Weathering Global Warming in Agriculture and Forestry

It can be done with free markets

Douglas Southgate and Brent Sohngen
Ohio State University

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International Policy Network
Third Floor, Bedford Chambers
The Piazza
London WC2E 8HA UK
t: +4420 7836 0750
f: +4420 7836 0756
e: publications@policynetwork.net
w: www.policynetwork.net

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info@macguru.org.uk

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About the authors

Douglas Southgate specializes in the study of environmental problems in developing countries and has been a faculty member in the Department of Agricultural, Environmental, and Development Economics at Ohio State University (USA) since 1980.

Southgate has written numerous chapters and journal articles on public policies contributing to tropical deforestation, the economics of watershed management and related topics. Southgate is also the author of four books, including *The World Food Economy* (Blackwell Publishing, 2006). Southgate has consulted in 15 African, Caribbean, and Latin American nations.

Brent Sohngen is an environmental and resource economist, and has been a faculty member in the Department of Agricultural, Environmental, and Development Economics at Ohio State University (USA) since 1996.

Sohngen has written numerous articles and book chapters on the economics of climate change, forestry markets, and tradable pollution permits. In addition Sohngen has participated as an author on the Intergovernmental Panel on Climate Change. Sohngen is currently developing models to assess the implications of climate change on global demands for agricultural and forestry.

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Executive summary

During the 20th Century, atmospheric concentrations of CO_2 and other greenhouse gasses (GHGs) rose appreciably. There is some evidence that this caused limited warming of the planet, with worldwide temperatures about 0.6°C higher in 2000 than in 1900. Since GHG concentrations will increase this century, some additional warming of the planet seems likely.

Specific climatic impacts that will result as atmospheric concentrations of GHGs continue to change are difficult to predict. But given specific assumptions about the future course of global warming,[1] economic consequences can be examined. Two sectors in which these consequences have been scrutinized are agriculture and commercial forestry.

In general, the costs of environmental change hinge on how people choose to adapt. In the agricultural and forestry sectors, successful accommodation of global warming will not require central planning by governments. To the contrary, adaptation is best accomplished by relying on the sort of decision-making that happens routinely in competitive and unregulated markets – decision-making that is decentralized and individualistic, yet coordinated because everyone faces the same prices for scarce resources.

Thanks largely to the adaptations that producers and consumers will make in the marketplace, global prices of farm products will not be greatly affected if average temperatures rise by 1.0°C to 4.0°C during the 21st Century, as the Intergovernmental Panel on Climate Change (IPCC) is currently forecasting. With prices staying about the same, the main economic consequence of global warming in the farm economy will be to raise or lower the values of agricultural land. Since the 1990s, economists have investigated this consequence in the United States. Some of this research suggests that the aggregate impact of global warming on land values will be negative. However, the expected magnitude is not all that great.

In the face of higher temperatures as well as less precipitation in some settings because of global warming, efficient adjustment is impeded when governments meddle with market forces. This is true of agricultural protectionism. It is also true of distortions in the pricing of water. In particular, farmers in dry regions have little reason to adopt conservation measures if governments subsidize their use of water.

On the whole, higher temperatures will promote tree growth, certainly in places which continue to receive adequate precipitation. Risks of fire will increase as well, although probably not enough to affect timber supplies. Moreover, expected trends in the forestry sector contradict a widely-held belief about the impacts of global warming, which is that developing regions close to the equator will suffer more than affluent settings in temperate latitudes. To be specific, higher temperatures are apt to accelerate a geographic shift that is already underway. As ever larger portions of the global timber supply are obtained from sub-tropical plantations, where trees are grown and harvested in cycles lasting just 10 to 20 years, the share of timber harvested from temperate and boreal forests will decrease.

In the forestry sector no less than in agriculture, efficient adaptation to global warming requires that protectionism be avoided. With or without global warming, the sector's development depends on strong property rights, in developing countries as well as in affluent nations.

Introduction

Available evidence suggests that average global temperatures have risen only slightly since the Industrial Revolution began. After no noticeable change during the 1800s, a slight rise occurred during the first half of the 20th Century. Next came modest cooling for about three decades, possibly in part because of increased emissions of particulates which reflect solar radiation out into space. Since 1970, warming has coincided with reduced particulate pollution. All told, average global temperatures are about 0.6°C higher today than they were 100 years ago (NCDC, 2007).

Meanwhile, atmospheric concentrations of CO_2, which is an important greenhouse gas, have risen from approximately 280 parts per million (ppm) before the Industrial Revolution to 380 ppm today (Marland et al., 2007). The current rate of increase is roughly 1.5 ppm per annum (Houghton, 2005) and the concentration at the end of the 21st Century might be as high as 970 ppm (IPCC, 2001).[2] In the absence of profound technological change, curtailing growth in CO_2 emissions would require severe economic contraction, entailing the decommissioning of most of the world's existing industrial capacity and abandoning the internal combustion engine.

No one is counting either on a technological revolution or on an economic collapse, so the debate among those who agree that variations in CO_2 have a noticeable effect on the global climate revolves around how fast, not whether, the molecule will accumulate in the atmosphere. To give one example, Demirbas (2004) argues that the rate of CO_2 emissions should be slowed by 60 percent, to prevent the mean global temperature from rising by more than a couple of degrees Celsius. In comparison, the policy measures adopted at Kyoto, Bonn, and other intergovernmental meetings are un-ambitious, which suggests that nearly everyone is resigned to at least some anthropogenic global warming.

Both authors of this paper are economists, so we lack the credentials needed to sort out how climatic conditions are affected as water vapor, CO_2, and other atmospheric components vary. Our expertise relates to evaluating the costs and benefits of global warming and its control (or mitigation). Observations that follow for two sectors, agriculture and commercial forestry, draw on a fundamental insight from economics, which is that the costs of environmental change depend largely on how people choose to adapt. For example, these costs consist mainly of diminished production of goods and services if adaptation is not economically practical. But if environmental change is easily accommodated, costs consist largely of adaptation expenses, which sometimes are fairly low.

This report takes as given the current projection from the Intergovernmental Panel on Climate Change (IPCC), which is that global temperatures will rise by 1.0°C to 4.0°C during the next 100 years (Solomon, Qin, and Manning, 2007). In addition, careful attention is paid to the guidance and incentives that markets will provide to producers and consumers as they adapt to warming of this magnitude. In a market setting, the choices made by individual economic agents reflect personal and local circumstances. These choices are also conditioned by prices, which are reliable indicators of the scarcity of goods such as food and timber which are bought and sold in markets.

