1. Introduction

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This book contributes to the growing field of assessments of impacts of climate change by discussing the regional distribution of market effects of climate change across the United States. Although there are now several estimates of the national impacts of climate change, there are no quantitative regional estimates in the literature. If the country experiences a few degrees of warming, what will happen in each region? What difference will it make to each region if the change in climate turns out to be more substantial? Are the effects about the same for everyone or are some regions more vulnerable than others? These are the questions that this book seeks to answer.

HISTORY

In the 1980s, as interest in climate change increased, researchers set out to identify what types of impacts climate change might cause. The first comprehensive assessment of impacts in the United States was compiled in a US Environmental Protection Agency (EPA) study (Smith and Tirpak 1989). This assessment found that scenarios of 3° to 5°C average global warming could cause adverse impacts to agriculture, forestry, energy, water, coastal resources, health and biodiversity.

Economists then used the EPA sectoral analyses and scattered other studies to value these impacts in the United States. After Nordhaus's (1991) pathbreaking estimate came a series of analyses (for example, Cline 1992, Titus 1992, Fankhauser 1995, Tol 1995). These analyses were then captured in the second assessment recent report of the Intergovernmental Panel on Climate Change (IPCC) in a chapter on climate change impacts (Pearce *et al.* 1996). The studies estimated the dollar magnitude of impacts to each climate-sensitive sector. These estimates included impacts to market sectors (agriculture, coastal resources, energy, forestry, and water) where there was substantial quantitative information and impacts to nonmarket sectors (aesthetics, ecosystem change, health, and recreation) where there was much less information. Although the analysts could not agree on the magnitude to assign each sector, their aggregate

estimates suggested that a doubling of greenhouse gases would cause long-run net damages in the United States equal to about 1–2 per cent of GDP.

The second comprehensive empirical study of impacts on the United States was completed in 1999 (Mendelsohn and Neumann 1999). That study examined the potential impacts of climate change on market sectors of the US economy as a whole. It examined impacts on agriculture, timber, water resources, coastal resources, energy, commercial fishing, and recreation. This second analysis included the full potential of adaptation to minimize costs of climate change and provided a more comprehensive analysis of the sectors. This examination of a complete cross-section of sectors revealed beneficial impacts that had been overlooked in earlier studies. This study found that a relatively small amount of warming (1.5 to 2.5°C) would produce small net benefits to the US economy (see Figure 1.1). Specifically, there would be large benefits in agriculture and small benefits in forestry, and the total benefits would be larger than the total damages from water, energy and coastal impacts nationwide. With more substantial warming (5°C), these net benefits would be substantially reduced and even become negative (see Figure 1.1).

Source: Derived from Mendelsohn and Neumann 1999.

Figure 1.1 Estimated economic impacts of climate change in 2060 at three different temperature scenarios with no change in precipitation

HYPOTHESES

One of the interesting aspects of climate change is that impacts will not be uniform across sectors, across the world, or even within many countries (see, for example, Watson *et al.* 1998). Some areas could have benefits while others

could have damages. Some sectors may see 'positive' impacts while other sectors may see 'negative' impacts. Impacts may also change as climate continues to change, changing the character and distribution of these impacts across sectors and regions. The EPA and other studies suggest that there could be substantial regional shifts in economic activity in the United States (for example, Smith and Tirpak 1989, Adams *et al.* 1999a, 1999b). These studies predict that southern areas of the nation are more likely to face adverse impacts than northern areas. Mendelsohn and Neumann (1999, p. 324) note: 'For the most part, these results support the intuitively plausible hypothesis that colder more northern states will enjoy higher than average benefits from warming.' Although the above studies provide broad predictions of regional impacts, they do not present quantitative predictions for each region and market sector.

