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Measuring the Impacts from Climate Change

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MEMORIAL LECTURE SERIES

This Memorial Lecture Series honors the late Hamilton Roddis who served as Secretary, President and Chairman of the Board of Directors of the Roddis Plywood Corporation for more than sixty years.

Hamilton Roddis was born in 1875 in Milwaukee, Wisconsin, and moved to Marshfield with his family in 1894 when his father invested in and assumed the direction of the Hatteberg Veneer Company. Mr. Roddis enrolled in the University of Wisconsin–Madison Law School in 1896, intending to proceed through a normal course of study. A fire destroyed the Hatteberg Veneer plant in 1897 and Hamilton Roddis remained in Marshfield to help get the new plant running smoothly—simultaneously, by independent study, he pursued his second-year law program by studying at night. He later rejoined his class in Madison and graduated on schedule. His capacity to operate on many functional levels served him well during the ensuing years in meeting the many challenges of the business world and at the same time maintaining an active involvement in civic, church and cultural affairs. Originally intending to enter the law profession, he was instead persuaded to join his father's firm (then known as the Roddis Veneer Company); he became president in 1920 and headed the company until his death in 1960. His character and intellect combined with his imaginative and progressive leadership spurred a business success through what we would today tout as Quality Management.

The Roddis enterprise spearheaded many innovations in forest products. It was the first to recognize the potential of the flush door and manufacture it on a large scale. During WW II it produced materials for the war effort by fabricating interior woodwork for the Liberty ships and aircraft plywood for the British Mosquito bomber and reconnaissance plane. In August of 1960 the Roddis Plywood Corporation, with holdings throughout the U.S. and Canada, was merged with the Weyerhaeuser Corporation.

Mr. Roddis's family, friends and university beneficiaries are pleased to honor the man and his extraordinary accomplishments in the Hamilton Roddis Memorial Lecture Series.

ABSTRACT

Economics has made three important contributions to climate change policy: cost benefit analysis, the measurement of abatement costs, and the measurement of the impacts of climate change. In this paper, I wish to provide an overview of the many contributions that economists, in cooperation with other disciplines, have made to determine the welfare impacts associated with climate change. Economists have contributed strong theoretical frameworks to analyze impacts, they have developed empirical methods to measure impacts, and they have conducted many empirical measurements of impacts. Impact research has made enormous strides towards understanding what will happen if climate changes. Of course, measuring how the world will change over the next century or two from climate change is not a trivial task and much remains to be done. However, enough progress has been made in impact analysis that policy makers must now take impacts into account.

First, we have learned that warming will not have the same effects on everyone around the world. People in cool places are likely to benefit on net from warming, people in temperate places may be only moderately affected, but people in hot places will be harmed. Because the benefits will offset damages, the globe as a whole may see little net effects from warming until warming becomes severe (over 2.5C). Nonetheless, there will be distributional effects as the low-latitude and island nations are harmed and the high- and possibly also the mid-latitude nations will benefit. These results suggest that: (1) There is little justification for expensive immediate short-term abatement; the costs will be high and the benefits will be low. (2) Abatement policy should focus on developing long-term low-cost abatement strategies. (3) The greenhouse gas emitters should develop a compensation package for low-latitude and island nations because these people will eventually be hurt by climate change regardless of likely abatement policies.

Measuring the Impacts from Climate Change

Dr. Robert Mendelsohn

INTRODUCTION

Climate scientists who recognized an historical and a physical link between greenhouse gases and temperature first uncovered the problem of greenhouse gases. Although the precise magnitude of this relationship continues to elude us, there is now widespread agreement that man-made carbon dioxide emissions will lead to future global warming (Houghton et al., 1996). Climate scientists consequently have pressed for an immediate reduction in especially carbon dioxide in order to stabilize global CO2 concentrations and global climate. Although no one is especially happy to cause climate to change in the future, society has been slow to adopt these recommendations by climate scientists. Partly this is due to the immense difficulty of coordinating national governments to adopt new global carbon and energy policies. However, part of the reluctance by society to adopt the scientists' recommendations of drastic emission reductions lies in a more fundamental question. Are these policies a good idea?

Economics has had a lot to contribute to the debate on greenhouse gases. Beginning with the seminal work by Professor William Nordhaus, economists quickly became active players in the debate about greenhouse gas policy (Nordhaus, 1991). Professor Nordhaus was the first to suggest the policy be defined by a benefit cost paradigm. We should spend money on abatement as long as there was a consequent reward. Because there is a long lag between emissions and final consequences, the benefit cost paradigm calls for predictive analysis. We must look at future impacts in order to determine our best abatement strategy today because if we wait for impacts to occur, we will be two or three decades too late. Further, given that greenhouse gases last a long time, the benefits of abatement are the discounted value of the stream of damages avoided by preventing an additional emission. Since the marginal damage of an emission depends upon the stock of greenhouse gases in the atmosphere, this implies that marginal damages would increase over time as the stock accumulated. The benefit cost model suggests a dynamic policy, beginning with relatively loose restrictions on emissions while concentrations are low and a gradually tightening restrictions as concentrations rise. How much we should spend on abatement each moment depends upon how much an additional unit of abatement costs and what the expected damages from that emission are likely to be. For example, using the expected value of each parameter in the model suggests starting with the equivalent of a $5 tax per ton of carbon that would gradually rise over the century to about $60 per ton (Nordhaus and Boyer, 2000).

The second major contribution by economics involves the analysis of the cost of abatement (see Hourcade et al., 1996). There are two competing methodologies that

have been used to estimate the cost of reducing energy and abating carbon emissions. The engineering approach, sometimes called bottom up analysis, begins with a micro goal such as providing x lumens to a room or traveling from point A to B, and then calculates the least energy or least carbon way of achieving this goal. The engineering approach often identifies no cost options that both reduce emissions and lower costs. For example, engineers promote the use of high-mileage vehicles that are both cheaper to build and use less gasoline. Economists begin with more general desires by the population such as the demand for different types of cars, and they estimate what must be paid to convince people to switch from what they want to do now to higher mileage vehicles. The economists find that changing people's behavior would actually cost quite a lot. The difference between the two approaches has to do with what people are actually being asked to give up. People willingly spend more money to buy low-mileage vehicles today because they provide horsepower for good performance and often safety in a heavy vehicle. Although the high-mileage vehicles may be cheaper, car owners are willing to pay quite a lot for the low-mileage cars. The cost of any rule that prohibits low-mileage vehicles is not the out-of-pocket expenses, but rather the loss in the quality of the driving experience. If the engineering models took these quality goals into account, they would arrive at the same conclusions. But for the moment, it is economic models alone that are claiming reducing carbon emission will be expensive.