By and large, our findings relate mainly to the world as a whole. We acknowledge the problems arising at a more limited geographic scale because of global warming, though we do not examine them in the pages that follow. Neither does this paper address catastrophic outcomes that are very unlikely, though not completely out of the realm of possibilities. Furthermore, entire categories of impacts – mass biodiversity loss, for example – are outside the scope of this paper.

Clearly, higher sea levels resulting from the thermal expansion of ocean surfaces would be devastating for places like Bangladesh and the Maldive Islands, not to mention Venice and New Orleans. Likewise, Norway, Scotland, and neighboring lands would suffer a great deal if the Gulf Stream weakened, say because accelerated melting of ice in Greenland and around the North Pole reduces the salinity of the northern Atlantic Ocean. All that said, our contribution to the debate over global warming is to assess whether or not humanity as a whole may run out of food or wood products as temperatures rise, particularly if these commodities are exchanged in free, competitive markets.

Agricultural adaptation

Due regard for arithmetic can be very important in economics. For example, macroeconomic trends in a country that is open to trade and investment tend not to be interpreted correctly if one forgets that a deficit in the current account is normally offset by a surplus of the same absolute magnitude in the capital account, and vice versa.

However, economics is not just about arithmetic. As emphasized right at the beginning of any introductory economics class, the discipline's main focus is on how people deal with scarcity, which cannot be captured by a subtraction or two here and a multiplication there. Sadly to say, some assessments of global warming amount to arithmetic masquerading as economics.

To illustrate the shortcomings involved, consider economic damages within the agricultural sector created by global warming if one assumes, unreasonably, that farmers do not adapt at all to higher temperatures. If they continue to plant the same crops in the same places, with no variation in the use of labor, chemicals, and other inputs, then the only things that change are yields, which may increase in some settings but will decline elsewhere. Suppose there is a net loss in total output, which can be called Δ and which is best expressed in cereal-equivalent tons. If this net loss is small relative to overall production, then prices are unaffected. In this case, economic damages are found by multiplying the prevailing price, called P, by Δ.

Estimating the cost of global warming is more complicated if Δ is not a minor portion of total agricultural production. In this case, the market-clearing price rises, to P' let us say, which causes consumption to decline (in line with the change in output). As explained in Annex 1, the value of lost production is represented by the area under the demand curve between (lower) consumption at P' and (higher) consumption at P, not a simple product of Δ multiplied by an unchanging price. Areas under demand curves were estimated in early economic assessments of the impacts of higher temperatures on agriculture. One such assessment was carried out by Rosenzweig and Parry (1994).

Adaptation with free trade

Subsequent economic research has not been based on the notion that farmers are completely passive in the face of climate change, but instead adapt in various ways – as do their customers. To describe various shifts in demand, supply, and price, Mendelsohn (2006) offers a stylized illustration, one involving two commodities (maize and wheat) and two nations (Russia and the United States). Wheat grows better in cooler weather, so a rise in temperatures would reduce the number of hectares planted in the United States, but increase the area in Russia, where most farmland is closer to the North Pole. Meanwhile, plantings of maize would increase in the former country and decline in the latter.

International trade would dampen the price adjustments resulting from these changes in agricultural land use. For example, a larger wheat harvest, which on its own would drive down domestic prices of that commodity, would be accompanied in Russia by increased wheat exports, which would push the domestic market value of that commodity back up. Russia would also import more maize, which would restrain any increases in that product's price. Actions taken on the demand side of the market would also prevent relative prices from changing much. If for example maize became much more expensive while the market value of wheat remained the same, then livestock producers would change the rations fed to cattle and other domestic animals. As they did this, demand for maize would decline, hence bringing down its price, and demand for wheat would increase, thereby putting upward pressure on its market value.

Note that, even in the absence of a large swing in relative prices, farmers face a strong incentive to adapt efficiently to climate change. Consider an individual who has been growing wheat in Iowa. With per-hectare production falling and the ratio of maize prices to wheat prices not changing much, switching to the other crop is attractive. Meanwhile, additional land is being sown to wheat at higher latitudes, in Russia. In each case, market forces are promoting exactly the right response to a warmer environment.

Ricardian analysis

The best economic studies of the agricultural impacts of global warming are based on two premises. One is that farmers and other participants in commodity markets adapt in various ways to climate change. The other is that price adjustments are limited, both because of these adjustments and because of free trade. In one study based on these premises, the investigators used an approach they called Ricardian, in the sense that the agricultural impacts of higher temperatures would consist entirely of changes in land values (Mendelsohn, Nordhaus, and Shaw, 1994). The general underpinnings of this approach, which also can be described as hedonic,[3] are explained in Annex 2.

The study's geographic scope only encompassed the United States, as opposed to being global. Accordingly, it did not consider some of the agricultural adaptations to be expected if farm products are traded freely. Also, Mendelsohn, Nordhaus, and Shaw (1994) supposed that a temperature rise of 1°C or 2°C would leave commodity prices little affected, which as already indicated is most plausible if governments do not interfere with exports and imports. In a regression analysis, the investigators related land values reported in the 1982 U.S. agricultural census to climate, soil parameters, and other factors. Using regression coefficients, they projected the effects of higher temperatures on land values. In some regions, the estimated effects were found to be negative. Elsewhere, global warming would cause land values to increase. For the country as a whole, economic impacts were anticipated to be modest, either slightly positive or slightly negative.

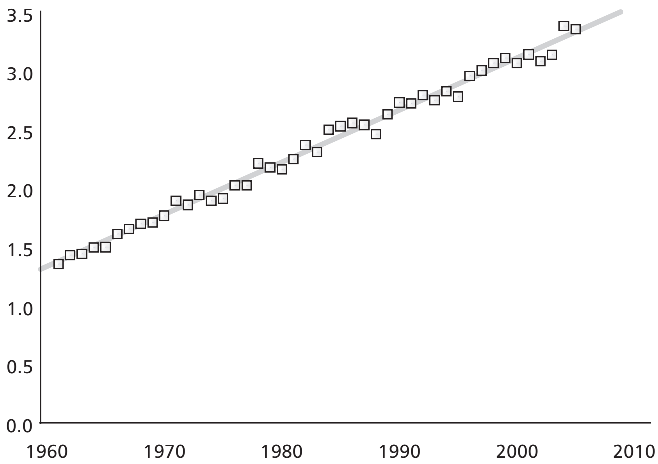
Improvements have been made subsequently in this sort of research. Deschenes and Greenstone (2007) applied statistical changes to estimate weather coefficients better. In addition, they used a panel of census data collected from 1978 through 2002. The two researchers found that modest warming on the scale investigated by Mendelsohn, Nordhaus, and Shaw (1994) would cause the value of agricultural real estate in the United States to decline by 3 to 6 percent. However, they could not reject the null hypothesis that there would be no statistically significant impact.