This study uses the methods and scenarios developed in Mendelsohn and Neumann (1999) to examine the regional distribution of the market impacts of climate change in the United States. The empirical studies in Mendelsohn and Neumann suggest that the economic productivity of market sectors has a hill-shaped relationship with absolute temperature (Mendelsohn and Schlesinger 1999), implying that the impact of climate change for a location will depend on the initial temperature of that region. Cold places (on the left side of the hill) are more likely to have benefits from warming (climb the hill), whereas hot places (on the right side of the hill) are more likely to have damages (fall further down the hill). For a temperate country like the United States close to the top of the hill, there could be economic benefits¹ associated with small amounts of warming such as 1.5 to 2.5°C and damages associated with larger amounts of warming such as 5°C (see Figure 1.1).

Our regional hypothesis is that economic activities in colder northern regions are more likely to have economic benefits from climate change (or have less harm) and those in warm southern areas are more likely to be harmed (or have fewer benefits). We expect the Northeast, Midwest and Northern Plains to have economic benefits from warming. In contrast, we expect the Southeast, Southern Plains and Southwest to have economic damages from warming. The effects in the Pacific Northwest are more difficult to hypothesize because the region lies in northern latitudes but enjoys a relatively mild climate.

The difference in the impacts between the northern and southern region is expected to increase the more severe the climate scenario. Although early analyses recognized that impacts would most likely become more severe as the magnitude of climate change increased, they often assumed climate change would be harmful across all scenarios (Nordhaus 1991, Pearce *et al.* 1996). With low temperature change scenarios (increases of 1.5°C), however, the universal benefits of carbon fertilization from higher levels of CO₂ could dominate. The expected regional differences may appear only with higher temperature change scenarios.

Regional effects may also vary because of other differences across regions. Regions with more productive cropland, such as the Midwest, are likely to have larger agricultural impacts. Regions with important forestland, such as the Southeast, are likely to have larger timber impacts. Regions with more people and more economic activity, such as the Northeast, are likely to have more energy impacts. Regions with more people are also more likely to have larger consumer impacts if prices for food or wood products change because of climate. Regions that are drier, such as the Southwest, or which have more hydropower, such as the Northwest, are more likely to be sensitive to changes in water flows. Regions with more low-lying and developed coastline, such as the Southeast, will be more sensitive to sea level rise.

SECTORS

This study addresses the following market sectors of the United States:

- agriculture
- timber
- water resources
- coastal structures
- energy.

Mendelsohn and Neumann (1999) also examined commercial fisheries, which is also a market sector, but only in a sensitivity analysis. There have been few scientific studies on the effects of climate change on commercial fisheries, identifying how specific marine and estuarine areas would be affected, so biophysical estimates of the effects of climate change on commercial fisheries are limited. Further, because the entire sector is relatively small, it is not likely that fishery effects will be large. Commercial fisheries are consequently not included in this study.

Mendelsohn and Neumann (1999) addressed only selected nonmarket sectors: recreation and water quality. Since we are not able to provide reliable estimates of the impacts in several important nonmarket sectors such as aesthetics, ecosystem change, and health, we felt it was important to omit all nonmarket impacts. Note that these impacts are omitted solely because we have little confidence in the available estimates, not because we judge these sectors to be unimportant. The effect of climate change on the quality of life in each region and in the world at large is an important topic that we leave for future research.

METHODS

One of the most significant changes in the methods presented in Mendelsohn and Neumann (1999) concerns adaptation. The sector studies attempted to fully assess the potential for efficient adaptation to offset the negative impacts of climate change and take advantage of positive impacts. In the studies in this book, the costs and benefits of adaptation are also weighed, and adaptations are included only if their benefit exceeds their cost.

There is considerable controversy in the literature about whether adaptation will be efficient or not. Adaptation is likely to be efficient if the decision maker is the sole beneficiary of the action taken and there are no adverse effects of the decision maker's actions on other parties. In this book, we consequently assume rational economic behavior by individuals and firms when the incentives to adapt to climate change are private. Because this book is concerned only with climate impacts in market sectors, most of the adaptations considered fall into this category. In agriculture, for example, farmers are likely to pick new crops that will grow under the new climates they will experience. The forestry model assumes that timber firms will harvest trees in peril and plant new species adapted to warming. The energy model assumes that people will change their buildings as climate warms, decreasing insulation from the cold and increasing cooling capacity.