The third area where economists have made a major contribution to greenhouse gas policy is measuring the damages associated with climate change. Initial impact studies used comparative equilibrium analysis to contrast today's conditions with what would happen with today's economy but another climate. The studies ignored the dynamic pathway of climate change and they ignored the changes that would occur to the economy in the absence of climate change. As a result, climate change was conceived of more as a shock to the system than a gradual event. The early studies consequently included very limited adaptation. Farmers were expected to continue to grow the same crops, foresters would plant the same trees, and construction would continue to occur at the same beachfronts. The result was large losses because society was expected to make few adjustments to the change in climate (see Smith and Tirpak, 1989).

More recent studies include dynamic analyses and efficient adaptation. The new studies examine gradual changes in climate and the impact of these changes on capital-intensive sectors such as coastal properties and forests that are slow to adjust. The new studies also explore how people and firms would adjust. That is, new studies assume that people would make changes in their work and life that would make them better off given the new climate. Finally, the new studies examine entire sectors including parts that might like a warmer temperature. These new studies not only suggest that damages are less than previously thought, but they even suggest that countries such as the United States would benefit (Mendelsohn and Neumann, 1999).

Of course, not all the results from the new studies are more optimistic. The new studies show, for example, that cooling will penetrate energy markets more completely in the future so that warming will cost more (Morrison and Mendelsohn, 1999). The new research also reveals that many sectors have a hill-shaped relationship with temperature. Although there would be benefits if a cool place were warmed slightly, there would also be damages if a warm place were further warmed. Consequently, northern states in the United States would benefit from warming and would not even be hurt by a large amount of warming but southern states would not be so fortunate (Mendelsohn, 2001). Even a moderate amount of warming would begin to hurt southern states and a large amount of warming could cause large damages. Extending these results to other countries, the polar countries are likely to be big beneficiaries of global warming and the mid-latitude countries will benefit as long as warming is not too severe. However, the low-latitude countries are likely to be damaged by even a small amount of warming (Mendelsohn et al., 2000).

In this paper, we shall examine this third area of research, measuring the impacts from climate change. In the next section, we will review the fundamental models that economists have used to measure climate impacts and the empirical methods they have developed. We will then move to the empirical results found by these methods. The fourth section will examine the remaining uncertainties and areas that need further attention. The paper will conclude with some policy observations.

METHODS FOR ASSESSING IMPACTS FROM CLIMATE CHANGE

The impact literature has relied on two critical approaches in order to estimate climate impacts. First, they examine the results of scientific experiments done in controlled settings (Smith and Tirpak, 1989; Sohngen and Mendelsohn, 1998; Adams et al., 1999). Holding all other environmental and management factors constant, the experiments explore the net effect of changing temperature, precipitation, and carbon dioxide. The results are then fed into simulation models that try to extrapolate from the experiments to the world. Second, scientists have examined cross-sectional evidence (Mendelsohn et al., 1994; Morrison and Mendelsohn, 1999; Mendelsohn, 2001). By looking at how farms and homes do in one climate versus another climate, they hope to learn how systems will adjust to climate change.

There are strengths and weaknesses to the experimental-simulation and the cross-sectional approach. Because each experimental site is expensive, the experimental approach is often limited to just a few sites. The experimental approach has to work hard to make the results representative. The cross-sectional approach, in contrast, is generally performed across the relevant sector and so is automatically representative. The experimental approach includes other factors only to the extent that the modeler remembers to include them. Thus the experimental approach has been criticized for not including human adaptation and possibly ecosystem adaptations (such as insects and disease) as well. The cross-sectional approach includes these factors because they are built into what is happening at each place today. However, the cross-sectional approach has its own weaknesses. It is difficult to control for all the things that vary across space. It is easy for unwanted factors to influence the results, thus raising questions of cause and effect. The experimental approach with its carefully controlled settings does not have this problem. The cross-sectional approach also cannot predict the effect of factors that have not yet appeared. For example, the cross-sectional approach cannot predict the consequences of higher CO_2 levels because every site in the cross section has the same CO_2 level. The experimental approach can create these new conditions. Because the strengths and weaknesses of the two approaches are so very different, both approaches should be applied whenever practical. The two methods check each other so that if results differ, impact researchers can be aware there is a problem.

However, if the results are the same, scientists can have confidence that they have gotten reliable results since the two methods rely on such different assumptions.

Arguing that the two general methods are good checks on each other does not eliminate all sources of error. There are some weaknesses that both methods are subject to in common. The most prominent problem is forecasting the future. Both methods must make allowances for how future conditions will be different from today. The simulations and the cross-sectional studies must cope with estimating both what the future world would look like without climate change and how climate sensitivity itself might change.

Another important methodological issue concerns the development of dynamic analyses. The early studies of climate impacts relied on comparative statics, contrasting current conditions to what might happen with the current economy and the equilibrium climate from doubling carbon dioxide. This methodology provided an initial glimpse into the importance of climate change but was inadequate for an accurate measurement. First, the climate associated with the doubling of CO_2 was not expected to occur until 2060. Examining the impacts of a 2060 climate on a 1990 economy asks the wrong question. What we want to know is what will happen to a 2060 economy with a 2060 climate. The early methods did not think about the future. Second, by using a 1990 economy as the point of comparison, authors reinforced a notion that little could possibly change in response to climate. Early studies underplayed adaptation partially because early authors could not imagine the economy being able to change in time. However, forecasts of climate change predict that climate is expected to change slowly. By 2060, the economy will change a great deal even without climate change. The idea that future planners might take the climate that they observe around them into account is very plausible. The preoccupation with climate change impacts on today's economy led early researchers to underemphasize efficient adaptation.

Adaptation is a very important though sensitive issue to include in impact analysis. Early studies provided some examples of adaptation and they did suggest it was going to be important (see for example Rosenzweig and Parry, 1994). However, the adaptation included in many early studies was limited and ad hoc. Researchers did not ask whether the adaptations would yield greater benefits than costs to the people doing them. The key is consequently not whether adaptation is included but rather whether the adaptation that is included is efficient (Mendelsohn, 2000). Impact studies should include efficient adaptation for private gain. When firms or households can make themselves better off by changing what they do, it is highly likely that these changes will take place. When the benefits of a change exceed the costs, it is efficient. If the only beneficiary is the person making the change, then it is private. Private adaptation will tend to be done and it will be efficient because it is self-rewarding. For example, farmers will shift planting dates and crops if they will profit from these changes. Foresters on private lands will cut down trees and replace them with new species if they think they will make money doing it.

