The Economic Impacts of Abrupt Climatic Change

William D. Nordhaus, Yale University

Paper prepared for a Meeting on Abrupt Climate Change: The Role of Oceans, Atmosphere, and the Polar Regions, National Research Council, January 22, 1999

Abstract

The present note investigates alternative approaches to estimating the economic impact of abrupt climate change. A number of different approaches are reviewed: surveys, time-series methods, sectoral studies, capital-stock-depreciation estimates, and threshold analyses. None of these is uniformly better than the others, and each has a niche in illuminating the major issues.

In terms of current knowledge, four tentative conclusions seem warranted. First, the major concern with climate change for high-income countries like the United States is from the potential for abrupt and unforseen climate change. Second, because the sources of abrupt climate change are poorly understood, it is difficult at present to link economic policies to abrupt climate change. Third, it must be emphasized that knowledge about the impact of abrupt climate change is extremely thin. Finally, from a social point of view, we must emphasize the crucial role of getting the geophysical facts right. Estimating the economic and social impacts, and designing and selling the appropriate policies, is virtually impossible without a clear and convincing scientific prognosis of the nature and timing of the abrupt climatic events.

Preliminary and For Discussion Purposes

Introduction

1. This note reviews the evidence on and alternative approaches to estimating the economic and social impacts of abrupt climate change. There has been extensive study of the impacts of what might be called "routine" climate change. This represents the gradual change in global mean temperature of 2 ºC to 4 ºC over the next century or so. The question reviewed here is the impact of more rapid and perhaps erratic changes in climate.

2. A number of recent reports emphasize that current climate is much more stable than were climates in earlier period; moreover, it appears that the climate has multiple, locally stable states with highly differentiated variability. Overpeck and Webb label this a *new paradigm of climate variability*: "Abrupt climate change now is recognized to be widespread throughout history, and many different variability states over all time scales of variability have been identified within the climate system."[1] Earlier research tended to focus on high variability in cool or transitional periods, but recent work emphasizes that "warm climate surprises" are also a feature of the historical record.[2] A recent IPCC workshop reviewed knowledge of non-linearities, focusing on variabilities and transitions of thermohaline circulation, ice-mass instability, nonlinear feedbacks in biogeochemical cycles, and feedbacks and nonlinear processes in radiative forcing and the climate system.

3. It appears that we know very little about the causes of abrupt climatic change. There is evidence for large shifts in the climatic record (such as the Younger Dryas). Moreover, changes in the thermohaline circulation (THC) might well be involved in major changes. However, there is no convincing evidence that changes in THC are in fact the cause of the abrupt changes.

4. From the point of view of policy, the key issue is whether human actions are affecting the conditional probabilities or transition probabilities of moving from the current relatively stable climate to a "flickering" state or into an abrupt event. One question is whether abrupt changes occur more frequently coming out of glacial periods, which would suggest that greenhouse warming would not increase the transition probabilities. On the other hand, given that we have been living in a unusually stable climatic regime, it might be argued that major changes in the current regime would increase the probability of an abrupt climatic change. This is clearly an open question.

---

[1] Overpeck and Webb [1998], p. 3.

[2] Overpeck [1996].

5. The major link from human activities to major climate changes is the prospect that significant warming could lead to a slowdown or reversal of the THC. Studies of Manabe and Stouffer and Stocker and Schmittner indicate that a major warming or a rapid warming could lead to slowing the THC with a major change in the climate of the North Atlantic region. In economic model runs below, we investigate the linkage between economic and emissions scenarios and the possibility of crossing a THC threshold. More generally, however, we want to know how serious a peril to our economies is abrupt climatic change.

6. Appropriate policies for abrupt climate change will depend critically on understanding the linkage between human activities and those events. For events that may be triggered by human activity, such as changes in the thermohaline circulation, there is in principle a clear link between industrial activity and the abrupt climate change. However, for events that are essentially exogenous (such as solar variability or volcanic activity), it is not clear that slowing climate change is the appropriate policy. Rather, if there is suspicion that we are headed into a more variable climate, then measures to promote adaptation are likely to be more efficient than measures that reduce greenhouse gas (GHG) emissions. There are many steps that can be taken to reduce vulnerability to climatic shifts or weather extremes. Ironically, in some cases, such as volcanic cooling, a case could be made that modest warming would be desirable because the volcanic cooling would then lead to less cooling relative to a baseline climate.