However, some of the adaptations in market sectors may depend on government action to perform activities that benefit many parties at once. When the incentives to adapt are shared across individuals, it is no longer obvious that rational economic behavior will be adopted. Examples of public adaptation include government agencies providing climate forecasts, building water facilities, reallocating water, or protecting coastal areas. All of these activities require coordinated engineering plans and social policies that will affect many people differently. In this book, we assume that these public actions will be efficient. For example, the water study assumed that water managers would reallocate water supplies to their highest valued use as water became scarce. The coastal study uses benefit-cost analysis to examine whether coastal property will be protected and what would be the optimal timing of adaptation measures, as opposed to assuming that all developed areas would be protected (as, for example, in Titus *et al.* 1991). Assuming that public adaptation is efficient may prove to be too optimistic. Whether public policy efficiently adapts to climate change is not clear. This is a controversial assumption and more research is needed to determine what to expect. Nonetheless, what is clear is that adaptation has the potential to substantially reduce costs and enhance benefits, is integral to impact assessment, and deserves careful policy analysis.

Measuring the impacts from climate change is very challenging. The climate since greenhouse gases began to accumulate in the atmosphere has

increased 0.6°C over 100 years. Given the myriad other factors that have changed over this time period, it is not straightforward to isolate the impacts of climate using intertemporal data. This study consequently does not rely on longitudinal analysis but, in common with most of the impact literature, depends on two other approaches instead. First, many studies have conducted controlled experiments to isolate the effects of temperature and carbon dioxide. The results are then incorporated into simulation models that predict future consequences from specific climate scenarios. We rely on simulation models to capture effects in agriculture, coastal structures, forestry and water. Second, some studies have examined cross-sectional differences between one climate zone and another. We rely on these empirical models to estimate both agriculture and energy impacts.

Most of the studies in this book rely on only one approach. However, given the prominent role of agriculture effects in aggregate outcomes, we rely on both experimental-simulation and cross-sectional methods for that sector. Both methods have strengths and weaknesses; however, since the strengths and weaknesses of the two methods are quite different, the methods serve as good checks and balances of each other. The experimental method, for example, isolates the effect of each stimulus, be it temperature, precipitation or carbon dioxide. The cross-sectional method relies on natural experiments and so is vulnerable to charges of misinterpreting causal agents. The experimental method explicitly models cause and effect and so satisfies a desire for logical connections between the stimulus and the final response. The cross-sectional approach relies on correlation and so does not provide causal insights. The cross-sectional method, however, includes all the responses by the system to being in a different climate. The simulation approach includes only what the analyst models. The cross-sectional approach consequently includes unknown responses such as changes in insects and actual changes in farmer behavior whereas the simulation approach must guess at these unmeasured factors. Thus, the simulation approach, by not examining all of the changes and particularly the adaptations, may overestimate the negative effects of climate change. In contrast, the cross-sectional approach, by assuming that all behaviors change, may overestimate the positive effects of climate change. Note that for systems such as agriculture, neither approach examines the costs and feasibility of rapid adaptation.

The point of the above argument is not to suggest one approach is superior to the other but rather to argue that using both methods is superior to relying on just one approach. If the results disagree, it is apparent that there are still important factors that one or both methods are not yet taken into account. If the results are quite similar, however, it suggests that there may be consensus about impact estimates (given the scenarios used).