What is not clear about adaptation is what will happen when the choice involves many beneficiaries. When there are many people who will gain or lose from a decision, the choice is public, not private. For example, if a seawall is built, it will often help all the owners along the coast. They share in the outcome of the decision together. Will public decisions be efficient? It is not clear because markets fail to make public decisions efficiently (Mendelsohn, 2000). For public decisions to be efficient, they need an agent who works in the collective interest such as the government. There are many examples of effective collective action being accomplished by government, but the historic record suggests such actions will not necessarily be efficient. In some cases, governments may be too active and provide too much adaptation, for example by building a seawall too soon or too high. In other cases, the government may react much too late and begin to build the seawall only after dramatic damages have already occurred. Similar issues arise when considering the management of public forests. Will the governments cut down the trees that are likely to die back and replant new species more suited for a new climate, or will they expensively fight change and struggle to keep ecosystems just as they are? The efficiency of public adaptation to climate change is an important topic that needs further research.

Another important dimension of adaptation is adjustments over time. Certain sectors that are very capital intensive, specifically forests and coastal structures, can only adapt slowly over time. For these two sectors, it is critical to move away from comparative static analysis and rely on dynamic studies instead. First, the speed of change is important to these sectors. More rapid change, leading to the same long-term outcome, would cause more damages in these sectors. Second, adaptation strategies themselves must be dynamic. One cannot change large capital stocks overnight. Adaptation strategies must reflect the changing conditions and the fact that change is slow. For example, with sea-level rise, one must be careful to build seawalls only where they are needed in each decade. By delaying seawall construction until it is required, one can reduce the present value of protection costs by an order of magnitude (Yohe et al., 1999). Forestry provides another potent example. By harvesting trees that are vulnerable to dieback, foresters can greatly reduce the damages associated with ecosystem change (Sohngen and Mendelsohn, 1998). Further, by planting new species more suited to the new conditions, foresters can speed how quickly ecosystems adapt (Sohngen and Mendelsohn, 1998). These changes can significantly reduce the damages and find the potential benefits from ecosystem change.

Another important methodological issue in impact assessment is developing tools that allow natural science and economics to communicate. Integrated assessment models that trace consequences through physical and ecological processes can help analysts link cause and effect. Making sure that what scientists measure is in fact what society cares about is a critical communication problem in multidisciplinary impact studies. For example, ending ecological modeling with just abstract changes in bioproductivity and biogeography is not enough. In order to translate these ecological measures to timber supply, it is necessary to determine how climate would shift the timber species in a region from one type to another. Further, the bioproductivity changes have to be translated to changes in the growth rates of the bole of the timber species. Making these connections may seem obvious after the fact but if they are not made correctly, one can be deeply misled by the results.

One important scientific result, for example, that was deeply discounted in early impact analyses was carbon fertilization. The experimental studies done on crops and seedlings almost universally suggested that rising carbon dioxide levels were going to increase the productivity and yields of crops and trees. Partly to illustrate the importance of carbon fertilization, the 1989 USEPA study showed results with and without carbon fertilization being taken into account (Smith and Tirpak, 1989). Unfortunately,

the early impact studies interpreted these with and without simulations as suggesting that either result was plausible. In fact, the science suggesting carbon fertilization is more certain than the science exploring climate sensitivity. Climate sensitivity experiments on various crops in various locations lead to a variety of results, from suggesting large reductions in yields to small increases (Reilly et al., 1996). Carbon fertilization studies show near universal increases in yields although the magnitude varies by crop (Reilly et al., 1996). The early impact literature mistakenly discounted carbon fertilization effects (see especially Cline, 1992).

The initial research into climate impacts was in search of large damages. That is, the researchers were asked to find out whether there were sufficiently harmful effects from climate change that they might justify a substantial greenhouse control program. Early studies consequently examined the most warming-sensitive part of each sector. For example, the comprehensive analysis by USEPA examined the electricity sector, not all energy, because electricity was going to be needed for cooling. Similarly, Cline (1992) examines the skiing industry, not outdoor recreation, because clearly warming is going to hurt skiing. The early agricultural studies focused on cool-loving grains grown in northern states, not the warm-loving crops associated with the southern United States. Although these selective choices may not have been malicious, the net effect of studying just selected parts of each sector was that the initial studies were not representative of sector-wide effects. Impact studies must develop representative analyses of entire sectors. Including more than just the parts of sectors that would be hurt by warming makes a large difference in what one predicts will happen (Mendelsohn and Neumann, 1999). It is no surprise that more representative studies found that warming was more beneficial than earlier studies.

FINDINGS

The first systematic analysis of climate effects for the United States was conducted by the U.S. Environmental Protection Agency at the request of Congress (Smith and Tirpak, 1989). The impacts were based on climate scenarios from three climate models. The study examined agriculture, timber, energy, water, coastal resources, ecosystem change, health, migration, and pollution. The study examined the effect an equilibrium climate caused by the doubling of greenhouse gases would have on the U.S. economy as it looked in 1990, and found that impacts on all the sensitive sectors would be harmful. Agriculture could have large damages of up to $10 billion in a hot and dry climate scenario if there were no fertilization effects (Adams et al., 1989). Ecosystems were predicted to collapse by gap models as many key species would not regenerate in the warmer climate. Dieback was expected throughout the country, but especially in the Southeast, seriously reducing key stocks of timber. Warming was expected to increase electricity demand as homes and businesses increased air conditioning in the summer. Large damages in water resources were expected from reductions in runoff in arid regions of the country and increases in floods in wetter regions. Coastal resources would be inundated by rising seas of 1 meter. Developed land would have to be protected by expensive seawalls and undeveloped land would be lost to the sea. All of these individual impacts were large, although aggregate estimates of damages were not reported in the study.

Beginning with the USEPA study and continuing to this day, several studies have identified climate changes that could lead to serious nonmarket effects (Pearce et al., 1996). Sea-level rise would inundate undeveloped land and reduce coastal wetlands. Ecosystem change would cause biomes to shift poleward, changing landscapes, species mix, and wildlife habitat. These changes could pose a new threat to endangered species. The changes could certainly pose a threat to conservation policies that rely on drawing boundaries around key ecosystems. Ocean temperatures and currents could shift changing the habitat of ocean fish and mammals. Climate would change altering weather in every location. Rising temperatures would affect atmospheric chemistry, speeding the formation of ozone and sulfates. Extreme weather such as hurricanes and intense precipitation could change in severity, frequency, or geographic distribution. Changes in water flow would affect aquatic habitats and the dilution of water pollution. Vector-borne diseases are known to be dependent on climate. As temperatures warm, mosquitoes and other insects can carry these diseases to new places. Further, people regularly die from sudden heat spells. Warming could increase this health risk as well.