Impacts of Climate Change on the Economy

7. What are current findings on the economic impact of climate change?[3] To begin with, it must be emphasized that our knowledge of the impacts of routine future climate changes is meager. For purposes of this paper, I will assume that slow climate change has relatively little impact on human societies. This is the thrust of current economic evidence, although it must be emphasized that many components are speculative. Table 1 shows the vulnerability of different industries in the U.S. to climate change. Tables 2 and 3 shows a recent survey of the impact of a 2.5 ºC global warming by major region and major sector. While the impact is small relative to the overall size of the economy (see Table 2), the absolute impacts are large, particularly in some regions (see Table 3). None of the studies, however, investigates a rapid or abrupt climate change, although Tables 2 and 3 incorporate estimates of the costs of "catastrophic climate change."

Alternative Approaches to Estimating Impacts of Abrupt Climate Change

[3] The IPCC has made a number of reviews. Also see Fankhauser [1992, 1994]. I have summarized results in a recent study, Nordhaus [1998].

8. There is very little work to date on estimating the economic and society impacts of abrupt climate change. In this note, I suggest and illustrate five different approaches which might be used: (1) expert opinion, (2) time-series approaches, (3) sectoral approaches, (4) capital-stock-depreciation estimates, and (5) threshold analysis.

Expert Opinion

9. One of the major difficulties with investigating abrupt climate change is that the problem is complex and difficult to model. In such a situation, it might be useful to make a systematic survey of expert opinion. Nordhaus undertook a survey on the impacts of climate change.

10. This survey asked about the probability of catastrophic events. It had the following question:

> "Some people are concerned about a low-probability, high-consequence output of climate change. Assume by "high-consequence" we mean a 25 percent loss in global income indefinitely, which is approximately the loss in output during the Great Depression. (a) What is the probability of such a high-consequence outcome for scenario A, i. e., if the warming is 3 degrees C in 2090 as described above? (b) What is the probability of such a high-consequence outcome for scenario B, i. e., if the warming is 6 degrees C in 2175 as described above? (c) What is the probability of such a high-consequence outcome for scenario C, i. e., if the warming is 6 degrees C in 2090 as described above?"[4]

The respondents showed greater relative concern about the large-temperature-increase and rapid-temperature-increase scenarios. The median probability of extremely unfavorable impacts was 0.5 percent for the 3-degrees-C-in-a-century scenario A; 2.0 percent for scenario B; 5 percent for scenario C with 6-degrees-C-in a century. The assessment of the catastrophic scenarios varied greatly across respondents and particularly across disciplines.

11. The usefulness of the survey approach is that it can include a wide variety of disciplines and approaches. The drawback is that, like a dog's breakfast, you never know what's in it.

[4] Nordhaus [1994a].

Time Series Approaches to Estimating Impacts

12. One approach that has not been used in impacts studies is the time-series approach. This is widely used in economics to investigate many phenomena, and involves estimating relationships between different variables using time series and structural specifications.

13. Time series approaches are not useful for estimating the long-run impacts of climate change because they measure the short-run impacts. However, this approach might be useful for examining the impact of abrupt changes, for these are similar to extreme weather events.

I have examined the relationship between annual GDP growth and global average temperature over the period 1880-1997 to determine whether there is evidence of a relationship between economic activity and short-run weather. Figure 1 shows a non-parametric kernel regression of the residual from a regression of the log of real GDP on time, time squared, and two lagged log output terms on the world temperature anomaly. The vertical scale should be interpreted as follows: a 0.01change on the vertical axis represents a 1 percent deviation in output. The range of temperature changes is relatively small (about one degree C), but there is no statistically significant relationship between temperature and the economy.

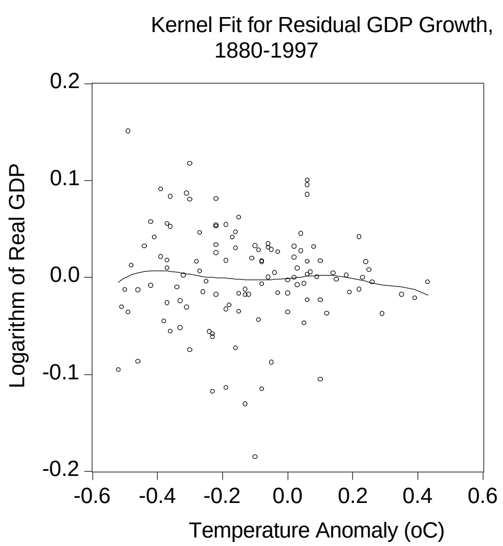


Figure 1. Relationship between U.S. output and global temperature anomaly, 1880-1997. The solid line is the non-parametric relationship.

