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Edited by Gregory K. Ingram and Yu-Hung Hong

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The Impact of Climate Change on Land

Robert Mendelsohn

The steadily increasing level of greenhouse gas emissions over the past century has led to a gradually increasing stock of greenhouse gases in the atmosphere (IPCC 2007b). Climate scientists anticipate that if these gases continue to accumulate, they will increasingly warm the planet (IPCC 2007b). Although the precise magnitude of the warming is not known, global temperatures are expected to rise by 2–6°C (34–41°F) by 2100. This warming will in turn affect precipitation patterns, sea levels, and extreme weather events (IPCC 2007b). Although climate change will not be uniform across the planet, exactly how it will vary is uncertain. This chapter evaluates the implications of these climate change projections for land and land use; examines what will happen to land values across regions given these projections; explores how land use will change and landowners will adapt; and briefly discusses possible mitigation policies that might also affect land use.

Early analysts of climate impacts identified five sectors of the economy that are sensitive to climate change: agriculture, forestry, water, coastal, and energy (Pearce et al. 1996). All of these sectors except energy involve land. Agriculture and forestry are key land uses. Water is important to land because its availability affects the viability of agriculture through irrigation. In the coastal sector, sea-level rise might alter the land available along the coasts for urban and other uses. A number of other climate impacts that could affect the quality of life—such as ecosystem change, endemic disease, and heat stress—are also relevant to land and the enjoyment of it.

Early studies suggested that doubling the amount of carbon dioxide (CO_2) in the atmosphere could lead to global damages ranging from 1.4 to 1.9 percent of gross world product (GWP) (Pearce et al. 1996). These studies predicted that between one-third and two-thirds of the damages in the United States could be attributed to impacts on land: agriculture, forestry, water, sea-level rise, outdoor recreation, lost species, and tropical cyclones (Pearce et al. 1996). Without global mitigation, CO_2 concentrations could double as early as 2040, although it would take global temperatures another 30 years to reach their equilibrium values (IPCC 2007b).

More recent estimates of the market impacts of climate change suggest much lower global damages of between 0.05 and 0.5 percent of GWP by 2100 (Mendelsohn, Dinar, and Williams 2006; Mendelsohn and Williams 2004; Tol 2002). Estimates of the damages to land range from 25 to 75 percent of market damages. Damages to nonmarket goods and services, such as loss of endangered species and potential health effects, are not included in these estimates. Although estimates of the costs of nonmarket changes are not available, if one substituted the management costs required to offset these changes, the nonmarket damages are not likely to be larger than aggregate market damages. This suggests that the total net annual damages from unmitigated climate change will be between 0.1 and 1.0 percent of GWP by 2100. The more recent damage estimates are much lower than the early ones because the initial estimates did not include benefits of warming, underestimated adaptation, and failed to account for the relatively slow growth of climate-sensitive sectors.

This chapter first evaluates the market impacts of climate change on land. It critically reviews studies of these climate-sensitive market sectors (agriculture, water, forestry, coastal, and extreme events) and explains why different methodologies that measure the same impacts can lead to different results. Evidence concerning the impact of changes in mean temperature and precipitation, as well as changes in the variance of these variables, is reviewed.

The chapter then turns to impacts on nonmarket sectors, including ecosystems, endangered species, public health, and climate preferences. Ecosystems are expected to shift poleward and to higher altitudes. This shift will lead to some ecosystems expanding and others contracting, with many local areas on the edges of ecosystems seeing dramatic changes. The process of change may affect endangered species that cannot easily adapt to changing climate conditions. In addition, certain vector-borne diseases may expand their domains, affecting public health, and heat stress and changes in ozone levels may have other health effects. Recreational opportunities are likely to be affected by all these changes.

Two forms of adaptation—private and public—are explored. Private adaptation is employed by individuals, farms, and firms for their own benefit. As climate change alters the relative attractiveness of different ways of using land, landowners will adapt. Market land will expand and contract in different places. Land also will move between agriculture and forestry. Within agriculture, land will move between crops and grazing. Within cropland, farmers will switch crops, and within grazing land farmers will switch animals. Even farmers growing specific crops will switch varieties, inputs (such as fertilizer), and timing. These adaptations are inherently local and will vary substantially across the landscape.

Efficient adaptations must be carefully timed to match actual climate impacts. In practice, many private adaptations can be done concurrently with climate change as it actually unfolds. In cases involving long-lived capital, however, private adaptation must anticipate future expected changes and cannot simply react to observed changes as they occur.

Public adaptation addresses climate impacts that affect multiple actors. In general, public adaptation requires that government entities consider changes in land management, water management, and research and development to assist market-based adaptation. Many public adaptation policies involve long lead times and must be initiated in anticipation of climate change. Consequently, governments may not have the luxury of simply waiting until climate changes before considering what to do.

In addition to adaptation, the chapter looks at mitigation efforts that could affect land and summarizes the main findings and conclusions.

Market Impacts

Six sectors of the global economy are climate sensitive: agriculture, water, forestry, coastal, extreme events, and energy. Only the first five deal with impacts on land. Agriculture is covered in more detail in this section because it potentially can lead to the largest effects.

AGRICULTURE

The largest climate-sensitive sector is agriculture. Both natural science experiments and economic analyses suggest that crop yields have a hill-shaped relationship with temperature and precipitation. There is an ideal temperature and precipitation level for every crop. Locations that are either cooler or warmer than the ideal, or drier or wetter, have lower productivity. Some crops are more valuable than others. The temperature and precipitation levels that produce the most valuable crop lead to the most net revenue. If a farm is either cooler or warmer than that ideal, or drier or wetter, it may be forced to grow a lower-valued crop. Consequently, net revenue also has a hill-shaped relationship with temperature and precipitation (Mendelsohn, Nordhaus, and Shaw 1994). The effect of a small amount of warming depends on where a farm is with respect to this hill-shaped function. If a farm is too cool to start with, then warming will lead to benefits because it will push the farm closer to the optimum. If a farm is close to the optimum to start with, warming will have little effect because the farm will still be close to the optimum. However, if a farm is too hot at first, warming will reduce net revenue because it will drive the farm even further away from the optimum. Climate change will therefore have very different impacts on low-latitude (hot), mid-latitude (optimal), and high-latitude (cool) farms (IPCC 2007a; Mendelsohn and Dinar 2009). In addition, there may be very different effects depending on whether an area is arid, of average rainfall, or wet and whether that area receives more rainfall or less. The result is that warming can lead to myriad effects across a landscape.