These nonmarket risks all warrant careful study. However, nonmarket effects have not yet received the careful economic analysis that has been devoted to market effects. Although several authors have ventured guesses concerning the magnitude of nonmarket effects, careful empirical studies have not yet been completed for most nonmarket effects. Except for recreation, most of the nonmarket studies done on climate change have no theoretical foundation to measure dollar damages. The nonmarket studies have not explored adaptation and many do not present entire sectors, but rather only the part of each sector harmed by warming. For example, the health studies have focused only on the possibility that warming is harmful. The climate implication, for example, of the fact that mortality rates are consistently higher in winter than in summer has not yet been explored. This review consequently discounts the reported nonmarket effects found in the literature. That is not to say that nonmarket effects are not important but just that existing estimates of nonmarket effects are unreliable.

The first aggregate estimates of damages from climate change did not come forth until the cost benefit paradigm for greenhouse gases was first developed (Nordhaus, 1991). In this seminal paper, Professor Nordhaus not only laid down a framework to make decisions about greenhouse gas policy, but he also compiled the results of the USEPA study into an estimate of aggregate damages. The predicted damages for the United States from this initial study are presented in Table 1. Again, the measurement is the predicted impacts of doubling CO2 on the 1990 economy. Nordhaus did not estimate damages in all sensitive market sectors but he provided estimates for agriculture, energy, coastal structures, and total effects. He estimated the net impact from doubling greenhouse gases on market sectors to be about $16 billion of damages a year. Including impacts to nonmarket sectors, the aggregate impact was estimated to be around $66 billion or about 1% of GDP.

TABLE 1

Initial Market Damage Estimates (billions 1998 USD/year)

Sector	Nordhaus	Cline	Fankhauser	Tol
Agriculture	−1.3	−20.7	−9.9	−11.8
Timber	...	−3.9	−0.8	...
Water	...	−8.3	−18.4	...
Energy	−0.6	−11.7	−9.3	...
Coastal	−14.4	−8.3	−10.6	−10.0
Total Market	**−16.3**	**−52.8**	**−49.1**	**−21.8**
NonMarket	−49.3	−19.5	−33.1	−66.0
Total Impact	**−65.6**	**−72.3**	**−82.2**	**−87.8**
% GDP	−1.0%	−1.1%	−1.3%	−1.5%

Sources: Nordhaus 1991; Cline 1992; Fankhauser 1995; Tol 1995. Tol's estimates include Canada.

Following Nordhaus, a series of authors reexamined the data from Smith and Tirpak (1989) and included further analyses done elsewhere (Cline, 1992; Fankhauser, 1995; Tol, 1995). Although they rely largely on the same set of evidence, these authors generated very different estimates of the impacts on the U.S. economy. The additional estimates are presented in Table 1 as well. Note that the authors rarely agreed about the size of the impact in each sector although they did agree that all impacts were harmful. Upon adding all the market impacts together, one can see that the authors did not agree about the magnitude of aggregate market impacts either, with estimates ranging from damages of $5 to $53 billion per year. One explanation for this range is that some of the authors discounted the role of carbon fertilization on crops and forests. The authors also varied the price inelasticity of the demand for agriculture and the importance of heating benefits. The total climate change impacts on the United States including nonmarket effects were estimated to be between $72 and $88 billion per year or between 1.1% and 1.5% of GDP.

Mendelsohn and Neumann (1999) conducted the second systematic analysis of market impacts on the United States with the help of many of the same experts involved in the first USEPA study. This second study did not look at nonmarket impacts but it made several improvements in market estimates. Mendelsohn and Neumann examined climate impacts on a future economy. They included efficient adaptation, dynamic models of timber and sea-level rise, more representative sectoral coverage, and close links between science and economics. These changes shifted the expected value of market impacts in the United States (see Table 2). Whereas the earlier studies all predicted market damages from doubling greenhouse gases, this new study predicted benefits as long as climate outcomes did not exceed 2.5C. When warming reached 5C, Mendelsohn and Neumann also predict damages. The biggest change in estimates was for agriculture, which becomes beneficial and large. It is the large benefits in the agricultural sector that make the 1.5C and 2.5C scenarios deliver net benefits. Benefits are now also predicted for the timber sector, partially because of dynamic adaptation but primarily because the new ecological predictions are more optimistic. Damages continue to be estimated in the energy and water sectors as earlier predicted. Although damages are also predicted for the coastal sector, the present values of these damages are much smaller than previously considered. The net effect of this second wave of studies is to shrink our estimates of the market damages from climate change and even to imagine them being beneficial to the United States. Although these studies have made some significant improvements, it should be reiterated that they have not eliminated the uncertainty surrounding the overall estimates. The estimates remain highly uncertain.

TABLE 2

New Estimates of National U.S. Market Impacts in 2060 (billions 1998 USD/year)

Climate: Scenario: 1.5 C			
Sector	0% Prec	7% Prec	15% Prec
Agriculture	30.0	30.9	31.4
Forestry	0.9	3.8	6.7
Energy	–1.7	–3.1	–4.5
Water	–2.6	–0.4	2.7
Coastal	–0.1	–0.1	–0.1
Total	**26.5**	**31.0**	**36.1**

Climate: Scenario: 2.5 C			
Sector	0% Prec	7% Prec	15% Prec
Agriculture	25.3	25.8	26.1
Forestry	1.5	4.2	6.9
Energy	–5.3	–6.9	–8.3
Water	–4.8	–3.1	0.6
Coastal	–0.2	–0.2	–0.2
Total	**16.5**	**19.8**	**25.1**

Climate: Scenario: 5.0 C			
Sector	0% Prec	7% Prec	15% Prec
Agriculture	14.1	16.1	17.0
Forestry	1.5	9.1	7.8
Energy	–21.3	–25.7	–26.9
Water	–11.3	–9.0	–5.4
Coastal	–19.9	–9.9	–7.8
Total	**–19.9**	**–9.9**	**–7.8**

Sea level is assumed to rise 33, 66, 100 cm by 2100 in 1.5C, 2.5C, and 5.0C scenarios.
Climate change is assumed to be uniform across country and season.
Source: Mendelsohn, 2001.