Another econometric study was carried out by Schlenker, Hanemann, and Fisher (2006). Among other things, their model featured different descriptions of linkages between climate and crop yields as well as an adjustment for spatial correlation of regression errors, which if left uncorrected can distort the testing of hypotheses. They only used data for that part of the United States east of the 100th meridian (which bisects North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas), where non-irrigated agriculture is the norm. In 75 percent of the sampled counties in this region, higher temperatures were found to have a statistically significant impact on land values. Schlenker, Hanemann, and Fisher (2006), who assumed no major change in commodity prices, concluded that the aggregate impact would be adverse.

Relative to what has been done in the United States, the Ricardian approach has not been used extensively to estimate how global warming would affect European agriculture. However, studies that focus on how climate change affects values of agricultural land have been undertaken in various parts of the developing world. Seo and Mendelsohn (2007), for example, surveyed 2,500 farms across Latin America and estimated how temperature and precipitation might influence net revenues and land values. Three climate scenarios were considered in this study and consequences for large and small operators were examined separately. For both categories of farms, the estimated impacts of two of the three climate scenarios were negative, with these impacts expected to worsen as temperatures reach high levels late in the 21st Century. However, the effects of the other scenario were found to be mildly positive, at least during the next two decades. Seo and Mendelsohn (2007) also found that irrigated farms would be affected less by climate change than rain-fed operations.

Using exactly the same climate model to project future environmental conditions, Kurukulasuriya and Mendelsohn (2007) investigated the effects of higher temperatures for a sample of more than 9,000 African farms. Estimated impacts varied substantially, more than what was found in Latin America. This is mainly because, under one of the climate scenarios, precipitation would increase more in Africa than on the other side of the Atlantic Ocean. Since dry conditions have prevailed in large swathes of the continent, any

Figure 1 **Average global cereal yield**
Mt/ha, 1961–2005



Source: Southgate, Graham, and Tweeten (2007), p. 58

change that would bring about more rainfall would be beneficial.

As a rule, research carried out in the United States and other settings does not place great emphasis on technological change, even though it is to be expected that higher temperatures will stimulate a search for new ways to use natural resources and other inputs to produce farm goods. This is a research gap of considerable importance since technological advances in the past have had a huge impact on agricultural yields. For example, maize yields in the United States, which held steady at 1.5 to 1.6 metric tons per hectare between the late 1860s and middle 1930s, subsequently increased five- or six-fold, due to hybridization, the use of inorganic fertilizer and other chemical inputs, and other improvements (Southgate, Graham, and Tweeten, 2007, p. 50). Likewise, technological improvements during and since the Green Revolution have caused average global cereal yields to climb from less than 1.5 metric tons per hectare in the early 1960s to more than 3.0 metric tons per hectare today (Figure 1). The adverse effects of global warming on crop yields would have to be enormous to counter the likely beneficial impacts of future technological developments on U.S. and global agriculture.

Will farmers be able to keep up with climate change?

Something to keep in mind about the research carried out by Mendelsohn, Nordhaus, and Shaw (1994) and other investigators is that it provides two snapshots of the agricultural economy. In each snapshot, input and output markets are assumed to have reached equilibrium, in the face of higher temperatures or the absence of same.

To be sure, this methodological approach neglects the costs of moving from one equilibrium to another, which would be substantial if climate change is so rapid that farmers' expertise is rendered irrelevant and machines tailored to old production technologies have to be junked before their functional lives have come to an end. However, neglect of the adjustment issue is not really worrying, at least for many of the world's farmers. Mendelsohn (2006) observes that most crops are sown and harvested annually and that agricultural machinery depreciates fully in just a few years. Under these conditions, farming systems can be revamped every decade or two, which is more than enough to keep pace with climate change. Essentially the same conclusion has been reached by Kaiser et al. (1993), who contend that farmers will be able to adapt to global warming as it occurs.

In other studies, an attempt is made to account for adjustments over time. These studies also focus on price changes. Parry et al. (2004) and Darwin (2004) both have utilized simulation approaches to analyze implications for the global food economy. In each case, crop yields were found to decline, thereby putting upward pressure on commodity prices. Depending on climate scenarios, price increases of as little as 1 percent in the near term to 25 percent by the middle of the 21st Century were projected. If this actually occurred, reductions in agricultural land values, which have been projected in some Ricardian studies that assume constant prices, would be ameliorated.

Once again, the advantages of free markets must be kept in mind. If the exchange of goods, services, inputs, and resources is not subject to egregious regulation, then shifts in demand, supply, or both lead to quick adjustments by individual actors. This capacity of markets will serve agriculture well as it adapts to global warming.

The importance of efficient pricing of water

As already indicated, Schlenker, Hanemann, and Fisher (2006) have concluded that global warming could do serious damage to rain-fed agriculture in the central and eastern United States. This result makes most sense if climate change causes precipitation to decline, in which case drier conditions might easily cause more harm than higher temperatures.

Just as they can adapt to warming, farmers are able to deal with diminished water availability in various ways. For example, Howitt (2005) found that a 25 percent cut in irrigation, which could easily happen due not only to drier conditions but also to increases in non-farm demand, would only cause agricultural earnings in California to fall by 6 percent. This is mainly because more land and water would be used to produce higher-valued crops. Mendelsohn and Dinar (2003) obtained similar findings in a study encompassing the entire United States.

Of course, this sort of adaptation occurs if prices for water are efficient. In contrast, proper adjustment to the drier conditions that higher temperatures will create in many settings is less likely if prices are distorted, by irrigation subsidies for example. More than in any other sector, payments by irrigators amount to a tiny fraction of the cost of delivering water to them (Okonski, 2006). As a result, adoption of conservation measures is discouraged, as is switching from one crop to another in response to mounting water shortages. By the same token, farmers enjoying irrigation subsidies are apt to resist the transfer of water to other sectors, which is what should happen as non-agricultural demands grow and resources become scarcer. Already excessive, the waste and misallocation created when water is supplied too cheaply to farmers will grow worse as the planet warms.

