about climate adaptation in the abstract and about concrete steps regarding how to adapt to weather, there are very few adaptation studies that show how farmers would adapt to climate change. This chapter discusses new cross-sectional methods to measure
how farmers alter their choices in response to climate. The studies examine such choices as whether to grow crops or raise livestock, whether to irrigate, which crops to plant, and which livestock to own. The research quantifies how these decisions are affected by climate.

Chapter 6 explores the merging of adaptation and Ricardian impacts into structural farm models. As with the two earlier approaches discussed in Chapters 4 and 5, this chapter relies on cross-sectional analysis. The structural approach begins with climate, soils and other exogenous variables and ends with predictions of net revenue, as in the Ricardian approach. However, rather than treating adaptation as a black box, the modeling explicitly captures the many choices that farmers make in response to climate, as in the adaptation chapter. The model makes clear what changes farmers would make on a farm that faces a different climate. The models then estimate the conditional income that a farmer would receive, given his/her choices. As a result, the approach can estimate the final expected income of a farmer and can predict how expected income would change as climate changes.

Chapter 7 reviews specific empirical studies that were conducted in the United States, Brazil, India and Sri Lanka, which relied on secondary data in each of those countries. The chapter discusses specific problems that had to be overcome in order to perform the analyses. For example, one important issue was how to measure farm performance. Brazil and the United States have land value data that can measure long-term farm net revenue, but such data does not exist in India. The Indian study consequently had to rely on farm net revenue. Another key question that is discussed is how to measure climate. Weather stations are scarce in rural parts of developing countries and yet there are serious drawbacks to using satellite data. Finally, the chapter also reviews the results from the countries studied. Although there are qualitative results that are consistent across all the countries, the quantitative results are quite different.

Chapter 8 discusses the application of the Ricardian method to Africa, South America and China. The continental scale analyses relied on primary data that was collected specifically for the study. Although the African and South American studies were designed to be as similar as possible, the studies had to make adjustments for each continent. In Africa and China, land value data is not available, so these studies relied on calculated net revenues to measure farm performance. In contrast, the South American data had reliable measures of land values. In Africa, most farmers relied on common lands to graze their livestock so it was not possible to measure the land used by livestock management. In South America, livestock management was largely done on farm and so was captured by farm land value. Satellite data was used to measure temperature in these studies and
weather station data was used to measure precipitation. In addition, the African data had measures of water flow through the district. Chapter 8 also reviews the results for each of these studies, which were quite distinct for each region.

Chapter 9 discusses empirical studies of adaptation that were undertaken in Africa and South America. Several decisions by farmers were found to be sensitive to climate: whether or not to plant crops, raise animals or do both depends on climate. Which crops to plant and which livestock to raise are also climate-sensitive decisions. Finally, whether or not to use irrigation was found to depend on both climate and water.

Chapter 10 estimates several structural Ricardian models. The first empirical model begins with the decision to adopt irrigation and then computes the conditional income of dryland and irrigated land. All three equations are climate-sensitive. The second model begins with the decision regarding whether to have crops, livestock or both. For farmers that choose crops, they must then choose whether or not to use irrigation. Finally, for every type of farm, the model estimates conditional income. Both of these farm models predict the impact of climate change. However, in contrast to traditional Ricardian models, these structural Ricardian models also explain how farmers change their behavior.

Chapter 11 synthesizes the results over the 22 countries and four continents. The review examines the overall impacts of climate change on agriculture. The empirical studies consistently reveal that climate is important. In locations that are relatively cool, warming has only a small impact on farm outcomes. But in places that are already hot, warming significantly reduces net revenue and land values. The effect of precipitation changes depends greatly on the level of existing precipitation. In places that are relatively dry, increased precipitation is highly beneficial. However, in places that currently receive relatively heavy amounts of precipitation, increased precipitation is harmful. Rainfed farms are more sensitive to temperature and precipitation changes than irrigated farms. In fact, in several places, warming increases the net revenue of irrigated farms. Provided there is adequate water, irrigation may be an effective adaptation to climate change. Another effective adaptation is shifting from crops to livestock. Shifting crops and shifting livestock species are also very effective climate adaptations. Contrary to expectations, many household farms may readily adapt to climate change because they have good substitutes for what they are doing now. Larger, more commercial farms may be more vulnerable because they have specialized in crops and livestock that are profitable but more heat-sensitive.

Chapter 12 draws overall policy implications at various levels, including local, country, regional and global levels. Because impacts vary
significantly across space, the actual impact on each farm is a local phenomenon. Consequently, adaptation must also be local. Some barriers to adaptation, however, are at the national level. For example, moving resources from public and common property ownership to private property ownership increases efficient adaptation. Finally, some adaptations may be regional or global. Encouraging free trade of farm products across climate zones increases the overall resilience of agriculture so that people become less dependent on local productivity. Developing more suitable crop varieties and animal breeds for a warmer world is more effective if there is a global market for the products rather than a national market. Other issues such as improved public management and income transfers are also addressed.

Chapter 12 also addresses future research needs. The chapter discusses the need to improve data collection, extend the analyses to all regions, and improve the analytical methods. One especially critical area that needs to be developed is closer interaction between agriculture and other sectors (especially water and forests).

REFERENCES