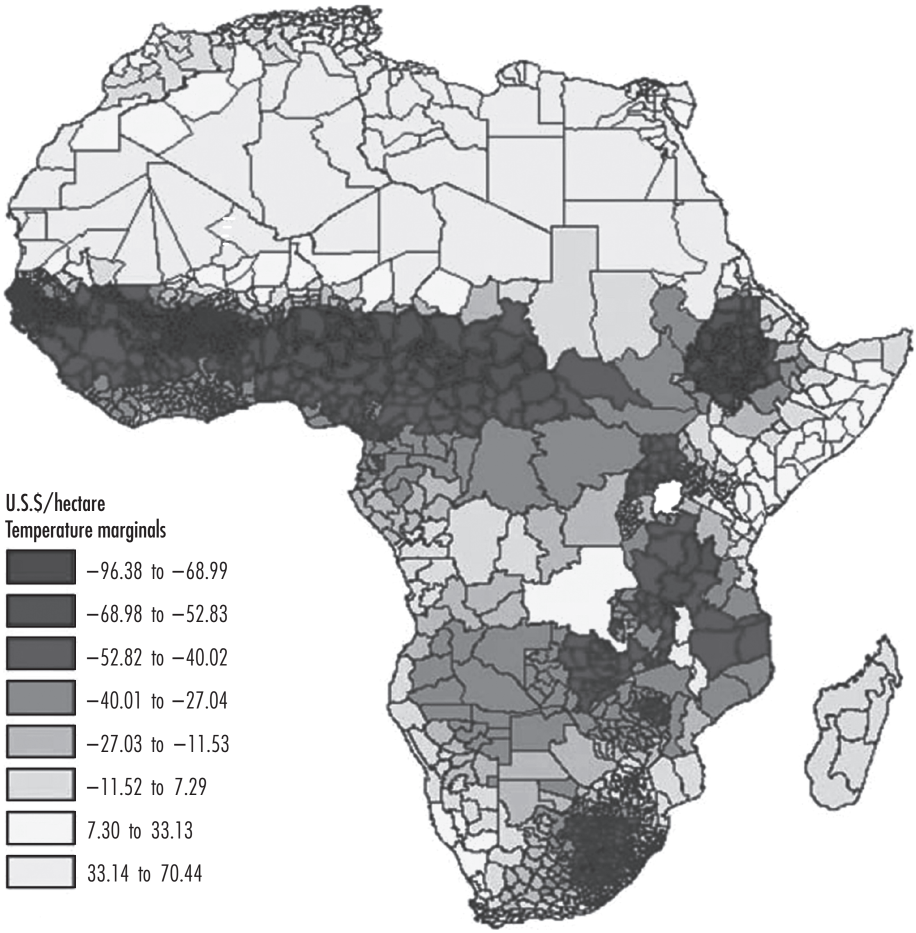
As warming continues, farms will continue to change their position along the climate gradient. Eventually, there will be no more benefits for the farm that was originally too cool. Similarly, the farm that was originally optimal will start incurring more damages. The farm that was originally too hot may eventually be driven out of agriculture.

Agronomic studies of climate change suggest that warming scenarios will be especially harmful in low-latitude areas (Iglesias and Minguez 1996; IPCC 2007a; Rosenzweig and Parry 1994). The crops grown in these areas are more sensitive to further warming because it is already quite hot in these places. Cross-sectional analyses of net revenue suggest a very similar pattern. Studies done in Brazil and India (Mendelsohn, Dinar, and Sanghi 2001), Sri Lanka (Seo, Mendelsohn, and Munasinghe 2005), eleven countries in Africa (Kurukulasuriya et al. 2006), seven countries in South America (Seo and Mendelsohn 2008a), and China (Wang et al. 2009) all suggest that warming will be harmful to farmers in low latitudes. In contrast, studies done in cooler countries show either mixed effects or benefits. For instance, many studies of the United States and Canada predict small benefits, and only a few predict losses (Adams, McCarl, et al. 1999; Adams, Rosenzweig, et al. 1990; Deschenes and Greenstone 2007; Easterling et al. 1993; Mendelsohn and Dinar 2003; Mendelsohn, Nordhaus, and Shaw 1994; Reinsborough 2003; Schlenker, Hanemann, and Fisher 2005, 2006). Studies of the United Kingdom (Maddison 2000) and Germany (Lippert, Krimly, and Aurbacher 2009) predict benefits from warming.

Despite similarities across methods, there is a general difference between agronomic and economic studies in the predicted magnitude of effects. Agronomic research tends to find that warming will lead to larger overall effects. This research is based on the assumption that farmers will continue to do what they have always done. In contrast, many of the economic studies have explored the consequences of private adaptation (a subject covered later in this chapter). Whereas the agronomic studies reveal the potential damages (if there is no adaptation) that will be caused by climate change, the economic studies reveal the actual damages (with adaptation).

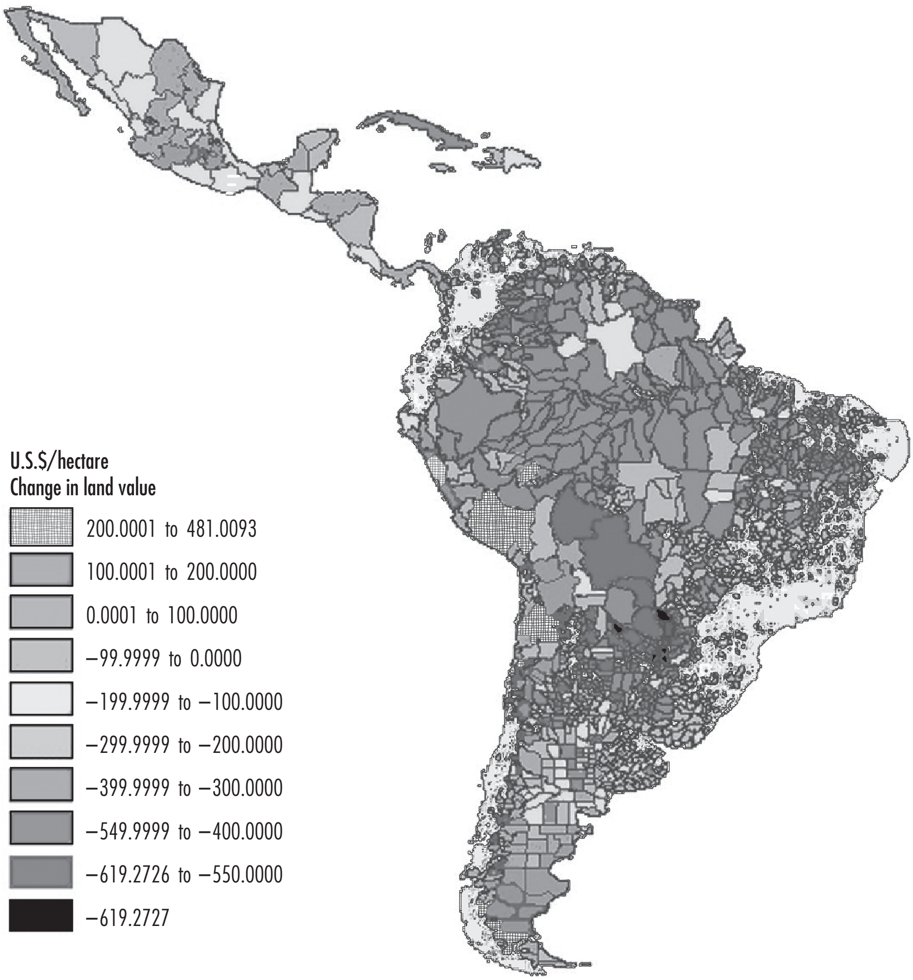
Even within broad regions defined by latitude, a wide dispersion of impacts is expected to take place across the landscape, depending on local conditions such as altitude, proximity to the ocean, and precipitation patterns. For example, a marginal increase in temperature throughout Africa would have widely varying effects on net revenue per hectare, as shown in figure 4.1. Warming along the Sahel or in eastern Africa would cause greater damages because these areas are already quite hot. Impacts across regions also would vary because of differences in underlying climate changes. Figure 4.2 shows a climate scenario in Latin America in which the impacts would vary a great deal across the landscape. Some of the effects, such as those near the equator, can be explained by the warmer

Figure 4.1
Impact of a Marginal Change in Temperature on Net Revenue per Hectare Across Africa



Source: Mendelsohn and Dinar (2009). Reprinted with permission of Edward Elgar Publishing, Ltd.