Another important improvement in recent impact studies is the attention being placed on dynamics. The early literature focused primarily on comparative equilibrium studies, comparing conditions today with equilibrium conditions in a doubled CO₂ world. For some sectors that can adjust relatively quickly, such as agriculture, such equilibrium comparisons may provide reasonable insights into the effects of climate change. However, comparative static analyses of sectors with substantial capital stocks, such as timber and coastal resources, can be misleading. For these sectors, the dynamic path of the change is critical. There is every reason to believe that the damages in these sectors are ‘path dependent’ (Schneider 1997). Very rapid changes would cause substantial damages in these sectors, but very gradual changes may be easy to adapt to. In this study, dynamic models are used to examine timber and sea level rise in order to capture the effects of both the pace and the level of climate change.

REGIONS

We define regions in the continental United States to be consistent with the US National Assessment (National Assessment Synthesis Team 2000). We excluded Alaska, Hawaii and the US territories because they represent entirely different systems that were not analyzed in Mendelsohn and

Table 1.1 Regional definitions

<i>Region</i>	<i>States</i>
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
Midwest	Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin
Northern Plains	Kansas, Montana, Nebraska, North Dakota, South Dakota, Wyoming
Northwest	Idaho, Oregon, Washington
Southeast	Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia
Southern Plains	Oklahoma, Texas
Southwest	Arizona, California, Colorado, Nevada, New Mexico, Utah

Figure 1.2 Seven regions used in this study

Neumann. We are specifically interested in comparing regions in the southern half of the country with those in the northern half so that we can explore our hypothesis concerning the relatively beneficial and harmful impacts in colder and warmer areas. However, these divisions are not perfect in this regard because parts of northern latitude regions, such as the Northwest, are somewhat mild and areas in the southern regions, such as the southern Rocky Mountains, can be cool relative to the rest of the country. The National Assessment regions divide the country between the north and south except for the Great Plains. We further divided the Great Plains region into Northern and Southern Plains, where the Southern Plains include Texas and Oklahoma. The National Assessment also divided Montana, Wyoming and Colorado between two regions. In some sectors, we cannot divide states into smaller areas because of the absence of information, and so we placed these states into the region where most of their area fell. The regions are displayed in Table 1.1 and Figure 1.2.

One of the main hypotheses of this book is that climate impacts will vary depending on initial climate. To understand what this might mean for each region, Table 1.2 presents current winter and summer temperatures and precipitation in each region. The table reveals that the three northern regions – the Northeast, Midwest and Northern Plains – are all currently relatively cool, whereas the three southern regions – the Southeast, Southern Plains and Southwest – are all currently relatively warm. The table also reveals that the

Table 1.2 Current regional climate

<i>Region</i>	<i>Temperature (°C)</i>		<i>Precipitation (cm/month)</i>	
	Winter	Summer	Winter	Summer
Northeast	-2.03	22.42	5.77	7.29
Midwest	-6.66	22.62	3.14	7.15
Northern Plains	-6.77	23.46	1.10	4.92
Southeast	5.25	26.05	7.20	9.52
Southern Plains	5.96	28.07	3.45	5.01
Northwest	0.45	22.76	7.96	5.16
Southwest	1.04	22.51	4.27	2.04
United States	-0.2	23.5	4.9	6.7

Note: Winter is December, January and February and summer is June, July and August. Climate variables are 30-year averages.

Source: Data from Mendelsohn et al. 1999.

Table 1.3 Regional characteristics

<i>Region</i>	<i>Cropland (million acres)</i>	<i>Farm value (billion USD)</i>	<i>Timber supply (%)</i>	<i>Population (%)</i>	<i>GDP (%)</i>
Northeast	22.2	56.6	5.7	27.4	25.0
Midwest	119.9	262.0	5.7	25.7	21.0
Northern Plains	115.5	132.51	1.0	3.0	6.0
Northwest	21.3	42.9	25.8	3.1	4.0
Southeast	59.0	129.6	55.5	20.9	21.0
Southern Plains	60.2	126.7	0.2	6.9	5.0
Southwest	25.6	116.2	6.1	13.2	18.0
United States	423.7	866.5	100.0	100.0	100.0

Note: All values are for 1990, except farm value, which is in 1998 USD.

Source: Data from Mendelsohn et al. 1999.