As emphasized in this paper, successful adaptation to global warming is most likely to happen where goods, services, inputs, and resources are allocated in markets that are free and competitive. In part, this means unencumbered agricultural trade at the international level. By the same token, efficient pricing of water – as occurs if that resource is bought and sold freely as opposed to being distributed by governments at subsidized prices – is essential at the national level.

Adaptation in the forestry sector

Climate change of the magnitude now being forecast by the IPCC will have pronounced influences on tree-covered ecosystems. Some forest types will shift location, farther from the equator or up mountain slopes. Others will burn more often, more severely, or both. Pests and diseases may affect new areas. Some locations will become unsuitable for trees, while tree growth will increase in other settings. While there is little agreement on the pattern and timing of impacts in specific locations, the ecologists consulted by the IPCC agree unanimously that climate change will affect forest structure and function profoundly (Parry et al., 2007).

By and large, this conclusion is based on research undertaken in unmanaged ecosystems, of the sort that remain in Alaska, Canada, and Russia as well as the Amazon and Congo Basins. However, most of the world’s forests have been heavily influenced by human management, having been harvested once or multiple times or having regenerated after prior agricultural use. Simply recognizing that climate change could have substantial consequences in the absence of management, as the ecologists have done, ignores human responses and the costs of these responses.

Significantly, the impacts of global warming on timber production are unlikely to be catastrophic, even in the absence of human adaptation. At present, estimated impacts range from small and negative to large and positive. One reason why a collapse is unlikely is that warmer conditions should promote tree growth, particularly in regions where there is enough precipitation to offset the drying caused by higher temperatures. Also, higher levels of CO_2 in the atmosphere can fertilize trees, provided that other nutrients and water are available.[4] It is hardly surprising, then, that a recent survey of available studies points to a recent acceleration of tree growth globally, in spite of forest decline in some regions (Boisvenue and Running, 2006).

If global warming causes trees to grow faster, even without management, then supplies of timber will increase. Consumers will benefit, as prices for wood products fall. Costs will mainly be localized – confined to regions that experience diminished tree growth but where producers will actually suffer more because of price declines. These conclusions have been arrived at by a number of investigators (Joyce et al., 1995; Perez-Garcia, 1997; Sohngen and Mendelsohn, 1998; Sohngen et al., 2001; Joyce et al., 2001; and Alig, Adams, and McCarl, 2001).

Increased fire incidence?

There is a potential caveat, which is that forest fires may occur more frequently, affect larger areas, become more commonplace in settings where these events currently are rare, or otherwise do more damage (Bachelet et al., 2003, 2004; Scholze et al., 2006). Statistics indicate that fire activity has increased in the United States, for example, in recent decades (http://www.nifc.gov/stats/fires_acres.html). On average, a little less than 1.8 million hectares have burned each year since 1960, although the average from 1997 through 2006 was nearly 2.4 million hectares per annum. Some authors suggest that the recent increase in forest fire activity in the western part of the country can be attributed to climate change (Westerling et al., 2006).

Even if a linkage exists between global warming and forest fires, the effects on markets for wood products, while negative, are not expected to be substantial. Inventories of standing timber around the world are huge. Also, extraction rates in temperate latitudes, which are the main source of supply, are lower than growth rates, which means that timber stocks are accumulating. As an example, standing timber in the United States, which currently amounts to 26 billion m^3, is accumulating at an annual rate of 672 million m^3, or 2.6 percent. Since the 1950s, per-hectare volumes have increased by 0.6 percent per annum, from 56 m^3 to around 79 m^3, both because growth has exceeded extraction and because mortality has remained fairly low. Currently, annual harvests and mortality are 448 million m^3 and 168 million m^3, respectively, which added together are less than yearly accumulation, 672 million m^3 (statistics on US forests from Smith et al., 2002). It is hard to argue that timber harvesting in the United States is unsustainable. Indeed, the area burned every year might well have increased because there is now more to burn – for example, because of substantial growth in standing timber per hectare during recent decades.

Notwithstanding these criticisms, the possibility that climate change will increase burn rates remains worth addressing, largely because of hydrological impacts and lost opportunities for forest-based recreation. Even so, it is doubtful that timber markets will be negatively affected. One reason is that, when forest fires occur, they rarely damage forests in a way that prevents salvage harvesting. Sohngen and Mendelsohn (1998) and Sohngen et al. (2001) examined a set of scenarios that considered large increases in forest fire activity due to climate change. Their results suggest a range of adaptive behaviors among foresters, including harvesting some forests in anticipation of fires, salvage logging, regenerating more suitable species, and shifting harvests from one region to another to maintain adequate supplies. Only under scenarios where the adaptive ability of landowners is seriously constrained would consumers and landowners experience overall losses in welfare.

Temperate versus subtropical settings

It is often claimed that less developed regions close to the equator will suffer disproportionately because of global warming. Commercial forestry is a major counter-example, however. As temperatures rise, wood products obtained from warm settings will increase, not decrease, and it is likely that the portion of global timber supplies coming from the low latitudes will increase as the portion harvested in temperate settings declines.

One of the main reasons for this geographic shift is that temperate and boreal species tend to take longer to mature than do species in the tropics and subtropics. Among the latter are Eucalyptus and certain varieties of pine, which can be grown in rotations of 10 to 20 years where temperatures are consistently moderate to high and where there is adequate precipitation. In contrast, rotations of Douglas Fir, which predominates in the forests of western Oregon, Washington, and British Columbia, last at least 40 years.

Due to the advantages of short rotations, plantations in warm settings where Eucalyptus, pine, and other fast-growing species are raised have been expanding. Globally, there are approximately 70 million hectares of fast-growing plantations used for commercial timber harvesting. These plantations currently account for 13 percent of the world's timber harvest. Over the coming several decades, the supply of timber from these plantations is expected to reach 40 percent of the market, largely because of fast-growing tree species (Daigneault, Sohngen, and Sedjo, 2007).

One of the main reasons for plantation development in the subtropics is that trees grow more quickly in this setting. In particular, species such as eucalyptus and pine thrive when introduced to regions that have, for instance, a longer growing season or more precipitation. For this reason, annual growth for non-indigenous trees in subtropical plantations varies between 10 and 15 m^3/ha, which is well above the average annual growth of 1–5 m^3/ha registered in temperate and boreal forests. Furthermore, traditional breeding programs may add 10 to 20 percent to timber yields across successive generations of trees (Sedjo, 2004). For rotations lasting just 7 to 20 years, these gains imply improvements of 0.5 to 2.0 percent per annum in the productivity of planted stands of trees. Application of modern genetics, which has barely begun in working forests, could further raise timber yields.