Figure 4.2
Impact of Climate Change on Land Values of Large Farms in Latin America Using CCC Climate Scenario for 2100



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initial temperatures there. Others simply reflect how climate change itself varies across the landscape.

Impacts also are expected to vary from one climate scenario to another. A mild and wet scenario could lead to an increase in agricultural annual net revenue in Africa of US$69 billion, but a severe and dry scenario could lead to losses of US$144 billion (Kurukulasuriya and Mendelsohn 2008b). Similarly, in Latin

America a milder climate scenario could lead to losses of only 12 percent of agricultural land values, but a harsh climate scenario could lead to losses of more than 50 percent of land values.

Whether farms in a particular area are fed by rainfall or are irrigated also will affect the impacts. Farms in the eastern half of the United States, which are fed by rainfall, will be more sensitive to warming than farms in the entire country (Schlenker, Hanemann, and Fisher 2005). African rain-fed farms will be more sensitive than irrigated farms (Kurukulasuriya and Mendelsohn 2008b), as will Chinese rain-fed farms (Wang et al. 2009). In fact, as shown in figures 4.3 and 4.4, warming will reduce the net revenues of rain-fed farms in China but increase the net revenues of irrigated farms there. Provided that there is adequate

Figure 4.3
Impact of Marginal Temperature on Net Revenue per Hectare for Rain-Fed Farms in China

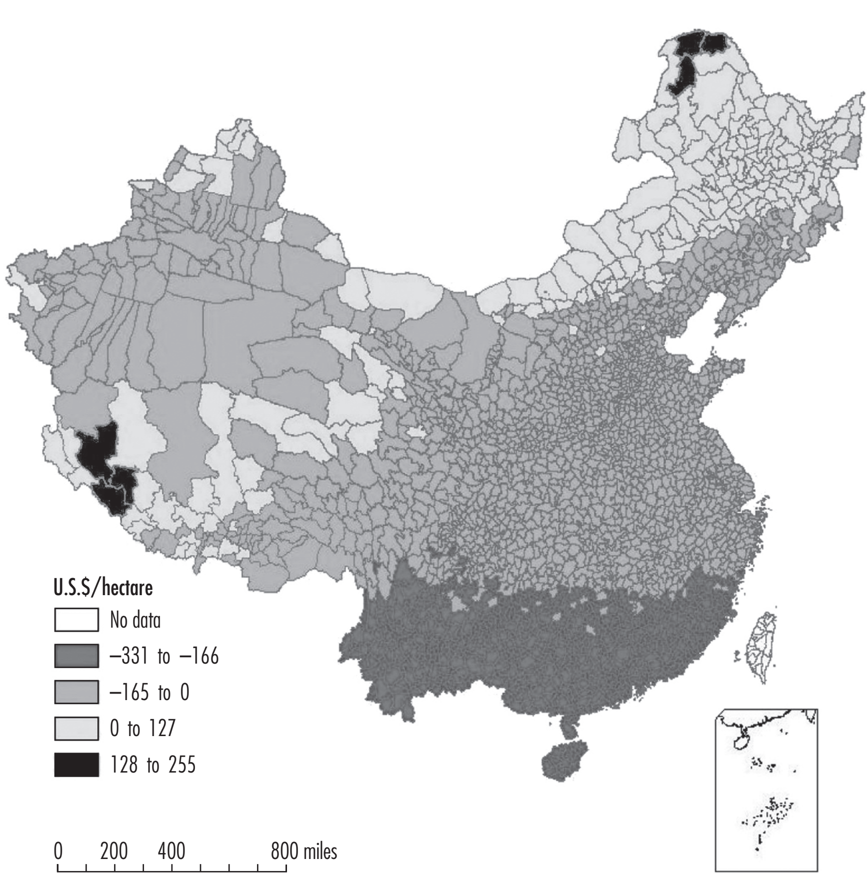

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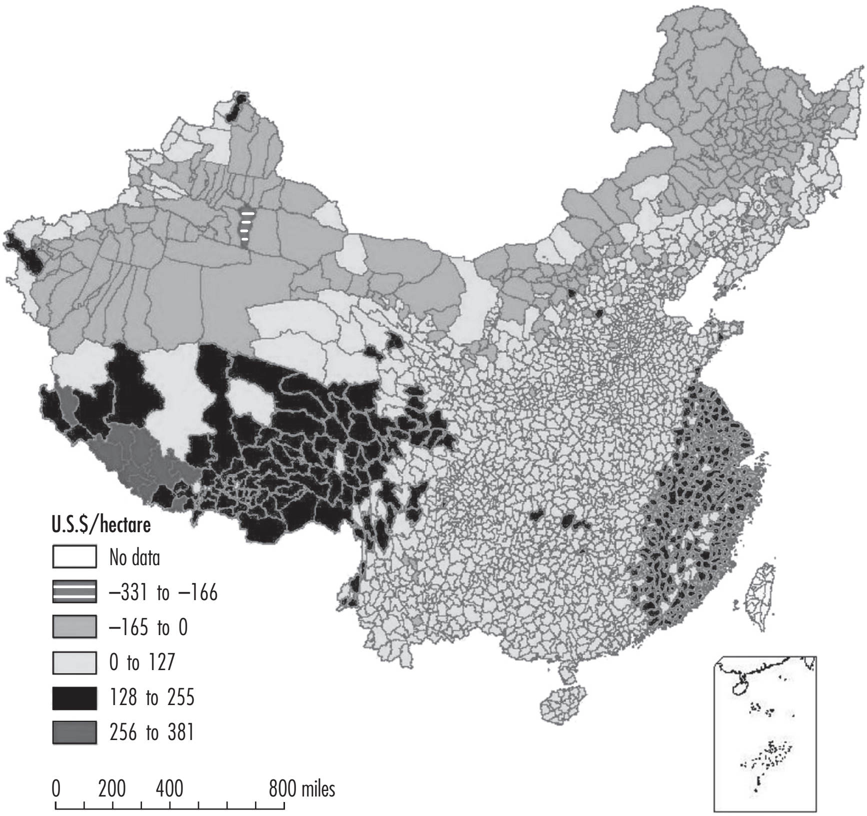
Figure 4.4
Impact of Marginal Temperature on Net Revenue per Hectare for Irrigated Farms in China



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water for irrigation, irrigated farms will be able to compensate for the higher temperatures and take advantage of the longer growing season to produce two harvests each year. At least in the case of marginal temperature changes in China, the gains of irrigated farms will offset the losses of rain-fed farms.