14. Extending the time-series approach would be relatively simple because we have good historical data on both temperature deviations and on output movements. This could be done for countries or regions within countries, and it could use individual sectors, such as agriculture. The major disadvantage of this approach is that the range of temperature deviations is limited, so that it could not estimate the impact of really huge climatic changes; moreover, it is generally limited to market sectors.

Sectoral Approaches

15. One promising approach would be to focus on individual sectors and undertake careful engineering and economic modeling of that sector. This approach has been the one used in most studies of the routine impacts of climate change. This could rely on historical and other evidence about the climatic sensitivity of different sectors.

16. If this approach were taken, there are a few obvious sectors to examine. Perhaps the most important is agriculture, which is the sector most heavily affected by weather and climate. Current studies indicate that the impact of modest and gradual climate change on agriculture is relatively modest. For example, my recent survey finds that the impact of a 2½ ºC gradual warming is likely to reduce agricultural value by between 0.1 and 0.2 percent of global income. (See Table 2.) However, it seems likely that abrupt climatic changes would disrupt agriculture, particularly for perennial crops like coffee and citrus fruits, and might have significant impacts upon forests. This is a fruitful area for research, but I know of none to date.

Another important area for research is water availability. This is important for agriculture as well as many industrial and household uses. Water research has been complicated because of poor data on use and transactions, however.

Impacts of Abrupt Change Looking at Capital Stocks

17. Another promising approach would be to examine the impact of abrupt climate change on the value of capital stocks. The basic idea is that much of society's capital is specifically designed for given sectors, locations, and even firms. A significant fraction of the capital stock would be rendered obsolete if there were rapid and unanticipated climate change. A rapid sea-level rise (SLR) would inundate or threaten dwellings; severe changes in climate would destroy many perennial crops, such as forests, vineyards, or fruit trees; changes in river runoff patterns would reduce the value of river facilities and flood-plain properties; warming would make ski resorts less valuable and change the value of recreational capital; changes in climate would reduce the value of improperly insulated, heated, and cooled houses. There might also be an impact on more intangible investments such as technological and "taste" capital, although this is more speculative.

The loss in capital value will depend upon the degree of abruptness of the climate change and upon the lifetimes of the capital. For very short-lived capital, such as computers or inventories of crops, climate change occurring over two or three decades would have little impact. On the other hand, for dwellings and infrastructure, which have lifetimes of 50 to 100 years, abrupt climate change could reduce the capital value significantly.

18. The most careful study of the dynamics of capital-stock depreciation under different climate-change scenarios is that of Gary Yohe and his colleagues. For this

purpose, I will review Yohe and Schlesinger [1998]. Their study includes a detailed simulation of the market value of land and structures of developed coastal structures in the U.S. on 500 meter by 500 meter samples of U.S. coastal properties. They compare the economic losses from perfectly anticipated and completely unanticipated sea-level rise of from 10 to 100 meters over the next 100 years. This is a particularly important example both because the capital stocks are long-lived compared to the average capital stock of the economy and because this is among the most vulnerable capital of the economy. This sector is probably less vulnerable to abrupt climate change than other sectors, however, because of the inertia in sea-level rise.

The key results of the Yohe-Schlesinger study are shown in Table 4. The top half shows the estimated transient impacts (that is, the flow damages in undiscounted dollars per year) for two different years and three different sea-level rise scenarios. These could be thought of as low, best-guess, and rapid sea-level rise scenarios. Not surprisingly, the high SLR scenarios show much higher damages. The bottom panel shows the ratio of the costs in the myopic case to the case of perfect foresight. Under perfect foresight, the property owner is assumed to optimize the depreciation schedule in light of the need for abandonment when SLR makes the structure unhabitable. Under the myopic case, the owner continues to operate and maintain the dwelling assuming no SLR until forced to abandon. The ratio of the myopic to the perfect-foresight case ranges from 1.02 for 2050 with slow SLR to 1.49 for 2100 and the rapid SLR case. The interpretation for our purpose is that an abrupt SLR of about one meter could add about 50 percent to the cost of coastal structures damaged by SLR.