The expansion of subtropical plantations is likely to be accelerated by global warming, with direct consequences for the locations where timber is harvested around the world. This is not to deny that there are some regions close to the equator where tree growth will slow due to diminished precipitation. But in other places, where rainfall remains adequate, plantations will spread due to an obvious advantage of short rotations, which is that adjustments to new environmental conditions can be made in just 10 or 20 years. With much longer rotations, temperate and boreal forests do not share this advantage, which will become even more significant as the Earth grows warmer.

Taking into account the faster adaptation that occurs in the low latitudes, Sohngen et al. (2001) find that the effects of global warming on global timber supplies will differ greatly from agricultural impacts. Whereas agriculture in northerly settings such as Canada and Russia are likely to benefit the most from higher temperatures, forestry in these same settings will probably be placed at a disadvantage. Among other things, Sohngen et al. (2001) predict that the share of global timber production from South America, which has experienced considerable plantation development, will increase by as much as 13 percent over the next 50 years. Meanwhile, timber production in North America, where a great deal of harvesting still takes place in natural forests rather than plantations, is anticipated to fall by around 11 percent.

In light of these findings about geographic realignment, one cannot draw inferences about global forestry from trends in the United States alone. Sohngen and Mendelsohn (1998) estimate that a rise in the average national temperature of 1.5ºC to 5ºC would cause net welfare[5] in the U.S. forestry sector to increase by 13 to 15 percent. Results from Irland et al. (2001) suggest smaller overall economic impacts: annual welfare gains of 0.05 to 0.18 percent over the coming century. But for the world as a whole, Sohngen et al. (2001) suggest welfare increases of 2 to 8 percent per annum, with the largest increases occurring in poorer, subtropical regions. These changes imply benefits of $6 billion to $12 billion per annum during the next 100 years.

The role of property rights

Solely in terms of its impacts on global timber production, a warmer global climate is beneficial. Moreover, the best way to capture the benefits of higher temperatures in the forestry sector is to allow markets to work. For this to happen, governments need to refrain from regulating or otherwise meddling with prices and commerce. Instead, they must solidify the legal and institutional framework that markets require, by strengthening property rights for example.

The importance of property rights is underscored by the fact that industrial timber plantations, which offer an excellent setting for adapting to climate change, are largely concentrated in places with secure land tenure: the Iberian Peninsula, New Zealand, and the southern United States as well as Argentina, Brazil, and South

Africa. Plantation development also has occurred in other parts of Africa and in Southeast Asia, often to provide firewood and other products for local markets. However, commercial success in these regions has been impeded. While investors often build wood-processing facilities near sources of raw material (or they locate new plantations by existing mills) to minimize transportation costs, they are unwilling to stake the large sums required if land rights are in any way clouded.

Even in the United States, property rights are not entirely conducive to global warming adaptation. Approximately 43 percent of the country's forests are owned and managed by federal, state, or local governments. Particularly in the United States, public agencies are much less flexible than private landowners, and therefore are not as able to deal with climate change. Consider the U.S. Forest Service, which is responsible for about 40 million hectares. Recent evidence indicates that conducting salvage operations after fires is severely impeded by complex bureaucratic procedures (Prestemon et al., 2006). This problem reflects the more general challenge of altering procedures and guidelines for harvesting and regeneration. In the face of global warming, guidelines and procedures will have to change with regard to converting forests from one species to another, rehabilitation of timberland, as well as salvage harvesting. Considering the rigidities inherent in bureaucratic administration of natural resources and the magnitude of changes needed, long-term contracts and leases with private companies (possibly including those environmental organizations which have the resources needed for large-scale operations) have considerable appeal. This holds particularly true if contract – and lease-holders are given wide latitude to adjust the use and management of forests.

Forest tenure issues are different in Europe, where public-sector ownership is less prevalent. Instead, regulatory burdens are often heavy on private owners of timberland. Also, local customs circumscribe the type and quantity of harvesting as well as modes of regeneration in many places. As a result, adapting to climate change is more difficult in Europe than in the United States. For example, some zoning ordinances require landowners to maintain forest cover or regenerate specific species. This tends to complicate tasks such as removing vegetation that burns easily, phasing out slow-growing species, and planting other sorts of trees that are better suited to new conditions. At the very least, countries and regions with tight controls on land use will have to update regulatory structures quickly in response to global warming.

Canadian institutions are an interesting alternative, especially in terms of direct government control and administration. Most of the country's forests are public "Crown Lands." However, extensive tracts are leased for longer time periods (usually 20 to 40 years) to timber companies and other entities, which are then required to harvest according to an estimate of the annual allowable cut. This cut is determined primarily by ecological criteria, although lease-holders are allowed some flexibility with respect to the specific timing and location of extraction. Also, land must be regenerated either through accepted natural practices[6] or manual planting. By stipulating these conditions, the public sector can, at least to some extent, regulate the flow of income to the state while simultaneously influencing environmental outcomes.

While climate change can be accommodated within the framework of long-term leases, additional modifications might well be in order if temperatures continue to rise. For example, leased areas may have to be adjusted if existing lands become unsuitable for production forestry. Also, large fires outside the boundaries of existing lease-holds may oblige the government to permit salvage harvesting. This latter adjustment might prove problematic in regions where access is poor. Building roads is costly in such regions and salvage operations typically have low margins, which are bound to decline as lumber prices fall. Federal and provincial authorities may need to develop innovative contracts with landowners, to give the latter additional flexibility on harvest levels in accessible regions in order to entice them to build roads and extract salvage timber in inaccessible regions. Clearly, climate change will provide new challenges to governments that are responsible for large tracts of land.

The importance of free trade

Bureaucratic administration of resources and regulation of private lands are major examples of government impediments to adaptation that arise at a local level. The most important challenge to successful adaptation, however, has to do with trade policy. Since the forestry sectors in some countries will be disadvantaged by global warming, governments in those same countries will come under pressure to apply tariffs, institute quotas, and interfere in other ways with timber imports. Protectionism, which long has been the norm in the forestry sector, may work for a time. However, the costs of trade restrictions will grow as the climate changes. Resources will be increasingly misallocated, with over-investment taking place where the timber industry is growing less competitive and under-investment occurring in settings where comparative advantage is strengthening.