Agriculture is vulnerable to more than just changes in the annual mean of temperature and precipitation. It is also vulnerable to how those changes are spread across seasons. For example, higher temperatures in the spring and fall can extend growing seasons, but higher temperatures in the summer can lead to crop stress (Mendelsohn, Nordhaus, and Shaw 1994; Schlenker, Hanemann, and Fisher 2006). Interannual temperature variance also has effects (Mendelsohn, Nordhaus, and Shaw 1999). Higher interannual variance during the growing season leads to losses, whereas higher interannual variance during winter leads to gains. Farmers cannot adapt to variance once they commit to planting, but they can adapt to changes in winter weather by changing crops and planting dates. Diurnal (within the day) variance also matters (Mendelsohn, Nordhaus, and Shaw 1999). Diurnal variance generally increases damages, but it is beneficial in the fall, when it signals many crops to ripen.

Finally, agriculture will be directly affected by rising CO_2 levels in the atmosphere. Plants can reduce the opening of their stomata in higher-CO_2 settings, which can in turn reduce their vulnerability to water and increase their productivity. How much productivity can increase is contentious. Laboratory experiments suggest an average increase in yields of 30 percent (Reilly et al. 1996), but experiments in open-field settings suggest much lower returns (Long et al. 2005).

WATER

Rising temperatures are expected to increase the hydrological cycle, leading to more evaporation and more rain (IPCC 2007b). Where that rain will fall is not clear. Many studies suggest that warmer temperatures also may reduce runoff (IPCC 2007b), which will result in lower water supplies (IPCC 2007a). In addition, these studies suggest that the demand for water will increase with higher temperatures (IPCC 2007a). Combining decreased supply with increased demand, researchers predict that water will become scarcer (Hurd et al. 1999; IPCC 2007a; Lund et al. 2006).

How harmful this scarcity is will depend on whether water is reallocated from low-valued to high-valued users. In many places in the world, water is scarce for high-valued urban and industrial users, despite the fact that they are willing to pay more for water than low-valued users. Yet the largest proportion of water is used by relatively low-valued agriculture (irrigation). If all consumers must reduce their use proportionally with reductions in supply, there will be large welfare effects for urban and industrial users (Hurd et al. 1999). However, if water is reallocated from low-valued agriculture to high-valued urban and industrial users, the welfare effects will shrink dramatically (Hurd et al. 1999). For example, an analysis of California revealed that shifting water away from low-valued agriculture in the Central Valley was sufficient not only to protect urban and industrial users in California, but also to protect high-valued crops (Lund et al. 2006).

Such adaptations in the water sector will have implications for land, at least in semiarid locations. Farmers who depend on water for irrigation may find that they have less water per unit of land. This will force some farmers to adopt more water-saving techniques, such as drip irrigation. It will force other farmers to shift from irrigated to rain-fed agriculture and possibly to livestock.

FORESTRY

The combination of rising temperatures and higher CO_2 levels is expected to have several major effects on trees. First, ecosystems are expected to shift poleward and toward higher elevations. This will cause some ecosystems, and therefore some timber types, to expand and others to contract. Second, this dynamic process is expected to cause dieback in some places and the disappearance of entire forests in others. There is a general expectation of a large expansion of boreal forests into the tundra in the far north, as well as losses of tropical and temperate forests to savanna. Third, forests are expected to increase in productivity. Overall, the ecological expectation is that natural forest land will expand and be more productive in most climate scenarios for the next century.

Modeling the impact of climate change on forests is more difficult than modeling the impact on agriculture because forests are long-lived assets. It is not appropriate to model forest effects using a purely comparative static approach. The dynamics of forest adjustment to climate change must be taken into account. It is also important to capture how the economy will adjust over time to changing timber types and growth rates. Research on these dynamics is still in the early stages, and there is not yet any model that combines the ecosystem dynamics caused by climate change with the economic effects. The best effort to date used a comparative static (equilibrium) ecological model, generated an artificial dynamic scenario, and then combined that with a dynamic economic model (Sohngen, Mendelsohn, and Sedjo 2002). This study predicted a gradual increase in timber supply over time as productivity increases overshadow losses from dieback. Timber prices will gradually fall, leading to global benefits. In one climate scenario, low-latitude forests will expand relatively more than high-latitude forests, but in another scenario, the opposite will occur. The net gains in present value to society will range from US$100 billion to US$250 billion. Note that some of these welfare gains will be due to reductions in prices, so they will be shared between consumers as well as producers of wood products.

COASTAL

Sea level is expected to rise for two reasons. First, global warming will expand seawater, which is expected to result in a sea-level rise of 0.3–1 m (1–3.3 ft.) by 2100 (IPCC 2007b). Second, warming will cause land-based glaciers to melt, which will release water into the oceans. Of course, more water is also expected to be held in the atmosphere, so that not every cubic meter of meltwater will end up in the ocean. Nonetheless, very long-term models of Greenland suggest that the ice sheet could disappear completely after several centuries of warming, which could lead to a staggering increase in sea level of 7 m (23 ft.) (IPCC 2007b).

Coastal land is obviously vulnerable to sea-level rise. One important question is whether to allow coastal land to be inundated or to protect it with seawalls. There are even methods of building undersea retaining walls that have been used to reclaim land from the sea. Seawalls can be expensive. The question is whether the value of the land that is protected is greater than the cost of the seawall. Economic analyses of this issue suggest that developed land on U.S. coasts would be worth protecting (Neumann and Hodgens 2006; Yohe, Neumann, and Marshall 1999). Lower-valued land, however, would probably be inundated, which would lead to a loss of agricultural and forest land along the coasts.

EXTREME EVENTS

Climate change may change the nature of extreme weather, events such as tropical cyclones, thunderstorms, droughts, and floods. Studies by natural scientists suggest that the intensity of tropical cyclones may increase, at least in the North Atlantic and western Pacific (Emanuel, Sundararajan, and William 2008). Using a nonlinear damage function, economic analyses suggest that damages from tropical cyclones in the United States will double by 2100 (Nordhaus 2010). Climate scientists also estimate that thunderstorms in the United States will be about 70 percent more frequent with warming (Trapp et al. 2007). This will likely increase damages from these storms proportionally. Though not yet quantified, increased damages from floods, droughts, extratropical storms, and heat waves are all considered likely (IPCC 2007a).

Extreme events could have an effect on land if they systematically increase in frequency or intensity in specific places. Capital-intensive land uses are much more vulnerable to intense storms. Increasing harm from such storms may push landowners to decide that such land is better suited for low-capital uses such as agriculture. For example, low-lying coastal land subject to tropical cyclones may become better suited for farming than for suburban development. Drought-prone land may become better suited for grazing than for raising crops.

Nonmarket Impacts

In addition to impacts on the economy, climate change is likely to affect people's quality of life. For instance, as ecosystems shift, some plants and animals may be lost as species endemic to a specific location find it hard to move to new locations. Some scientists warn that there could be massive losses of species associated with even relatively modest warming. The Intergovernmental Panel on Climate Change (IPCC) argues that 20–30 percent of species are likely to be at risk of extinction if warming exceeds 1.5–2.5°C (2.7–4.5°F) (IPCC 2007a, 11). The shifting of ecosystems also may bring disease, as some vector-borne pathogens may move into new territory (IPCC 2007a). Heat stress might increase as a result of more intense or more frequent heat waves. And some outdoor recreational activities, such as skiing, will be curtailed.