Southwest, Northern Plains and Southern Plains are also drier than the other regions. Given the initial temperature conditions, greater damages are expected in the southern regions and greater benefits are expected in the northern regions.

The magnitude of impacts in each region is also likely to be related to the region's characteristics. Table 1.3 provides some basic background measures for each region in this study: cropland, farm value, timber supply, population and percentage of GDP by region. Regions with more of these basic elements are likely to have larger effects in corresponding sectors.

For some purposes, these regions are too large. One cannot see important impacts within some of the regions. For example, some of the vegetation studies that are the basis for the forestry analysis show vegetation productivity in the upper Southeast (particularly Kentucky and Tennessee) increasing while productivity in the lower South is decreasing. These dramatic differences in local areas can balance out for the region as a whole. Just as national results mask underlying effects in each region, regional results may mask significant changes in local areas. Whenever possible, we attempt to provide qualitative discussion of important variation within regions. Readers should be cautious not to assume that region-wide findings necessarily apply at the state or local level: impacts can vary within regions.

BASELINE SCENARIOS

The early impact literature generally examined climate change impacts as though they would happen to a 1990 economy, although a few studies such as Rosenberg (1993) did project into the future. The advantage of using a 1990 economy is that it is well understood. With a well-defined economic baseline, the impact measurement appears more precise. Climate change, however, is predicted to unfold over the twenty-first century. By focusing on a 1990 economy, the conventional impact studies obtained an accurate measure of the wrong phenomena. What we want to measure is the effect of climate change on our future world. Unfortunately, since it is difficult to determine what the future will look like, we must settle for an impact analysis based on an uncertain future scenario. This approach increases the sources of uncertainty. Key socioeconomic factors such as population, income and technology will change, all of which are likely to affect how climate change will affect the United States. Although focusing on the future is more uncertain, estimates of future impacts consider what society needs to have measured.

Mendelsohn and Neumann (1999) developed a scenario of economic conditions in 2060 from background research on population projections and economic growth. They assume that in 2060 the US GDP will be \$21.8 trillion (1998 USD) and the population will be 290 million. There is enormous uncertainty about the socioeconomic conditions in 2060. Who in 1940 could have imagined what life in 2000 would be like, with the information age, expanding service sector, declining manufacturing sector, globalization and modern government programs? We cannot accurately predict what life will be like in 2060, nor is it possible to know how future changes might affect each region. A baseline scenario is indeed a scenario, not a prediction. What is important to realize is that the economy will not resemble the current 2000 economy by the time that climate changes.

To get a sense of the importance of projecting forward, the sectoral studies in Mendelsohn and Neumann (1999) compared the climate impacts to both a 2060 economy and the 1990 economy. They found that the 2060 impacts were significantly larger than the 1990 impacts; however, the impacts as a fraction of GDP were the same. Baseline economic conditions consequently do matter. Further, under some scenarios of climate change, total welfare decreased with 1990 socioeconomic conditions but increased with 2060 socioeconomic conditions. In this study, we focus on the impacts to a projected 2060 economy. Readers should keep in mind that alternative baselines could affect the magnitude and possibly even the direction of the impacts.

CLIMATE CHANGE SCENARIOS

Mendelsohn and Neumann (1999) used uniform annual and national changes in temperature and precipitation. The same nine scenarios are used in this study and are displayed in Table 1.4.

Table 1.4 Climate change scenarios

<i>Scenarios</i>	
1	+1.5°C; 15% increase in precipitation
2	+1.5°C; 7% increase in precipitation
3	+1.5°C; 0% change in precipitation
4	+2.5°C; 15% increase in precipitation
5	+2.5°C; 7% increase in precipitation
6	+2.5°C; 0% change in precipitation
7	+5°C; 15% increase in precipitation
8	+5°C; 7% increase in precipitation
9	+5°C; 0% change in precipitation

Note: Scenario 1 is the mild scenario; scenario 5 is the central scenario; and scenario 9 is the harsh scenario.