In contrast, free trade and the unencumbered flow of capital will produce two benefits. First, international markets will grow for timber producers in developing countries who stand to benefit from climate change. Second, prices will stay low for consumers of wood products, particularly in nations where global warming weakens the comparative advantage of the domestic forestry sector.

Conclusions

Compared to disagreements over how much temperatures will rise as levels of CO_2 and atmospheric components vary, there is strong consensus that profound changes in the global economy will be required if greenhouse-gas emissions are to be curbed. Some observers contend that the technological changes unleashed as people and firms search for ways to mitigate global warming will be beneficial, maybe even in the near term. But most concede that the adjustment will be costly, perhaps extremely so. For example, Weyant et al. (2006) have examined the economic sacrifice required to reduce temperature increases by 25 percent, relative to the business-as-usual trend. Using approximately 15 well-known energy models, they estimated that global GDP would be 0.4 percent smaller in 2025 and 4.8 percent smaller in 2100.

If mitigation is burdensome, then it makes sense to keep greenhouse gases in check only if the alternative, which is to adapt to global warming, is equally or more costly. Our findings for two key sectors of the economy suggest this is not the case. We will not all go hungry or run out of wood products if temperatures rise. To the contrary, the agricultural and forestry impacts could be modest, at least on a global scale.

This is not to suggest that global warming will not affect agriculture and forestry in some parts of the world. Temperate and boreal forests comprise one case in point; low-lying agricultural regions are another. Consider Bangladesh, where millions of rural households could be placed in jeopardy if higher temperatures lead to a rise in sea levels and an increase in the incidence of flooding.

A case can certainly be made for international support to help the Bangladeshi littoral deal with global warming. This assistance might consist of investment in dikes and other infrastructure for flood-control. Something important to keep in mind, however, is that much of the rural population that would be at risk will also be impoverished and vulnerable without global warming. For these people, the best assistance, regardless of what nature has in store, is to create new economic opportunities, outside of subsistence farming and other traditional lines of work. In turn, the best way to do this is to open up markets and invest in human capital.

The most important thing governments can do to limit the potential impacts of global warming is to avoid undercutting markets. Irrigation subsidies, weak property rights in forests, and protectionism in agriculture and forestry are harmful even when environmental conditions are consistently ideal. The damage will be multiplied if the Earth grows warmer. Indeed, the waste and misallocation created by these policies will almost certainly exceed the costs which could occur in commodity markets because of climate change.

Annex 1
Valuing consumption: a welfare perspective

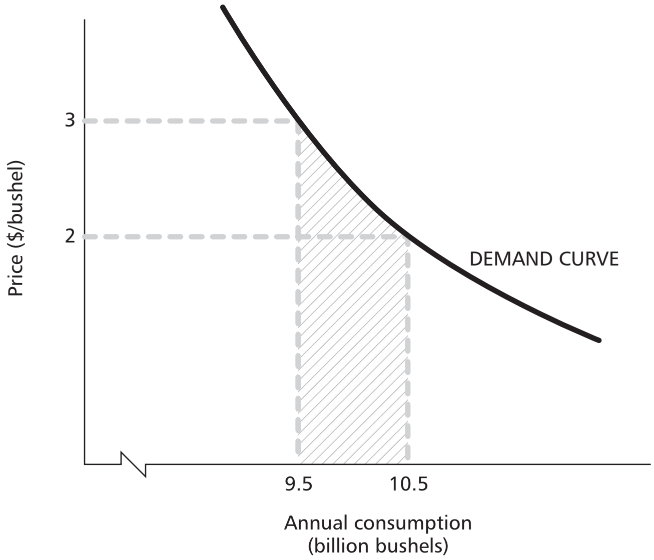
Many people are familiar with demand curves, each of which expresses the inverse relationship between consumption of a good and that good's price for a pre-determined combination of household incomes, prices of other goods, people's tastes, and so forth.

However, demand curves have another interpretation – one used in welfare analysis, which provides a framework for evaluating an economy's performance (or efficiency). In a conventional market setting, such a curve indicates the marginal value of consumption – in other words, the maximum amount that someone would offer for a small (e.g., unitary) increase in product availability. Consistent with this interpretation, the value of a non-marginal change comprises the marginal value of the first additional (or lost) unit plus the marginal value of the second such unit, etc. This sum, which is often referred to as consumers' willingness-to-pay (WTP) for the change, consists of the integral of the demand curve (i.e., the area under the curve) between the two consumption levels, the original one and the one after the change.

An illustration is provided in Figure 2, which depicts the U.S. market for maize in stylized fashion. To begin with, 10.5 billion bushels are purchased annually at a price of $2/bushel. If the price goes up to $3/bushel, yearly purchases fall to 9.5 billion. WTP for this change is the shaded area in Figure 2 between the two consumption levels.

This value comprises two parts. One is the market value of the billion bushels evaluated at the original price: in other words, $2 billion, which equals $2/bushel x (10.5 – 9.5) billion bushels. The other component, called consumers' surplus, is not captured by maize suppliers, in the form of sales revenues. This surplus –represented in Figure 2 by the area bounded by the vertical line intersecting the horizontal axis at 9.5 billion, the horizontal line extending out from $2 – arises because the marginal value (to some buyer) of the 9,500,000,001st bushel is nearly $3 while the same bushel's price is just $2, the marginal value of the 9,500,000,002nd bushel is slightly lower while its price is (again) $2, and so forth.

Figure 2 **Demand of and consumers' WTP for U.S. maize**



WTP and its constituent parts are easy to calculate if the demand curve happens to be a straight line. To be specific, the integral under the demand curve is a simple trapezoid equal to ½ x (P + P') x |Q – Q'|, where P and Q represent the original combination of price and quantity and P' and Q' are the combination after the change. For example, the value that consumers would attach to 1 billion bushels of lost maize production if the demand curve in Figure 2 were a straight line would be ½ x ($2 + $3) x |10.5 billion – 9.5 billion| = $2.5 billion. Of this amount, the market value comprises $2 billion (see above). The balance, which is consumers' surplus, is represented by the triangular area: ½ x (10.5 billion – 9.5 billion) x ($3 – $2) = $0.5 billion.

Finally, welfare analysis takes into account the opportunity cost of factors of production as well as WTP. In the preceding example, the value of any inputs no longer used to produce maize as output falls from 10.5 billion to 9.5 billion bushels would be deducted from WTP ($2.5 billion for the straight-line case) to determine net impacts on welfare.