It is difficult to place a value on the damages resulting from such changes. It is not clear whether people living in 2100 would prefer the ecosystem they grew up in or the ecosystem that existed in 2000. For example, people living in Connecticut or Massachusetts today would not like to see their forests cut down to make the current landscape look like the farming landscape of the nineteenth century.

Valuing the loss of species is quite difficult. One strategy to value endangered species is to determine what it would cost to protect them. The same strategy could be used to value desired species in the face of climate change. The protection cost would then be the damages resulting from climate change. Similar strategies could be used to value the potential loss of life from disease or heat stress. The cost of the public health response needed to address these problems could be a measure of the damages.

There are well-developed techniques to value recreation. By examining how much travel cost that visitors are willing to spend to get to sites, travel cost studies can value the loss of specific sites and even systems of sites (Mendelsohn and Olmstead 2009). Early studies clearly identified the loss of ski resorts as a cost of global warming (Pearce et al. 1996). More recent studies, however, have noted that the bulk of outdoor recreation occurs in the summer, meaning that warming would actually be a boon to recreation (Loomis and Crespi 1999; Mendelsohn and Markowski 1999). Indeed, outdoor recreation and tourism in general are expected to benefit from warming. Note that tourist destinations such as Disneyland and Disney World were intentionally built in warmer climates, and a large proportion of travel is based on going to warm places such as southern Europe and the Caribbean.

Private Adaptation

Private adaptation refers to actions that a decision maker takes to accommodate climate change that will benefit only herself. Because she is the beneficiary, she has every incentive to make choices that will maximize her own welfare. If efficient adaptation is defined as performing all actions that maximize welfare, there is every reason to expect that private adaptation will be efficient.

There are many examples of private adaptation in market sectors. In agriculture, for example, virtually all the decisions that a farmer makes about output and inputs could be adjusted to accommodate climate change. For example, he could expand or shrink the amount of land he has in agriculture; shift land among crops, grazing, and forests; select different crops to grow or different livestock to raise; change the amount or type of fertilizer and irrigation used; adapt the timing of planting and harvesting; or change the equipment used on the farm.

Several studies have shown that farmers already make many of these adjustments in response to climate conditions. Farmland as a fraction of all land is higher in more productive climates (Mendelsohn, Nordhaus, and Shaw 1996). Farmers in Africa (Kurukulasuriya and Mendelsohn 2008a), South America (Seo and Mendelsohn 2008b), and the United States (Adams, McCarl, et al. 1999; Adams, Rosenzweig, et al. 1990) often switch crops depending on local temperature and precipitation levels. They also switch livestock species depending on climate (Seo and Mendelsohn 2008c).

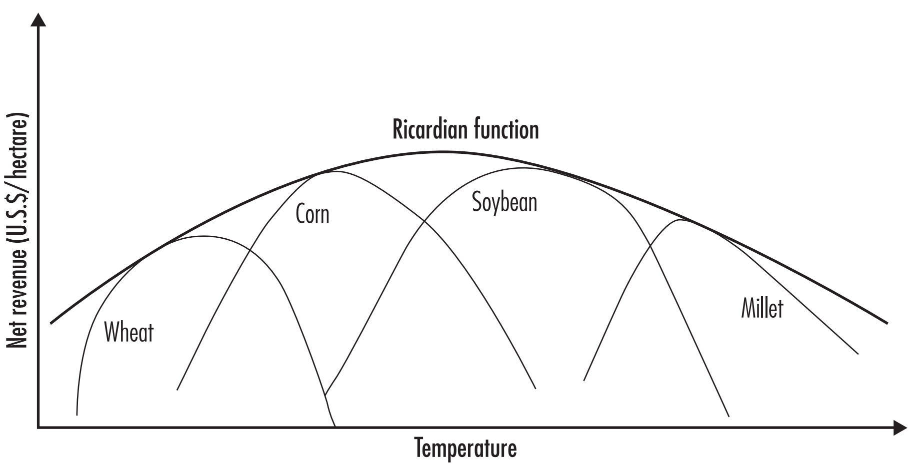
One of the important insights of this empirical literature is that private adaptation is local: each individual and each farm adapts to the local climate. Thus, private adaptation is bottom-up. The outcome is the result of myriad small decisions that are made individually. Adaptive actions will vary dramatically across the landscape, depending on the types of farms, climate changes, and opportunities to adjust in each location. Efficient private adaptation does not resemble a uniform response, but rather a patchwork of actions that vary from place to place.

Private adaptation aims to reduce the damages that otherwise would occur. For example, if a farmer was forced to stay with his current crop, warming could lead to large immediate damages, because yields of that crop depend on a narrow temperature range. If, however, he was allowed to switch crops, he could offset the potential damages and would be better off. In some cases, this could lead to an overall increase in net revenue if it permitted the farmer to select a more profitable crop (see figure 4.5). Crop switching on a yearly basis would likely entail high adjustment costs, because of the machinery and other fixed costs associated with each crop (Kaiser et al. 1993). However, most farm machinery has a relatively short life and must be replaced about every 10 years. Thus, crop switching every 10 years would cost the farmer almost nothing.

One complication of adaptation is that it must respond to actual climate change. If farmers were forced to construct complex models of future climate change in order to adapt, the process of adjustment might be quite costly (Kelly, Kolstad, and Mitchell 2005). However, if farmers simply wait for climate change to occur and then adjust to what they observe, they will remain very close to the actual climate at each moment in time. Presumably, the cost of keeping track of climate change as it unfolds will be relatively cheap compared to forecasting change.

It is more difficult to adapt in more capital-intensive sectors. For example, many trees are grown for decades before being harvested, making it impossible

Figure 4.5
Economics of Crop Switching



for forest owners to adjust to climate change at each moment in time. Instead, they must rely on climate and ecological forecasts to anticipate what adjustments should be made. But even forest owners can adapt by planting fast-growing trees to fill immediate gaps in stock and slow-growing trees to take advantage of future conditions. In anticipation of climate change, they can also harvest trees that are vulnerable to dieback and plant species that will be more suited to future conditions. All of these adjustments can reduce damages and increase benefits (Sohngen, Mendelsohn, and Sedjo 2002).

Similar adjustments can be made regarding coastal resources, by building seawalls in advance of when they are needed and by depreciating capital that is about to be inundated (Neumann and Hodgens 2006; Yohe, Neumann, and Marshall 1999).

Public Adaptation

Public adaptation concerns adjustments to climate change that involve multiple beneficiaries. The decision maker has to take into account not only the costs but also the benefits to many actors. Public adaptation is much more difficult to organize than private adaptation, and market forces tend to underprovide public adaptation. Governments at the local, regional, national, and international levels have the primary responsibility for public adaptation. As with private adaptation, public adaptation should be efficient—that is, it should maximize net benefits. Whether the net benefits come from avoiding potential damages or exploiting potential new opportunities, the adaptive actions should make people better off.