All the studies in Mendelsohn and Neumann suggest that temperature has a quadratic effect on economic impacts in every market sector (except coastal structures which have a quadratic relationship with sea-level rise). That is, at low temperatures, warming is beneficial. However, each sector has a point where further warming becomes harmful. The point where impacts turn from benefits to damages varies across sectors. The maximum benefit temperatures for the water and energy sectors tend to be relatively low, close to the northern temperatures found in the United States. Agriculture seems to maximize near the current U.S. mean temperature. Outdoor recreation seems to maximize near the temperatures currently found in the southern U.S. and forestry has the highest maximum temperatures, apparently close to subtropical climates.

In the last few years, two more systematic impact studies have been conducted on the United States. The USEPA conducted a National Assessment Report that examines the effect of climate change on each region of the country (Reilly and Melillo, 2001). The authors of the original Mendelsohn and Neumann study have also conducted a regional assessment using the methods in their national study (Mendelsohn, 2001). The two sets of studies use many of the same authors to examine regional effects. However, the studies use very different climate scenarios. The National Assessment Report relies on the climate predictions of two General Circulation Models (GCM's): Canadian Climate Center (CCC) and the Hadley (UKMO) models. These two models have many attractive characteristics that led to their being chosen from the myriad of possible GCM's. Unfortunately, the two models generate similar and unusual scenarios that differ from the scenarios predicted by the rest of the GCM community. This does not necessarily make the scenarios wrong but it does suggest that the National Assessment Report is not representative of the full range of outcomes predicted by GCM's. The Mendelsohn study is also limited by the climate scenarios chosen because this study relies primarily on uniform change scenarios. Although the Mendelsohn study makes an attempt to examine regional climate variation, most of the results are based on scenarios that assume uniform changes in climate across regions and across seasons. The advantage of the uniform scenarios is that one can examine a full suite of climate outcomes including low and high temperature increases and low and high precipitation changes. However, the uniform scenarios do not capture the variation in climate change across space and time that the GCM's do. Thus, both studies could be criticized for their choice of climate scenarios.

Both the National Assessment Report and Mendelsohn (2001) find that regional impacts vary. That is, the impacts from climate change are not uniform across the country. The National Assessment Report finds this result partially because they utilize climate scenarios which themselves vary from region to region. However, the Report also generally finds that northern regions are much less vulnerable to warming than southern regions. The Report also finds that the regional distribution of impacts will vary across sectors. Regions that have important agricultural sectors will consequently be heavily affected by that sector. Regions with large vulnerable coasts and forests, such as the Southeast, will be relatively more vulnerable to impacts in those sectors.

TABLE 3

U.S. Regional Estimates of Market Impacts in 2060 (billions 1998 USD/year)

Region	Agri	For	Energy	Wat	Cst	**Total**
			Climate: Scenario: 1.5 C, 15%P			
Northeast	3.1	1.5	–0.7	0.0	–0.0	3.9
Midwest	7.5	1.3	–0.5	0.1	–0.0	8.4
N. Plains	5.3	1.1	–0.2	0.2	–0.0	6.5
Northwest	2.2	0.1	1.5	1.0	–0.0	4.8
Southeast	6.7	1.1	–2.0	0.2	–0.1	5.8
S. Plains	3.3	0.4	–1.7	0.2	–0.0	2.2
Southwest	2.7	1.1	–0.9	1.1	–0.0	4.0
			Climate: Scenario: 2.5 C, 7%P			
Region	**Agri**	**For**	**Energy**	**Wat**	**Cst**	**Total**
Northeast	3.2	2.2	–0.4	0.0	–0.1	4.9
Midwest	6.5	1.3	–0.2	–0.1	0.0	7.5
N. Plains	3.9	0.8	–0.1	–0.3	0.0	4.4
Northwest	2.0	–0.3	1.6	–1.8	–0.0	1.5
Southeast	5.7	–1.0	–3.5	–0.5	–0.1	0.6
S. Plains	2.0	0.3	–2.9	–0.2	–0.0	–0.8
Southwest	2.1	1.0	–1.4	–0.2	–0.0	1.4
			Climate: Scenario: 5.0 C, 0%P			
Region	**Agri**	**For**	**Energy**	**Wat**	**Cst**	**Total**
Northeast	1.8	2.6	–2.6	–0.1	–0.2	1.6
Midwest	3.6	1.0	–1.6	–0.5	0.0	2.4
N. Plains	2.7	0.5	–1.2	–1.2	0.0	0.8
Northwest	1.7	–0.6	1.6	–5.7	–0.0	–3.1
Southeast	3.6	–2.8	–9.5	–0.5	–0.2	–9.4
S. Plains	0.5	0.1	–6.7	–0.9	–0.0	–7.0
Southwest	0.5	0.6	–1.5	–2.5	–0.0	–2.7

Sea level is assumed to rise 33, 66, 100 cm by 2100 in 1.5C, 2.5C, and 5.0C scenarios. Climate change is assumed to be uniform across country and season. Source: Mendelsohn, 2001.

The Mendelsohn (2001) study is able to discern how regional impacts will change depending upon the severity of the forecasted climate change. Because the study relies solely on uniform climate scenarios, the differences across regions are due just to differences in climate sensitivity and initial climates. Despite the fact that all the scenarios assume uniform change across regions, as can be seen in Table 3, the impact in each region depends upon the climate change scenario. With a relatively mild scenario such as 1.5C, with a 15% increase in precipitation, the effects are more uniform across the entire country. The harmful effects of climate are small and the beneficial impact of carbon fertilization is felt universally. Every region benefits in this scenario and every sector

benefits, except the energy and coastal sectors. With a 2.5C increase, the benefits in the southern regions shrink and the damages increase, leaving them with almost a zero net effect. Benefits from warming continue to occur in the northern regions. The Pacific Northwest acts more like a southern than a northern region because of its mild current climate. With a 5C increase, damages in the southern regions become severe and all the southern regions are hurt. In the north, benefits just offset damages and these regions see little net effect. The study consequently suggests that the damages from warming are not likely to be uniformly felt across regions unless the climate scenarios turn out to be mild. With warming of 2.5C or more, the southern regions will be the first to be damaged and these damages will accelerate as warming continues.

The Mendelsohn (2001) study found one other useful insight. For market sectors such as agriculture and timber, the impact falls as much on the demanders in that sector as the suppliers. Prices for both agricultural goods and timber products are expected to change as a result of climate change. The distribution of who wins and loses thus does not depend upon just where the goods are produced. With mild scenarios in both sectors, prices are expected to fall. Consumers of food and timber products benefit everywhere. The consumer impacts of warming are shared across regions depending on population, not farmland or forestland.