19. We can extend the Yohe-Schlesinger analysis to the entire economy using simplified distributions of capital stocks, lifetimes, and rates of obsolescence. We draw upon the Commerce Department's IIESA accounts, which are the most comprehensive set of accounts for social capital and include some environmental capital variables as well.[5] The total capital U. S. capital stock for 1987 (the latest year for which estimates are available) was valued at $24.4 trillion (in 1998 prices).

To provide an upper-bound estimate of the economic impact of abrupt climate change, we assume that all climate-sensitive capital is rendered obsolete by an abrupt climatic change. The change is assumed to be completely unanticipated, and the change is assumed to occur alternatively during a period of 10, 20, 50, or 100 years. For simplicity, we assume that the obsolescence schedule is centered on the mid-point of the period of change (e.g., 5, 10 , 20, or 50 years). The depreciation schedule is derived

[5] See *Survey of Current Business* [1994].

from patterns used by the Bureau of Economic Analysis in constructing the National Income and Product Accounts.[6]

Tables 5 and 6 show the results of this calculation. It must be emphasized that these should be seen only as order-of-magnitude calculations and apply to the extreme case of no foresight at all and assume a major obsolescence of the U.S. capital stock. Table 6 shows that the overall impacts might be substantial: a capital loss of between $1.3 and $2.3 trillion depending upon the period of obsolescence (4.2 and 8.7 percent of the capital stock, respectively). These represent between 0.8 and 1.7 percent of annual GDP in annuitized form. Table 5 shows the major areas of vulnerability. The most vulnerable sectors in dollar terms are residential structures and agricultural and forest land. Note that these values are almost ten times larger than the values associated with routine climate damages shown in Table 2.

20. These estimates can usefully be compared with the damages from severe hurricanes. Hurricane Andrew hit the Miami area in 1992. Maximum sustained surface wind speed were estimated to have been 145 mph, with gusts near 175 mph. Andrew came ashore near high tide and brought with it a 17 foot storm tide (the sum of the storm surge and astronomical tide) into Biscayne Bay, a record maximum for the southeast Florida peninsula. The number of homes destroyed was 25,524 and 101,241 were damaged. According to NOAA, it caused about $25 billion of damages in Dade county. These estimates include not only property damages but loss of life and other costs.[7]

The Miami metropolitan district has a per capita income very close to the national average and has a population about 0.8 percent of the national total. The total damage was about 23 percent of the estimated tangible capital in the Miami metropolitan area. The methodology used here predicts a loss of $11 billion, or about 10 percent of the capital stock, for abrupt climate change. However, the climatic vulnerability to severe hurricanes is probably larger than the vulnerability to abrupt climate change estimated here. It would be useful to do a more detailed study to determine the source of the discrepancy as a way of testing the capital-stock methodology used here for examining the economic costs of unforeseen climatic events.

Threshold Analysis:
The Potential for Triggering Thermohaline Circulation Reversals

---

[6] This follows Katz and Herman [1997]. Lifetimes are drawn from that article where available and from the IEESA accounts in *Survey of Current Business* [1994] where appropriate.

[7] See the discussion at http://www.ncdc.noaa.gov/satgallery/ hurricanes/andrew92/ andrew.html.

21. Concerns about climate change increasingly focus on the "catastrophic" impacts. Among the potential severe events are a sharp rise in sea level, shifting monsoons, a runaway greenhouse effect, collapse of the West Antarctic Ice Sheet, and changing thermohaline circulation (THC). At present, there has been little systematic modeling of the prospects or costs of triggering catastrophic events.

22. Recent work has investigated the potential for triggering a change in the THC. For this calculation, I have used a recent version of the "DICE model" of climate change and the economy. The DICE model integrates in an end-to-end fashion the economics, carbon cycle, climate science, and impacts in a highly aggregated model that allows a weighing of the costs and benefits of taking steps to slow greenhouse warming. The DICE model is a globally aggregated version of the more detailed "RICE model," which is a 13-region model of the global economy.[8]

23. The issues investigated here are two: (1) According to current estimates of the trajectory of the world economy, are we likely to trigger a slowdown or reversal of the THC? (2) What impact would alternative approaches to climate-change policy have upon the likelihood of triggering a THC reversal?