A recent government study of adaptation ignores the concept of efficient adaptation (World Bank 2010). As a result, the study vastly overestimates the adaptive actions that should be taken over the next century to offset potential climate change. Many of these measures would make society worse off, not better off, because they have low benefits and high costs. For example, the study recommends building seawalls by 2050 that would prevent sea-level rise not expected until 2100. Building seawalls 50 years before they are needed vastly inflates the cost (at a 4 percent interest rate, by more than sevenfold). The study recommends adapting to extreme events by giving women more years of formal schooling, although this would likely have only a very small effect on reducing the damages from floods and tropical cyclones. The only adaptive action the study advises to prevent water shortages is to build more hard structures, such as dams and canals. Many of the measures above cannot be justified on a cost-benefit basis.

Many public adaptations address the nonmarket impacts of climate change. If ecosystems shift, threatening endangered species, the protection of those species benefits many people. Although preventing climate change is one way to reduce this threat, society can take other actions as well. For example, it can reduce pressures on these species from other causes, such as pollution, habitat encroachment, and hunting. One option is to develop dynamic habitat programs that shift protected areas as climate change occurs, enabling each species to have a minimum habitat at all times. Another is to improve the chances that a species will survive by encouraging breeding, increasing food supplies, and reducing natural predators. These measures are costly, but they may neutralize the enhanced risk to species loss resulting from climate change.

Another obvious public adaptation issue is public health. Although there have been extensive studies showing that certain diseases, such as malaria and dengue fever, could expand their territories with warming, no studies have addressed public health measures that might be taken to eliminate this threat. Many countries, including the United States, have eliminated malaria with effective mosquito control and medical care. It is estimated that the cost of preventing the spread of malaria is actually quite low. Thus, it is quite clear that public health expenditures to prevent the spread of this and other diseases would be an efficient adaptive measure.

Public adaptation also is needed to protect market sectors. The allocation of water must be revisited if the water supply drops or the demand for water increases. Moving water from low-valued to high-valued users will be far cheaper than building new dams or canals, although there may be circumstances under which new hard structures are needed. The primary low-valued user is agriculture. In some situations, mining is another low-valued user. Farmers may have to learn to use less water by restricting irrigation to high-valued crops and by using irrigation technologies that consume less water, such as drip irrigation. A study of California found that just by eliminating low-valued crops, farmers could reduce water use by 24 percent, and they would lose only 6 percent of their net revenue by doing so (Howitt and Pienaar 2006).

Another very important public adaptation concerns the creation of private property rights in locations dominated by common property ownership (Mendelsohn 2006). Whether the resource is fisheries, grazing land, farmland, or forests, pervasive evidence shows that common property management underinvests in natural resource capital: fisheries are overharvested, grazing land has too many animals, forests are understocked, and farmland is undercapitalized. As long as people share ownership of these resources, they will not sacrifice short-term gains for long-term benefits. The conversion of economically active land to private property would not only make them more efficient today, but it would also give people incentives to engage in private adaptation in the future.

Sea-level rise is expected to inundate coastal areas. As mentioned earlier, seawalls are an efficient adaptive measure to prevent inundation of developed land (Neumann and Hodgens 2006; Yohe, Neumann, and Marshall 1999). However, seawalls require coordination; an entire coastline has to be protected for a seawall system to be effective. The timing of the construction of these walls also must match the advance of the sea. At the moment, there is considerable uncertainty about how climate change will affect sea levels in 2100 or later. Given that uncertainty, the most efficient approach is to plan to build walls in response to observed sea levels, making them adjustable so that they can be heightened as needed.

It may not be possible or desirable to build seawalls in all locations. Seawalls could not preserve beaches, for example. For small changes in sea levels, it may be sufficient to engage in beach nourishment to protect and replace existing sand. For larger changes in sea levels, undersea containment walls might be built to raise the effective height of the beach. Care must be taken, however, not to create dangerous currents and exposed structures. In many locations, the ideal adaptation may be retreat. Marshes, mangroves, and beaches could all move inland in response to higher seas. Planning can ensure that these coastal ecosystems have sufficient inland space for retreat.

Another public adaptation is the use of research and development to, for example, create new plant and animal species that would be more suited for a warmer world. New ways to cope with warmer temperatures also could be developed. Innovations might include new shelter systems for crops, new housing for animals, and new fertilizers and feed that would help plants and animals thrive in a warmer world. Research and development also may find better methods of building seawalls and structures to withstand extreme events. Current analyses of adaptation tend to rely only on existing technologies, but as adaptation becomes widely needed, research and development can create new technologies that will allow society to adjust to climate change.

Mitigation

The bulk of mitigation options involve reducing the burning of fossil fuels, especially coal. One way this can be done is by increasing reliance on renewable energy. Many renewable energy options require land. The two most land-intensive options are solar photovoltaics and biomass energy. To replace 1 gigaton (1 billion tons) of CO_2, 2 million hectares (5 million acres) of land are needed for photovoltaics and 250 million hectares (600 million acres) for biomass energy (Pacala and Socolow 2004). The photovoltaics would ideally be placed near the equator in places with a great deal of sunshine. These locations tend to be deserts, so they have few competitive land uses. What would be lost is the conservation value of the land. The biomass program would be much larger and more likely to compete with agriculture and forestry. Although scientists have talked about using plankton and grasses as biomass, the most viable sources at the moment are crops, specifically corn and sugarcane. Early attempts to build an ethanol industry have relied entirely on arid land that would otherwise be used for high-valued crops. Although using a small fraction of this land for biomass rather than food crops would have no effect on land prices, a large biomass program would clearly contribute to the depletion of land and water resources. Given that there is about 1.1–1.5 billion hectares (2.7–3.7 billion acres) of cropland worldwide, replacing 1 gigaton of CO_2 would require diverting between one-sixth and one-quarter of all cropland to biomass, which would significantly reduce global food production and increase food prices. In other words, the biomass solution may be worse than the problem it is intended to solve.

Another source of biomass energy is wood. Many people in the world, especially rural people, already rely heavily on wood for fuel. To expand its use, people would need to harvest a great deal more wood. Although this might be viable in a few places where there is an extensive wood supply and few people, most of the world's forests could not sustain extensively increased harvesting. Given that maintaining and even increasing the stock of wood (and therefore carbon) in existing forests is an important mitigation strategy, increased harvesting may be counterproductive. It would almost certainly be to the detriment of the conservation value of forests. Again, using forests for energy may be worse than the problem it is intended to solve.

A final use of forests would be to store carbon, which trees extract from the CO_2 in the atmosphere. By extending the rotation ages of forests, more carbon could be stored in them. Rotation ages could be extended by paying forest owners to store carbon rather than cutting their trees for profit. There is an opportunity cost of lengthening forest rotations. The value of forests for timber falls as rotations lengthen, so that forest owners would have to be compensated in order to increase the desired aggregate amount of carbon stored. The price per ton of CO_2 would have to be US$17 to store 40 gigatons (Sohngen and Mendelsohn 2003), US$51 to store 100 gigatons (Sohngen and Mendelsohn 2003), and US$400 to store 350 gigatons (Sathaye et al. 2007).