Annex 2
Resource rents: a Ricardian perspective

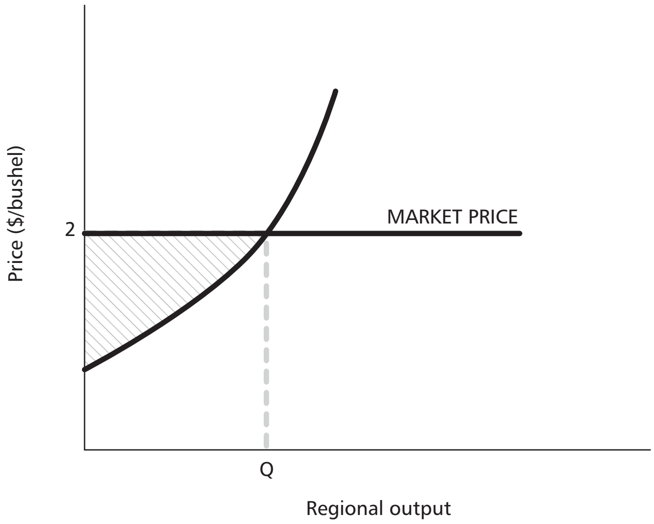
Just as practitioners of welfare analysis refer to demand curves to evaluate consumption, resource values can be described with reference to the supply curve. Classical economist David Ricardo developed this approach as he built a case against agricultural protectionism early in the 19th Century.

Let us think again of the maize market, in which equilibrium has been reached at a price of $2/bushel. Instead of examining the U.S. market in its entirety, consider what is happening in just one part of the country. Variations in that region's output have no impact on the market price, as indicated by the horizontal line extending out from $2 on Figure 3's vertical axis. The supply curve slopes upward, which reflects the tendency for production to rise as price goes up, given cumulative investment in productive capacity, the existing state of technology, input prices, and other exogenous factors. As explained in any introductory textbook, the curve indicates the marginal cost of output, exactly as the demand curve can be interpreted as a marginal-value curve. Just as marginal value declines as consumption goes up, marginal cost is positively tied to the output level

Reflected in the positive slope of the supply curve is heterogeneity among producers. Some of them possess resources that are unusually productive, others are located close to market hubs, still others enjoy both advantages. Regardless of the reason, these producers could supply maize at a price well under $2/bushel and still cover the costs of labor, chemicals, and other non-land inputs. Their output is represented by the lower part of the supply curve, close to the vertical axis. But there are also farmers whose land is both inferior and remote, who can barely cover non-land expenses even at the prevailing price. Production by these growers corresponds to the portion of the supply curve nearer its intersection with the price-line.

Significantly, everyone receives exactly $2 for every bushel delivered to market. What can be said of the residual balance between sales revenues and non-land expenses captured by farmers enjoying an environmental or locational advantage? Ricardo called this balance rents. These rents, which are represented by the shaded area in Figure 3, comprises the difference between market value of output – that is, sales revenues, which is found by multiplying output (Q in Figure 3) by price ($2) – and non-land costs, which are represented by the area under the supply curve between the origin and Q.

Figure 3 **Regional supply and producers' surplus in the maize market**



Ricardo contended that rents are expressed in real estate prices, which makes perfect sense. In land markets, bids for productive holdings that are centrally located are high, depending on prices for farm products as well as costs of inputs other than land. In contrast, prices offered for marginal land, where sales revenues barely cover non-land expenses, are modest.

Finally, rents and prices of real estate vary as market conditions change. For example, high commodity prices cause the area in Figure 3 bounded by the vertical axis, the supply (or marginal cost) curve, and the horizontal line representing price to increase. Rents can also increase even with no change in price, in particular because supply grows (i.e., shifts outward) due to low production costs. In contrast, higher production costs, which might result if global warming causes regional precipitation to decline, diminishes rents and, in turn, resource prices.

Notes

1 Throughout this paper, where we discuss "global warming," we mean human-induced, or anthropogenic, warming – unless we explicitly say otherwise.

2 The 970 ppm figure derives from the IPCC's Special Report on Emissions Scenarios, which has not been updated for the 2007 Fourth Assessment Report. The assumptions underlying this very high upper estimate have been called into question by many analysts.

3 Hedonic pricing is frequently used to evaluate environmental services that are not bought and sold in markets. Supposing that environmental quality is among the variables that influence property values, the analyst begins by running a regression in which these values are dependent. This yields regression coefficients that are then used to predict how real estate prices change in response to variation in right-hand side parameters, particularly including measures of environmental quality.

4 Although scientists have debated the potential role of carbon fertilization (Gitay et al., 2001), recent evidence points to strong positive effects on forests (Norby et al., 2005).

5 As explained in Annex 1, net welfare is found by subtracting input costs from WTP for consumed goods.

6 An example of natural regeneration would be to leave seed-trees in place after harvests.

References

Alig, R., D. Adams, and B. McCarl. 2002. "Projecting Impacts of Global Climate Change on the U.S. Forest and Agriculture Sectors and Carbon Budgets,' *Forest Ecology and Management*, 169, pp. 3–14.

Bachelet, D., R. Neilson, J. Lenihan, R. Drapek. 2004. "Regional Differences in the Carbon Source-Sink: Potential of Natural Vegetation in the U.S.A," *Environmental Management*, 33, pp. S23–S43.

Boisvenue, C. and S. Running. 2006. "Impacts of Climate Change on Natural Forest Productivity: Evidence since the Middle of the 20th Century," *Global Change Biology*, 12, pp. 862–882.

Daigneault, A., B. Sohngen, and R. Sedjo. 2007. "Exchange Rates and the Competitiveness of the United States Timber Sector in a Global Economy," *Forest Policy and Economics*, in press.

Darwin, R. 2004. "Effects of Greenhouse Gas Emissions on World Agriculture, Food Consumption, and Economic Welfare," *Climatic Change*, 66, pp. 191–238.

Demirbas, A. 2004. "Bioenergy, Global Warming, and Environmental Impacts," *Energy Sources*, 26, pp. 225–236.

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, pp. 354–385.

Duncan, Emma. "The Heat Is On: A Survey of Climate Change," *The Economist*, 9 September 2006, 24 pp.

Gitay, H., S. Brown, W. Easterling, B. Jallow. 2001. "Chapter 5: Ecosystems and their Services" *Climate Change: Impacts, Adaptation, and Vulnerability* (contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change).