Examining these scenarios is a sensitivity analysis. The analysis examines a range of outcomes that climate scientists think are plausible (Houghton *et al.* 1996). However, climate is not necessarily going to change uniformly across seasons and across the entire country. The IPCC predicts that there will be more warming in inland areas than in coastal areas, more warming in higher latitudes than in lower latitudes, more warming in winter than in summer and more warming at night than during the day. Precipitation is highly unlikely to change uniformly, because there will be variation by season and location. Actual changes in every region are not likely to be the same, even if we cannot predict how they will differ.

To address this problem, many studies of climate change impacts have used outputs from general circulation models (GCMs) because they provide plausible (although certainly not accurate) estimates of regional and monthly variation from climate change (for example, Smith and Tirpak 1989, National Assessment Synthesis Team 2000). There are three problems with using a limited set of GCM runs for impact assessment. First, it is difficult to compare results across models. It cannot be determined which of the many climate variables are responsible for observed effects, whether the average level of the variables are important or whether the distribution of these variables over space and season

is the most critical factor. The second problem is that each new GCM run produces a new set of results, displacing previous GCM runs. Impact studies based on old GCM outputs can quickly become out of date. Third, using such a small sample of GCM outputs does not necessarily provide a representative sample of climate outcomes.

Instead of relying directly on GCM outputs, this study examines a set of uniform climate change scenarios. Within each scenario, every location and every season is expected to experience the same climate change from their current condition. Mendelsohn and Neumann (1999) developed these uniform scenarios to examine a broad range of plausible changes. The scenarios capture a temperature range from 1.5°C to 5.0°C and a precipitation change from 0 per cent to 15 per cent (see Table 1.4). The temperature range compares closely with the range predicted by the IPCC for the twenty-first century of between 1.5°C and 4.5°C (Houghton *et al.* 2001), although warming in the United States may well be somewhat greater than global average warming (Wigley 1999).

These climate scenarios do not capture the full range of plausible climate changes that could occur over the coming century. The uniform scenarios do not permit regional variation in climate, nor do they allow the climate change to vary across seasons. In a recent comparison of the national impacts from the climate predictions of 14 GCMs, Williams *et al.* (1998) demonstrated that regional and seasonal differences lead to a wide range of impact estimates. The uniform scenarios do not reflect this range of outcomes; they do not project changes in interannual or diurnal variation. They show only the effect of average temperature and precipitation changes across a plausible range of climates.

The studies add these uniform changes to current climate as observed over a period of 20 to 30 years. Thus, as with many GCM-based studies, studies using uniform scenarios do not account for changes in climate variance, particularly the frequency and intensity of extreme events.

There are many advantages to using the uniform climate change scenarios. First, the scenarios are transparent and understandable. Unlike GCM output, the uniform scenarios translate easily to all locations and seasons. Second, the scenarios permit analysis of the sensitivity of the impacts to changes in temperature and precipitation. The effects of increasing temperature alone can be determined by examining results holding the change in precipitation constant (for example, at +7 per cent), and the effects of increasing precipitation can be determined by examining results when the change in temperature is held constant (for example, at +2.5°C). Third, the method makes it relatively easy to compute how the sector responds across climate outcomes. One can estimate climate response functions to changes in average annual temperature and precipitation from the results of the detailed studies (Mendelsohn

and Schlesinger 1999). Fourth, the scenarios will stand the test of time. Researchers in the future can use these impact results to estimate the consequences of new GCM predictions. The results are no longer tied to specific climate models and so they are more robust.

Of course, if the focus of future concerns becomes variations in climate outcomes across seasons or regions, the uniform scenarios would not be helpful. Because climate scientists do not yet agree upon how greenhouse gases affect climate variability (Houghton *et al.* 1996), the study did not examine the impact of climate variability. If climate scientists predict that greenhouse gases will change these features of the climate, these effects will have to be added to the results in this book.