As discussed in the next section, estimating global impacts is far more difficult than estimating impacts for the United States, the most heavily studied country in the world. The geographic distribution of climate is uncertain, the geographic distribution of economic activity is difficult to measure below national scales, and growth is hard to forecast. Perhaps the hardest task is determining the climate sensitivity of each country. Impact analysts first believed that every country would be damaged by warming. For example, Fankhauser (1995) assumes that every region is hurt by warming although he assumes that the OECD countries would suffer damages of only 1.3% whereas the poorer non-OECD countries would have damages closer to 1.6%. Tol (1995) allows the former Soviet empire to benefit from warming but assumes that all other regions will be hurt. Tol assumes that the OECD countries would suffer damages of 1.6% and the poorer non-OECD countries would have damages closer to 2.8% of GDP. Pearce et al. (1996) predicts damages between 1 and 2% for all developed countries and between 2 and 9% for developing countries. Nordhaus and Boyer (2000) assume that aggregate climate damages would vary between 0.5% and 3% of GDP for a 2.5C warming, Russia would gain 0.7%, and the poorer low latitude countries would suffer damages between 2 and 4%. All of the above estimates include both market and nonmarket impacts.

However, economic analyses of sectoral climate sensitivity are rare outside the United States. Many of the impact estimates for other countries come from the climate sensitivity functions estimated for the United States and have simply been fit to conditions in each country (Fankhauser, 1995; Tol, 1995; Mendelsohn et al., 2000). Empirical climate sensitivity studies are quite limited for the rest of the world. There has been one agronomic study of world agriculture (Rosenzweig and Parry, 1994). There have also been a host of agricultural studies in each country (Reilly et al., 1996; Iglesias and Minguez, 1997; Mendelsohn and Dinar, 1999). Most of these studies are agronomic analyses that might have examined some adaptations but did not examine whether the adaptations were efficient or not. For example, crop model analysis suggested that the yields of at least some grains could fall by 30–40% with warming in India (Rosenzweig and Parry, 1994). A cross-sectional study of agricultural impacts in India suggested that warming would be harmful to India but that the economic effects would be much smaller, with damages of between 9 and 21% depending on the climate scenario (Dinar et al., 1998). Empirical studies of the climate sensitivity of countries other than the United States are rare and almost nonexistent in low latitudes.

One major exception to this rule is the global timber study by Sohngen et al., (2001). This study relies on a global model of ecological change (Haxeltine and Prentice, 1996) and a complex dynamic general equilibrium model of forestry (Sohngen et al., 1999). Of course, the dynamic ecological model is a crude construction and the estimates of forest responses across the world are highly uncertain. Nonetheless, using a global model yields some important insights that the United States analyses missed. The global model suggested that subtropical regions could adapt quickly to the more productive conditions from carbon fertilization and warming and would actually cause a near term reduction in prices. This would hurt producers in mid- and high-latitude countries through 2050 as they were hit by dieback and slow adaptation. It is not until the second half of next century that the productivity gains in the mid and high latitudes would allow these regions to share in the production increases from warming. In short, although estimates of global impacts are currently only crude guesses, they nonetheless can provide useful insights that limited national studies miss.

The current state of the art of global impact assessment extrapolates from U.S. climate response functions to other countries to estimate impacts by sector. Conditions in each country are included in the analysis but the climate sensitivity does not come from each region. In the following analysis, we combine the U.S. response functions with new agricultural studies that have just been completed in India (Dinar et al., 1998). We improve slightly on previous estimates by relying on the Indian response function to predict what would happen to low income tropical countries. This is still far short of a desired objective of conducting empirical studies in each region.

The results suggest that warming will lead to large damages in the low-latitude countries and benefits in the high-latitude countries. With small changes in climate, the net effect will be a small global benefit. The fertilization benefits will at first outweigh the climate impacts. As warming exceeds 1.5C, however, the benefits from warming begin to shrink and the damages steadily increase. With large but uncertain benefits in the polar and temperate countries and large but uncertain damages in the low-latitude countries, the effects will initially be quite small, but it is not clear whether they are negative or positive. That is, the damages and benefits will balance each other at first. It is not clear at what temperature the net effects clearly turn harmful but it is likely that warming above 2.5C will be harmful.

In order to illustrate the types of results the new models provide, Tables 4 and 5 present some preliminary results for a uniform climate change scenario. Note that the uniform climate change scenario is not a good representation of climate change for the world as it misses the larger warming expected towards the poles. Two sets of results for the globe are presented for 2100. In Table 4, the estimates come from experimental-simulation models. In Table 5, the climate sensitivity results come from cross-sectional studies. Both tables imply that a mid-range climate forecast of 2.5C with a 7% precipitation increase would result in small net benefits for the globe. In Table 4, the net benefits amount to $85 billion/year for the globe. The low latitude countries of Africa, Asia, Latin America and Oceania suffer damages of $235 billion whereas the mid- and high-latitude countries of Europe, North America, and the former Soviet Union enjoy benefits of $320. With the cross-sectional results, the global effect from this climate scenario is $28 billion/year of benefits. However the cross-sectional model predicts less regional differences. The low-latitude countries suffer only $7 billion of damages and the mid- to high-latitude countries gain just $35 billion of benefits per year.

TABLE 4

Global Market Impacts by Region for 2100 Experimental-Simulation (billions 1998 USD/year)

			Climate: Scenario: 2.5 C, 7%P			
Region	Agric	Forest	Energy	Water	Coast	**Total**
Africa	–28.6	1.4	–4.6	0.5	–0.0	–31.2
Asia	–99.2	7.2	–18.1	–3.2	–0.9	–114.2
Lat America	–55.8	2.0	–16.2	1.0	–0.1	–69.1
Oceania	–17.5	0.4	–2.7	–0.8	–0.0	–20.7
USSR+EE	216.3	3.5	16.0	–21.0	–0.0	214.8
W. Europe	19.5	4.1	5.8	–3.8	–0.6	25.1
N. America	84.9	5.9	2.2	–12.2	–0.4	80.3
Globe	119.5	24.4	–17.6	–39.4	–2.0	14.9
			Climate: Scenario: 5.0 C, 15%P			
Region	Agric	Forest	Energy	Water	Coast	**Total**
Africa	–57.4	2.1	–10.1	2.6	–0.0	–56.8
Asia	–231.7	11.1	–50.8	–0.6	–3.7	–275.8
Lat America	–120.7	3.1	–35.8	3.9	–0.4	–149.9
Oceania	–17.7	0.5	–6.1	–1.0	–0.1	–24.4
USSR+EE	360.0	5.0	27.9	–39.5	–0.1	353.3
W. Europe	15.3	6.0	–2.6	–6.6	–2.4	9.6
N. America	108.6	8.5	–9.7	–22.1	–1.6	83.7
Globe	62.1	36.3	–87.3	–63.2	–8.4	–60.4

Source: Forecasts with GIM2.0 assuming uniform climate change. Sea level assumed to rise 0.5 and 1.0 m with 2.5C and 5.0C scenarios.