Houghton, J. 2005. "Global Warming," *Reports on Progress in Physics*, 68, pp. 1343–1403.

Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: Synthesis Report*. Cambridge: Cambridge University Press.

Irland, L.; D. Adams, R. Alig, C. Betz, C. Chen, M. Hutchins, B. McCarl, K. Skog, and B. Sohngen. 2001. "Assessing Socioeconomic Impacts of Climate Change on U.S. Forest, Wood-Product Markets, and Forest Recreation," *Bioscience*, 51, pp. 753 – 764.

Joyce, L., J. Mills, L. Heath, A. McGuire, R. Haynes, and R. Birdsey. 1995. "Forest Sector Impacts from Changes in Forest Productivity under Climate Change," *Journal of Biogeography*, 22, pp. 703–715.

Joyce, L., J. Aber, S. McNulty, V. Dale, A. Hansen, L. Irland, R. Neilson, and K. Skog. 2001. "Chapter 17: Potential Consequences of Climate Variability and Change for the Forests of the United States," in *Climate Change Impacts on the United States: The Potential*

Consequences of Climate Variability and Change (National Assessment Synthesis Team, US Global Change Research Program), http://www.usgcrp.gov/usgcrp/Library/nationalassessment/.

Kaiser, H.M., S.J. Riha, D.S. Wilkes, D.G. Rosster, and R.K. Sampath. 1993. "A Farm-Level Analysis of Economic and Agronomic Impacts of Gradual Warming," *American Journal of Agricultural Economics*, 75, pp. 387–398.

Kurukulasuriya, P. and R. Mendelsohn. 2007. "A Ricardian Analysis of the Impact of Climate Change on African Cropland" (Policy Research Working Paper 4305), World Bank, Washington.

Marland, G., T.A. Boden, and R.J. Andres. 2007. Global, Regional, and National CO_2 Emissions. In *Trends: A Compendium of Data on Global Change*. Oak Ridge: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.

Mendelsohn, R. 2006. "The Role of Markets and Governments in Helping Society Adapt to a Changing Climate," *Climatic Change*, 78, pp. 203–215.

Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. "The Impact of Global Warming on Agriculture: A Ricardian Analysis," *American Economic Review*, 84, pp. 753–771.

National Climate Data Center (NCDC). 2007. *Climate of 2006 – Annual Report*. Asheville, NC.

Norby, R., E. DeLucia, B. Gielend, C. Calfapietra, C. Giardina, J. King, J. Ledford, H. McCarthy, D. Moore, R. Ceulemans, P. de Angelis, A. Finzi, D. Karnosky, M. Kubiske, M. Lukac, K. Pregitzer, G. Scarascia-Mugnozzan, W. Schlesinger, and R. Oren. 2005. Forest Response to Elevated CO2 Is Conserved across a Broad Range of Productivity," *Proceedings of the National Academy of Sciences*, 102, pp. 18052–18056.

Okonski, K. (ed.). 2006. *The Water Revolution: Practical Solutions to Water Scarcity*. London: International Policy Press, 2006.

Parry, M., O. Canziani, J. Palutikof, P. van der Linden, and C. Hanson. 2007. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Cambridge: Cambridge University Press. [Official IPCC report.]

Parry, M., C. Rosenzweig, A. Iglesias, M. Livermore, and G. Fischer. 2004. "Effects of Climate Change on Global Food Production under SRES Emissions and Socio-Economic Scenarios," *Global Environmental Change*, 14, pp. 53–67.

Perez-Garcia, J., L. Joyce, A. McGuire, and C. Binkley. 1997. "Economic Impact of Climatic Change on the Global Forest Sector," in R. Sedjo; R. Sampson; and J. Wisniewski (eds.), *Economics of Carbon Sequestration in Forestry*. Boca Raton: Lewis Publishers.

Prestemon, J., D. Wear, F. Stewart, and T. Holmes. 2006. "Wildfire, Timber Salvage, and the Economics of Expediency," *Forest Policy and Economics*, 8, pp. 312– 322.

Rosenzwieg, C. and M. L. Parry. 1994. "Potential Impact of Climate Change on World Food Supply," *Nature*, 367, pp. 133–138.

Schlenker, W., W.M. Hanemann, and A.C. Fisher. 2006. "The Impact of Global Warming on U.S. Agriculture: An Econometric Analysis of Optimal Growing Conditions," *Review of Economics and Statistics*, 88, pp. 113–125.

Scholze, M., W. Knorr, N. Arnell, and I. Prentice. 2006. "A Climate-Change Risk Analysis for World Ecosystems," *Proceedings of the National Academy of Sciences*, 103, pp. 13116–13120.

Sedjo, R. 2004. "The Potential Economic Contribution of Biotechnology and Forest Plantations in Global Wood Supply and Forest Conservation," in S.H. Strauss and H.D. Bradshaw (eds.), *The Bioengineered Forest: Challenges for Science and Society*. Washington: Resources for the Future.

Seo, N. and R. Mendelsohn. 2007. "A Ricardian Analysis of the Impact of Climate Change on Latin American Farms" (Policy Research Working Paper 4163), World Bank, Washington.

Smith, W., P. Miles, J. Vissage, and S. Pugh, 2003. "Forest Resources of the United States, 2002" (General Technical Report NC-241), North Central Research Station, U.S. Forest Service.

Sohngen, B. and R. Mendelsohn. 1998. "Valuing the Market Impact of Large Scale Ecological Change: The Effect of Climate Change on US Timber," *American Economic Review*, 88, pp. 689–710.

Sohngen, B., R. Mendelsohn, and R. Sedjo. 2001. “A Global Model of Climate Change Impacts on Timber Markets,” *Journal of Agricultural and Resource Economics*, 26, pp. 326–343.

Solomon, S., D. Qin, and M. Manning (eds.). 2007. *Climate Change 2007: The Physical Science Basis*. Cambridge: Cambridge University Press. [Official IPCC report.]

Southgate, D., D. H. Graham, and L. Tweeten. 2007. *The World Food Economy*. Malden: Blackwell Publishing.

Westerling, A., H., Hidalgo, D. Cayan, and T. Swetnam. 2006. Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity,” *Science*, 313, pp. 940–943.

Weyant, J., F. de la Chesnaye, and G. Blanford. 2006. “Overview of EMF-21 : Multigas Mitigation and Climate Policy,“ *Energy Journal*, 27, pp. 1–32.