It is possible that individual regions will be more sensitive to regional temperature change than to national temperature change. A benign (adverse) temperature change may be amplified if the climate changes were region specific and not national. For example, if a region enjoyed a warming that increased agricultural production and this warming did not occur nationally, prices might not fall. The welfare gain from the regional climate change would be larger than if the change were national. Welfare responses, for both good and ill, might be larger for regional climate variations.

For agriculture and timber, we consequently examined the sensitivity of individual regions to changes in their climate. We assumed that the entire nation would have a 2.5°C increase in temperature and a 7 per cent increase in precipitation (scenario 5, or the central scenario). Regions were examined separately and were assumed to be exposed to a scenario of +1.5°C and 15 per cent increase in precipitation (scenario 1, which is relatively mild and wet) and a scenario of +5.0°C increase in temperature and no change in precipitation (scenario 9, which is relatively hot and dry). We examined whether regional climate sensitivity exceeds national sensitivity and whether regional sensitivities vary.

STRUCTURE OF THIS BOOK

This book systematically measures the sectoral impacts in each region of the United States to the nine climate scenarios outlined above. Chapters 2 through 7 of this book consider the regional impacts of climate change on market sectors in the United States, following the format in Mendelsohn and Neumann (1999). Chapters 2 and 3 examine agriculture using an experimental-simulation approach and a cross-sectional approach. Chapter 2, by Richard Adams and Bruce McCarl, uses an agronomic-economic general equilibrium modeling approach, and Chapter 3, by Robert Mendelsohn, uses a cross-sectional empirical approach. Chapter 4, by Brent Sohngen and Robert Mendelsohn,

begins with ecological forecasts of changes in biomes and productivity and then uses a dynamic economic model to predict harvest, planting and management intensity. This model then estimates the welfare effects in timber markets over time. In Chapter 5, by Brian Hurd and Megan Harrod, economic models allocate water-given changes in runoff due to climate change. The welfare effects of these changes are measured for selected watersheds and then extrapolated to each region. James Neumann and Nicholas Livesay use an intertemporal economic model to examine the economically efficient response to sea level rise over time and the resulting damages in Chapter 6. In Chapter 7, Robert Mendelsohn uses cross-sectional analysis to estimate short-run and long-run changes in residential and commercial energy expenditures. The chapter then calculates the welfare effects from climate change in the energy sector.

Chapter 8 covers the potential effectiveness of adaptation to ameliorate the negative effects of climate change or to enhance the positive effects. This topic was addressed in each sector in Mendelsohn and Neumann (1999) but was not discussed as a whole, as we do here. It is critical not only for understanding the vulnerability of US market sectors to climate change but also to provide information to policy makers on what types of adaptations should be encouraged to reduce risks to climate change. The chapter makes the critical distinction between private adaptation (where the benefits of the change accrue to the person making the change) and public adaptation (where there are many people affected by the adaptation). The chapter discusses what actions government must take to encourage more efficient public adaptation.

Finally, Chapter 9 synthesizes the results. We examine the overall benefits and damages that occur across the United States under alternative warming scenarios. We focus on how these impacts are distributed across the regions and across sectors. We specifically test whether northern regions benefit more than southern regions and how these regional results are affected as temperatures warm. Finally, we note the importance of including impacts on consumers as well as producers, because the market spreads impacts across people from every region.

NOTE

1. Note that this study does not consider potential damages to natural ecosystems, endangered species, coastal wetlands or human health. This book evaluates only market sectors; a complete evaluation of climate change must include both market and nonmarket effects.