TABLE 5

**Global Impacts by Region for 2100
Cross-Sectional
(billions 1998 USD/year)**

Region	Agric	Forest	Energy	Water	Coast	**Total**
			Climate: Scenario: 2.5 C, 7%P			
Africa	–5.6	–0.2	–1.4	0.5	–0.0	–6.7
Asia	21.7	2.3	–3.0	–3.2	–0.9	16.9
Lat America	–9.0	0.0	–0.8	1.0	–0.1	–8.8
Oceania	–7.0	0.1	–0.5	–0.8	–0.0	–8.2
USSR+EE	12.5	5.2	11.2	–21.0	–0.0	7.9
W. Europe	2.3	3.3	12.0	–3.8	–0.6	13.2
N. America	18.6	3.5	4.3	–12.2	–0.4	13.8
Globe	33.5	14.1	21.9	–39.4	–2.0	28.3

Region	Agric	Forest	Energy	Water	Coast	**Total**
			Climate: Scenario: 5.0 C, 15%P			
Africa	–17.7	–1.0	–3.7	2.6	–0.0	–19.7
Asia	–20.6	1.5	–22.0	–0.6	–3.7	–45.3
Lat America	–28.1	–0.8	–3.6	3.9	–0.4	–29.0
Oceania	–18.1	0.0	–1.4	–1.0	–0.1	–20.7
USSR+EE	–16.5	8.5	16.3	–39.5	–0.1	0.3
W. Europe	–10.1	4.6	4.8	–6.6	–2.4	–22.3
N. America	0.4	4.0	–3.0	–22.1	–1.6	–22.3
Globe	–110.9	16.8	–2.6	–63.2	–8.4	–168.3

Source: Forecasts with GIM2.0 assuming uniform climate change. Sea level assumed to rise 0.5 and 1.0 m with 2.5C and 5.0C scenarios.

With a more severe 5C warming accompanied by a 15% precipitation increase, net effects become harmful. According to the experimental results, net global effects are $60 billion/year in damages. A $447 benefit in mid- and high-latitude countries mitigates a $507 billion loss in low-latitude countries. According to the cross-sectional model, almost every country is harmed. Global impacts amount to $168 billion in damages with low-latitude countries suffering $115 billion of these losses and mid- to high-latitude countries losing $44 billion each year. These simulations suggest that net global impacts on economies are likely to be small, especially compared to the predicted size of the world economy, around $200 trillion by 2100.

Note that agriculture plays a large role in the estimates in Tables 4 and 5. Agricultural impacts are frequently the same size as global net effects. That is, climate change impacts in agriculture across countries and across scenarios are the single most important impact. Energy and water also play a big role in more severe scenarios. Timber and coastal impacts, in contrast, are much smaller. Although previous studies supported many of these sectoral findings, the shrinking role of coastal impacts is in contrast with the early literature that thought coastal impacts would be the single

largest impact. This study does not follow this wisdom partly because forecasts of sea-level rise have shrunk over time and partly because dynamic analyses suggest this effect is much smaller than first thought.

REMAINING UNCERTAINTIES

Despite all the research that has been conducted to date on both the science and the economics of pollution impacts, uncertainty pervades damage estimates across all pollution control problems. The global nature, the uniqueness of climate change as a phenomenon, and the fact that climate change occurs so far into the future combine to cloud any estimate that we make concerning the damages from accumulating greenhouse gases. The uncertainty surrounding the impacts from climate change cannot be understated.

There are several sources of uncertainty. The link between emissions, climate change, and ecosystem change, the link between these changes and the quality of life, and the link between these changes and impacts on the economy are all sources of uncertainty. The fact that human emissions of carbon dioxide are causing increases in the observed concentrations of carbon dioxide is one of the more certain facts about greenhouse gases (Houghton et al., 1996). However, even this link is uncertain in the future. We cannot be sure that the carbon cycle will continue to behave as it now does. Sinks might get overloaded and sources might suddenly appear from the biosystem as the climate changes. Although further emissions will clearly lead to higher concentrations, how quickly concentrations rise given the level of emissions could change in the future.

The link between concentrations of greenhouse gases and radiative forcing also seems well understood. Controlled experiments reveal that greenhouse gases do in fact trap infrared energy. Examinations of planets strongly suggest that greenhouse gas atmospheres affect observed temperatures. However, the effect of concentrations of different gases at each altitude has proven to be more complex than first thought. How gases behave at different altitudes and how clouds might change in response to both radiative forcing and climate changes make the link between greenhouse gas concentrations and radiative forcing uncertain as well.

The link between increased radiative forcing and changes in our climate has always been poorly understood. It is very difficult to know how a complex system such as climate will be affected by a change that may never have happened before. It is clear that more heat will be trapped on the earth's surface and that this will speed the hydrological cycle. However, the magnitude of temperature and precipitation changes remains uncertain. Even less well-understood is how the distribution of climate change will unfold across the earth's geography. Ecosystems are undoubtedly going to be affected by changing climates. Precisely how they will react over time is not known. Productivities will certainly change and biomes are likely to shift. These changes will affect runoff and the hydrological cycle. They could also change how much light and heat is absorbed at the earth's surface and how winds will behave. How quickly changes will occur and what will happen during the transition is not known at this moment. In short, the biological and physical science underlying impact estimates is uncertain as to the magnitude and distribution of effects.

Even if the natural science links were completely understood, precise estimates of the damages from climate change would continue to elude us. We do not know what our economic system or lifestyle will be like even without climate change in a few decades much less by the end of the century. We do not know how sensitive our future economic sectors or quality of life will be to changes in climate. We do not know how important society judges these changes to be; that is, what values to associate with each change.

The impacts of specific climate scenarios on the American economy have been studied at depth. Despite this effort, uncertainty pervades even here. The size of impacts will depend upon how quickly the economy grows in general and specifically how quickly climate-sensitive sectors grow. The impacts will also depend upon the climate sensitivity of these future sectors. We can study how sensitive the current economy appears to be, but this may provide only an indication of future sensitivity. Future impacts will undoubtedly be dependent on how large each sector becomes in each region and what new technologies are adopted. Our ability to perform accurate long-run forecasts of all these phenomena is limited.