Conclusions

Accumulating greenhouse gases could have widespread effects on land across the planet. In fact, most of the impacts of climate change can be viewed as impacts on land. Agriculture and forestry are two economic activities that are both land intensive and climate sensitive, making them vulnerable to climate change. Coastal areas will be vulnerable to sea-level rise and extreme events such as tropical cyclones. The water sector will be affected by both reductions in supply and increases in demand. This will in turn affect agriculture. Land providing nonmarket values will not be exempt. Conservation areas will be affected by shifting ecosystems, outdoor recreation will change, and even some diseases may spread as a result of climate change.

Although the impact of climate change will vary depending on location, some overall patterns are to be expected. Agriculture will be more vulnerable in low latitudes, where it is often too hot already. High-latitude farming will likely expand. There may be some local reductions in forest stocks, but globally forestry will benefit from warming. Reductions in water supply are likely to be more damaging in places that are already dry, but uncertainty about how precipitation patterns might change prevents more careful predictions of the pattern of impacts. Coastal damages are potentially higher in cities than in less developed areas. But because cities will likely be protected by hard structures, damages from inundation are expected to be higher in less developed locations. Tropical cyclones and floods are the most harmful extreme weather events that will be caused by climate change. The damages from these events are expected to be concentrated in the United States, eastern Asia, and the Caribbean.

The degree to which land use will be affected will depend on the severity of each climate scenario. As greenhouse gases accumulate, every scenario predicts that the problem of global warming will gradually get more severe and cause greater climate change. Although harsher climate scenarios predict net damages in the next few decades, milder scenarios may not cause net damages until later in the century.

Efficient adaptation—that is, adaptive actions in which benefits exceed costs—can reduce the overall damages from climate change. For example, farmers can reduce their damages by shifting crops and livestock in response to climate change. Foresters can reduce damages by harvesting trees before they die naturally and replacing them with species more suited to the changing climate. Water managers can reduce damages by shifting water allocation from low-valued to high-valued users. Coastal engineers can build cost-effective seawalls to protect cities as sea levels rise. Conservationists can protect endangered species by developing dynamic conservation zones that shift with changing climates. Public health officials can virtually neutralize the expansion of certain diseases by taking effective preventive measures. Governments can protect economically valuable commonly owned property by converting it to private property. All of these measures are likely to be very cost-effective.

In contrast, governments must be careful not to make matters worse. Government officials must not sit on their hands and fail to engage in efficient public adaptation. They also must allow private adaptation to occur and be careful not to discourage, through legislation or subsidies, private actors from adapting to climate change. They must be careful not to create “climate insurance” that compensates actors who remain in harm’s way. People who choose to live in risky coastal zones must be required to pay the full costs of making this decision.

Many of the most attractive adaptations to climate change are institutional. They are attractive because they would make current land and resource use more efficient while also promoting adaptive actions. Converting commonly owned property to private property, and securing individual property rights would be particularly beneficial. In some cases where common property is under the complete control of a local institution, is relatively immune to outside influence, and is shared by a common heritage, it may not be necessary to convert common property to private property (Ostrom 1991). Unfortunately, these situations are by far the exception rather than the rule. In general, common property resources are undervalued throughout the world and have been grossly mismanaged. When common property is converted to private property, the decision to adapt becomes the responsibility of the individual, who is motivated to act in her own self-interest.

These institutional reforms would make resources less vulnerable to climate change. Despite their large benefits, however, institutional reforms are not easily accomplished. In many cases, governments are unable or unwilling to make the difficult choices necessary to confront climate change.

REFERENCES

Adams, R. M., B. A. McCarl, K. Segerson, C. Rosenzweig, K. J. Bryant, B. L. Dixon, R. Conner, R. E. Evenson, and D. Ojima. 1999. Economic effects of climate change on U.S. agriculture. In *The impact of climate change on the United States economy*, ed. R. Mendelsohn and J. E. Neumann. Cambridge, U.K.: Cambridge University Press.

Adams, R., C. Rosenzweig, R. M. Peart, J. T. Ritchie, B. A. McCarl, J. D. Glyer, R. B. Curry, J. W. Jones, K. J. Boote, and L. H. Allen. 1990. Global climate change and U.S. agriculture. *Nature* 345:219–224.

Deschenes, O., and M. Greenstone. 2007. The economic impacts of climate change: Evidence from agricultural output and random fluctuations in weather. *American Economic Review* 97:354–385.

Easterling, W., P. Crosson, N. Rosenberg, M. McKenney, L. Katz, and K. Lemon. 1993. Agricultural impacts of and response to climate change in the Missouri-Iowa-Nebraska-Kansas (MINK) region. *Climatic Change* 24:23–61.

Emanuel, K., R. Sundararajan, and J. William. 2008. Tropical cyclones and global warming: Results from downscaling IPCC AR4 simulations. *Journal of Climate* 89:347–367.

Howitt, R., and E. Pienaar. 2006. Agricultural impacts. In *The impact of climate change on regional systems: A comprehensive analysis of California*, ed. J. B. Smith and R. Mendelsohn, 188–207. Cheltenham, U.K.: Edward Elgar.

Hurd, B., J. M. Callaway, J. B. Smith, and P. Kirshen. 1999. Economic effects of climate change on U.S. water resources. In *The impact of climate change on the United States economy*, ed. R. Mendelsohn and J. E. Neumann. Cambridge, U.K.: Cambridge University Press.

Iglesias, A., and M. I. Minguez. 1996. Modeling crop-climate interactions in Spain: Vulnerability and adaptation of different agricultural systems to climate change. *Mitigation and Adaptation Strategies for Global Change* 1:273–288.

IPCC (Intergovernmental Panel on Climate Change). 2007a. *Climate change 2007: Impacts, adaptation, and vulnerability*, ed. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. Cambridge, U.K.: Cambridge University Press.

———. 2007b. *Climate change 2007: The physical science basis*, ed. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Cambridge, U.K.: Cambridge University Press.

Kaiser, H. M., S. J. Riha, D. S. Wilkes, D. G. Rossiter, and R. K. Sampath. 1993. A farm-level analysis of economic and agronomic impacts of gradual warming. *American Journal of Agricultural Economics* 75:387–398.

Kelly, D. L., C. D. Kolstad, and G. T. Mitchell. 2005. Adjustment costs from environmental change. *Journal of Environmental Economics and Management* 50: 468–495.

Kurukulasuriya, P., and R. Mendelsohn. 2008a. Crop switching as an adaptation strategy to climate change. *African Journal of Agricultural and Resource Economics* 2:105–126.

———. 2008b. A Ricardian analysis of the impact of climate change on African cropland. *African Journal of Agricultural and Resource Economics* 2:1–23.

Kurukulasuriya P., R. Mendelsohn, R. Hassan, J. Benhin, T. Deressa, M. Diop, H. Mohamed Eid, K. Yerfi Fosu, G. Gbetibouo, S. Jain, A. Mahamadou, R. Mano, J. Kabubo-Mariara, S. El-Marsafawy, E. Molua, S. Ouda, M. Ouedraogo, I. Sène, D. Maddison, S. Niggol Seo, and A. Dinar. 2006. Will African agriculture survive climate change? *World Bank Economic Review* 20:367–388.