REFERENCES

- Adams, R.M., B.H. Hurd and J. Reilly (1999a), *Agriculture & Global Climate Change: A Review of Impacts to US Agricultural Resources*, Arlington, VA: Pew Center on Global Climate Change.
- Adams, R.M., B.A. McCarl, K. Segerson, C. Rosenzweig, K.J. Bryant, B.L. Dixon, R. Conner, R.E. Evenson and D. Ojima (1999b), 'Economic effects of climate change on US agriculture', in R. Mendelsohn and J.E. Neumann (eds), *The Impact of Climate Change on the United States Economy*, Cambridge, UK: Cambridge University Press, pp. 18–54.
- Cline, W.R. (1992), *The Economics of Global Warming*, Washington, DC: Institute for International Economics.
- Fankhauser, S. (1995), *Valuing Climate Change: The Economics of the Greenhouse*, London: Earthscan Publications Ltd.
- Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, D. Xiaosu and K. Maskel (eds), 2001, "Climate Change 2001: The Scientific Basis", Cambridge, UK: Cambridge University Press.
- Mendelsohn, R. and J.E. Neumann (eds) (1999), *The Impact of Climate Change on the United States Economy*, Cambridge, UK: Cambridge University Press.
- Mendelsohn, R. and M. Schlesinger (1999), 'Climate response functions', *Ambio*, 28, 362–6.
- Mendelsohn, R., W. Nordhaus and D. Shaw, 1994, "The Impact of Global Warming on Agriculture: A Ricardian Analysis", *American Economic Review* 84 (4): 753–71.
- National Assessment Synthesis Team (2000), *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, Report for the US Global Change Research Program. Cambridge, UK: Cambridge University Press.
- Nordhaus, W.D. (1991), 'To slow or not to slow: The economics of the greenhouse effect', *Economic Journal*, 101, 920–37.
- Pearce, D.W., W.R. Cline, A.N. Achanta, S. Fankhauser, R.K. Pachauri, R.S.J. Tol and P. Vellinga (1996), 'The social costs of climate change: Greenhouse damage and the benefits of control', in J.P. Bruce, H. Lee and E. F. Haites (eds), *Climate Change 1995: Economic and Social Dimensions of Climate Change*, Cambridge, UK: Cambridge University Press, pp. 179–224.
- Rosenberg, N.J. (1993), 'Towards an integrated impact assessment of climate change: The MINK Study', *Climatic Change*, 24, 1–173.
- Schneider, S. (1997), 'Integrated assessment modeling of global climate change: Transparent rational tool for policy making or opaque screen hiding value-laden assumptions?' *Environmental Modeling and Assessment*, 2, 229–49.
- Smith, J.B. and Tirpak, D. (eds) (1989), *The Potential Effects of Global Climate Change on the United States*, EPA-230-05-89-050, Washington, DC: US Environmental Protection Agency.
- Titus, J.G. (1992), 'The costs of climate change to the United States', in S.K. Majumdar, L.S. Kalkstein, B. Yarnal, E.W. Miller and L.M. Rosenfeld (eds), *Global Climate Change: Implications, Challenges, and Mitigation Measures*, Philadelphia: Pennsylvania Academy of Science, pp. 384–409.
- Titus, J.G., R.A. Park, S.P. Leatherman, J.R. Weggel, M.S. Greene, P.W. Mausel, S. Brown, C. Gaunt, M. Trehan and G. Yohe (1991), 'Greenhouse effect and sea level rise: The cost of holding back the sea', *Coastal Management*, 19, 171–204.

- Tol, R.S.J. (1995), 'The damage costs of climate change toward more comprehensive calculations', *Environmental and Resource Economics*, 5, 353–74.
- VEMAP (1995), 'Vegetation/Ecosystem Modeling and Analysis Project (VEMAP): Comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO₂ doubling', *Global Biogeochemical Cycles*, 9, 407–37.
- Watson, R.T., M.C. Zinyowera and R.H. Moss (eds) (1998), *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, Cambridge, UK: Cambridge University Press.
- Wigley, T.M.L. (1999), *The Science of Climate Change: Global and US Perspectives*, Arlington, VA: The Pew Center on Global Climate Change.
- Williams, L., D. Shaw and R. Mendelsohn (1998), 'Evaluating GCM output with impact models', *Climatic Change*, 39, 111–33.