Estimating the impacts to the world economy is far more problematic. Our ability to estimate world economic development is even more primitive than forecasting American growth. Conditions across the world are far more heterogeneous and dependent on social, political, and cultural phenomenon that are beyond our current understanding. American climate responses suggest a hill-shaped relationship between economic welfare and temperature. These results imply that countries currently in warmer climates will be more vulnerable to warming. Unfortunately, these same vulnerable countries (low-latitude nations) also are the least developed, which likely compounds their climate sensitivity (Mendelsohn et al., 2001). Further, there is no clear economic theory why so many low-latitude countries are less developed. Our inability to explain the current growth rates of these countries clearly is not a good indication for our ability to make long-run projections. In summary, we are especially concerned about predicting what will happen to low-latitude countries. Current economic conditions are more uncertain, forecasts of growth are more uncertain, and measurements of climate sensitivity are more uncertain for tropical and subtropical countries.

Measuring the impacts of climate change to the quality of life could well be the most challenging of all the links between emissions and damages. Changes in ecosystems, life expectancy, and weather are all likely to be important to people. However, even today, we do not know how important these aspects of quality of life are to Americans. What would Americans pay to prevent biomes from shifting poleward, what is the value of increasing the risk of unspecified endangered species becoming extinct, how much should we count the increased risk of new tropical diseases entering our country, and what is the value of living in a slightly warmer climate? We do not know what these values are today, much less what we would pay far into the future. Compound this problem by extending the analysis to the entire world, across myriad cultures and beliefs and you quickly realize that the uncertainty surrounding the damage estimates of nonmarket climate effects is huge. The uncertainty surrounding these estimates is so large that it calls into question whether we currently can measure the magnitude of nonmarket climate impacts at all.

CONCLUSION

The IPCC has recommended that action be taken to prevent climate from changing enough to present a danger to mankind and the world. This policy initiative implies there may be some clear threshold that society does not want to cross. Such a threshold has eluded researchers to date, despite an avid search. It is clear that the more severe the temperature change, the higher the damage, above at least 2.5C. However, the evidence suggests a steadily increasing risk, not a threshold phenomenon.

Impact research by itself cannot determine an acceptable atmospheric concentration or on acceptable temperature change. The damages from the impacts must be weighed against the costs of abatement. This is why it is so important to place a dollar value on the magnitude of climate impacts.

One cannot underestimate the uncertainty surrounding our estimates of future climate impacts. The uncertainty surrounding impact estimates is a great weight that both scientists and policy makers concerned with climate change must carry. It depresses the bright enthusiasm of researchers to unfold the mysteries of climate and climate's relationship with the human race. It burdens anyone bold enough to recommend a climate policy to the world's population. Unfortunately, it is a weight that is unlikely to be lifted in the near term. Decisions about what to study and what to do about climate change will have to cope with this uncertainty for decades. Perhaps as we go through the experience of changing the earth's climate, we will learn a great deal about what will happen, what will happen to us, and how much we care. However, it is unlikely that the next few decades will provide the strength of signal over noise for us to learn a great deal. It may well be true that we will have to be far into the experience of climate change before much of this uncertainty will be lifted.

Initial research on impacts suggested that climate warming would be bad for all countries. Developed and developing countries all had an incentive to reduce emissions. However, the magnitude of damages found in the first wave of studies was not that great (Pearce et al., 1996). When placed in contrast to abatement costs, the damages suggested only a modest program of control. For example, Boyer and Nordhaus (2000) recommend that controls in 2000 be only 4% of potential emissions. These "optimal targets" are much lower than the Kyoto targets for Annex I countries since Kyoto asks for reductions not from 2000 levels but from 1990 levels.

However, the second wave of impact research has revealed that the first wave was biased upwards. The first wave of studies did not take efficient adaptation into account, did not conduct dynamic analyses of capital laden sectors, did not take carbon fertilization fully into account, and they overlooked many benefits from warming. Once these factors are accounted for, damage estimates from climate change fall substantially. In fact, it is likely that modest warming will be beneficial to the United States, not harmful as first thought. More severe warming of 5C will clearly be harmful but not nearly to the same degree as first thought. Extrapolating these results to the rest of the world reveals that net global damages from modest warming will be much smaller than first thought. Warming will clearly be harmful only with global temperature changes of 2.5 C or above. These new results suggest that there is very little motivation for carbon controls in the immediate future. Whereas controls by the end of the century may still make sense, the results imply that we have time to plan efficient long-term control strategies. There is little motivation to rush into expensive emergency short-term actions. Abatement strategies should focus on inexpensive long-term actions that can make a difference in the second half of this century.

The new empirical results contain another important policy insight. The impacts from global warming are not going to be shared equally as was originally thought. Some countries are likely to benefit, some are likely to be unaffected at first, and some will be hurt. Island countries will be disproportionately affected. The results suggest that there is a serious distributional problem associated with greenhouse gases where the countries that are doing the most emissions suffer the least consequences. The victims of global warming emissions will largely be the low latitude countries that contribute only a small share to emissions. Global warming policy must begin to deal with these distributional consequences.

The results strongly call for compensation of some kind being paid to the most severely impacted nations. Whether this compensation takes the form of emergency relief from weather catastrophes as they occur or payments today for future potential effects, carbon emitters should help the most vulnerable nations cope with the damages from global warming. Compensation today is an immediately attractive policy action. Paying compensation in advance is much less expensive than the mitigation programs suggested by climate scientists. Helping poor nations develop today can provide market and nonmarket benefits that are far greater than the long-term impacts from climate change. It is not necessary to count the value of lives or other nonmarket effects. The compensation program can save more people or ecosystems today than climate will ever threaten. Helping countries develop will undoubtedly make them more resilient to future climate change. Helping low-latitude countries develop may even lead to future markets and trade that benefit everyone. Finally, last but not least, compensating poor nations, and helping them reach their potential, is an important equity issue for rich nations that should be addressed for its own reasons.

About the Author: Dr. Robert Mendelsohn is a resource economist who specializes in valuing the environment. He received his BA from Harvard where he graduated magna cum laude in 1973. He then received his PhD in economics from Yale University in 1978 and has taught at the University of Washington, the University of Michigan, and for the last 14 years at Yale University, where he is now the Edwin Weyerhaeuser Davis Professor in the School of Forestry and Environmental Studies.

Dr. Mendelsohn began his research career with a dissertation estimating the damage of air pollution emissions from fossil fuel plants using an integrated assessment model. He went on to develop methods to value local hazardous waste pollution, local wildlife populations, recreation areas, oil spills, and non-timber products from tropical forests. Over the last 8 years, Dr. Mendelsohn and his colleagues have been involved in measuring the impacts from climate change.

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