Lippert, C., T. Krimly, and J. Aurbacher. 2009. A Ricardian analysis of the impact of climate change on agriculture in Germany. *Climatic Change* 97:593–610.

Long, S. P., E. Ainsworth, A. Leakey, and P. Morgan. 2005. Global food insecurity: Treatment of major food crops with elevated carbon dioxide or ozone under large-scale fully open-air conditions suggests recent models may have overestimated future yields. *Philosophical Transactions of the Royal Society* 360:2011–2020.

Loomis, J., and J. Crespi. 1999. Estimated effect of climate change on selected outdoor recreation activities in the United States. In *The impact of climate change on the United States economy*, ed. R. Mendelsohn and J. E. Neumann, 289–314. Cambridge, U.K.: Cambridge University Press.

Lund, J. R., T. Zhu, S. K. Tanaka, and M. J. Jenkins. 2006. Water resources impacts. In *The impact of climate change on regional systems: A comprehensive analysis of California*, ed. J. B. Smith and R. Mendelsohn, 165–187. Cheltenham, U.K.: Edward Elgar.

Maddison, D. 2000. A hedonic analysis of agricultural land prices in England and Wales. *European Review of Agricultural Economics* 27:519–532.

Mendelsohn, R. 2006. The role of markets and governments in helping society adapt to a changing climate. In Climate, economy, and society: From adaptation to adaptive management climate, special issue, *Climatic Change* 78:203–215.

Mendelsohn, R., and A. Dinar. 2003. Climate, water, and agriculture. *Land Economics* 79:328–341.

______. 2009. *Climate change and agriculture: An economic analysis of global impacts, adaptation, and distributional effects*. Cheltenham, U.K. and Northhampton, MA, U.S.: Edward Elgar.

Mendelsohn, R., A. Dinar, and A. Sanghi. 2001. The effect of development on the climate sensitivity of agriculture. *Environment and Development Economics* 6:85–101.

Mendelsohn, R., A. Dinar, and L. Williams. 2006. The distributional impact of climate change on rich and poor countries. *Environment and Development Economics* 11:1–20.

Mendelsohn, R., and M. Markowski. 1999. The impact of climate change on outdoor recreation. In *The impact of climate change on the United States economy*, ed. R. Mendelsohn and J. E. Neumann, 267–288. Cambridge, U.K.: Cambridge University Press.

Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. Measuring the impact of global warming on agriculture. *American Economic Review* 84:753–771.

———. 1996. Climate impacts on aggregate farm values: Accounting for adaptation. *Agriculture and Forest Meteorology* 80:55–67.

———. 1999. The impact of climate variation on U.S. agriculture. In *The impact of climate change on the United States economy*, ed. R. Mendelsohn and J. E. Neumann, 55–74. Cambridge, U.K.: Cambridge University Press.

Mendelsohn, R., and S. Olmstead. 2009. The economic valuation of environmental amenities and disamenities: Methods and applications. *Annual Review of Environment and Resources* 34:325–347.

Mendelsohn, R., and L. Williams. 2004. Comparing forecasts of the global impacts of climate change. *Mitigation and Adaptation Strategies for Global Change* 9:315–333.

Neumann, J., and D. Hodgens. 2006. Coastal impacts. In *The impact of climate change on regional systems: A comprehensive analysis of California*, ed. J. B. Smith and R. Mendelsohn, 233–249. Cheltenham, U.K.: Edward Elgar.

Nordhaus, W. 2010. The economics of hurricanes and implications of global warming. *Climate Change Economics* 1:1–20.

Ostrom, E. 1991. *Governing the commons: The evolution of institutions for collective action.* Cambridge, U.K.: Cambridge University Press.

Pacala, S., and R. Socolow. 2004. Stabilization wedges: Solving the climate change problem for the next 50 years. *Science* 305:968–972.

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 *Climate change 1995: Economic and social dimensions*, ed. J. Bruce, H. Lee, and E. Haites, 179–224. Cambridge, U.K.: Cambridge University Press.

Reilly, J., W. Baethgen, F. Chege, S. van de Geijn, L. Erda, A. Iglesias, G. Kenny, D. Patterson, J. Rogasik, R. Rotter, C. Rosenzweig, W. Somboek, and J. Westbrook. 1996. Agriculture in a changing climate: Impacts and adaptations. In *Climate change 1995: Impacts, adaptations, and mitigation of climate change: Scientific-technical analyses*, ed. R. Watson, M. Zinyowera, R. Moss, and D. Dokken, 427–468. Cambridge, U.K.: Cambridge University Press.

Reinsborough, M. J. 2003. A Ricardian model of climate change in Canada. *Canadian Journal of Economics* 36:21–40.

Rosenzweig, C., and M. L. Parry. 1994. Potential impact of climate change on world food supply. *Nature* 367:133–138.

Sathaye J., W. Makundi, L. Dale, P. Chan, and K. Andrasko. 2007. GHG mitigation potential, costs and benefits in global forests: A dynamic partial equilibrium approach. *Energy Journal* 3:127–172.

Schlenker, W., W. M. Hanemann, and A. C. Fisher. 2005. Will U.S. agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach. *American Economic Review* 95:395–406.

———. 2006. The impact of global warming on U.S. agriculture: An econometric analysis of optimal growing conditions. *Review of Economics and Statistics* 81:113–125.

Seo, N., and R. Mendelsohn. 2008a. A Ricardian analysis of the impact of climate change on Latin American farms. *Chilean Journal of Agricultural Research* 68:69–79.

———. 2008b. An analysis of crop choice: Adapting to climate change in Latin American farms. *Ecological Economics* 67:109–116.

———. 2008c. Measuring impacts and adaptation to climate change: A structural Ricardian model of African livestock management. *Agricultural Economics* 38:150–165.

Seo, S. N., R. Mendelsohn, and M. Munasinghe. 2005. Climate change and agriculture in Sri Lanka: A Ricardian valuation. *Environment and Development Economics* 10:581–596.

Sohngen, B., and R. Mendelsohn. 2003. An optimal control model of forest carbon sequestration. *American Journal of Agricultural Economics* 85:448–457.

Sohngen, B., R. Mendelsohn, and R. Sedjo. 2002. A global model of climate change impacts on timber markets. *Journal of Agricultural and Resource Economics* 26:326–343.

Tol, R. 2002. Estimates of the damage costs of climate change. *Environmental and Resource Economics* 21:135–160.

Trapp, R. J., N. S. Diffenbaugh, H. E. Brooks, M. E. Baldwin, E. D. Robinson, and J. S. Pal. 2007. Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. *Proceedings of the National Academy of Sciences* 104:19719–19723.

Wang, J., R. Mendelsohn, A. Dinar, J. Huang, S. Rozelle, and L. Zhang. 2009. The impact of climate change on China's agriculture. *Agricultural Economics* 40: 323–337.

World Bank. 2010. *Economics of adaptation to climate change*. Washington, DC.

Yohe, G., J. Neumann, and P. Marshall. 1999. The economic damage induced by sea level rise in the United States. In *The impact of climate change on the United States economy*, ed. R. Mendelsohn and J. E. Neumann. Cambridge, U.K.: Cambridge University Press.