24. We adopt the analysis of Stocker and Schmittner for the purposes of determining the potential for triggering a reversal of the THC.[9] That study has been adopted by Toth, Petschel-Held, and Brucker to provide both ranges of temperature and temperature change as well as low and high sensitivities.[10] Their ranges are shown in Figure 2. We have further simplified by (1) taking the climate change only for the next 200 years and (2) assuming that the rate of change of temperature is constant over this period. The solid straight line out of the origin marked "rate line" in Figure 2 shows the locus of constant rate trajectories which attain the given rate of change on the horizontal axis in 200 years. The points marked *L*, *SS*, and *H* in Figure 2 are then the thresholds associated with low sensitivity, the Stocker and Schmittner threshold, and high sensitivity. The threshold points used in the following runs of the DICE model are 3.9 ºC for the high hydrological sensitivity (point *H* in Figure 2), 5.2 ºC for the Stocker-Schmittner estimated threshold (point *SS* in Figure 2), and 6.6 ºC for the low hydrological sensitivity (point *L* in Figure 2).

[8] The original version of the DICE model can be found in Nordhaus [1994b]. A short version appears in Nordhaus [1992]. The 1998 update of the models, available in manuscript, is Nordhaus and Boyer [1998].

[9] Stocker and Schmittner [1997].

[10] Toth et al. [1998].

25. Using the DICE-98 model, we can made an estimate of the chance of crossing a THC boundary. The runs indicate that the “baseline” run (using the best-guess parameters) is comfortably away from the THC threshold over the next 200 years. The baseline run estimates that the global temperature increase over the next 200 years is around 3.3 ºC, which is marginally below the high hydrological sensitivity and well below the S&S estimated threshold of 5.2 ºC.

26. Economists have analyzed alternative policies to slow global warming. These generally involve imposing carbon taxes or other way of inducing emissions reductions. The RICE-98 model calculates a number of different approaches. One approach, which is called the “optimal” policy, sets the carbon taxes to balance the costs and benefits of emissions reductions. If countries follow what we estimate to be the optimal policy, the temperature increase is estimated to be 2.6 ºC over the next 200 years.

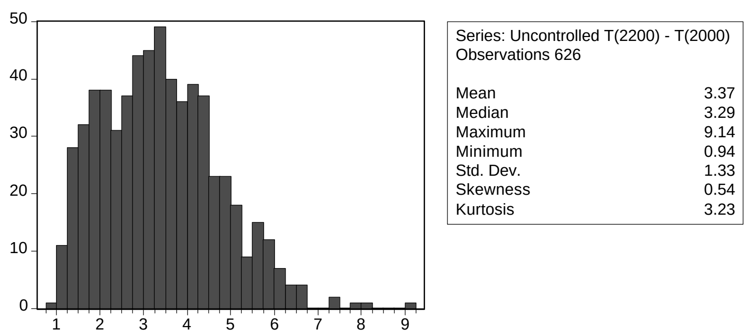


Figure 3. Distribution of temperature change over next 200 years from DICE-98 model with no climate-change policy. Horizontal axis is the estimated increase in global mean temperature (ºC) from 2000 to 2200.

27. The estimated trajectories for the baseline and optimal path do not take into account the geophysical and economic uncertainties about future climate change. There have been several studies investigating the uncertainties about future warming, and these indicate that the range of possible future outcomes is extremely large. It is therefore useful to consider the possibility that because of high economic growth, less rapid decarbonization, or high temperature-GHG sensitivity, the trajectory of climate change might differ from the baseline DICE model estimates.

To analyze this issue, I used Monte Carlo simulations of the original DICE model and adjusted those to fit the central case of the DICE-98 model. In a study of the uncertainty of future climate change, Nordhaus and Popp [1996] estimated the uncertainty of the temperature change over the 1990-2100 period. For the present simulations, I assume that the dispersion over time conforms to a model with independent and identical multiplicative increments (such as the additive log-normal distribution). Using that assumption, I then adjust the distributions from Nordhaus and Popp to the central trajectory in DICE-98.[11]

Figure 3 shows the distribution of temperature increases from the adjusted Monte Carlo runs for the uncontrolled case (without any climate-change policies). According to this simulation, there is a 34 percent probability of hitting the high-sensitivity threshold, a 9 percent probability of hitting the S&S threshold, and a 1 percent probability of hitting the low-sensitivity threshold.

Figure 4 shows the distribution of temperature increases from the runs with the optimal carbon tax. That is, carbon taxes in this case were set to balance the costs and benefits of emissions reductions. In the optimal simulations, there is a 12 percent probability of hitting the high-sensitivity threshold, a 1 percent probability of hitting the S&S threshold, and a negligible (less than ½ percent) probability of hitting the low-sensitivity threshold.

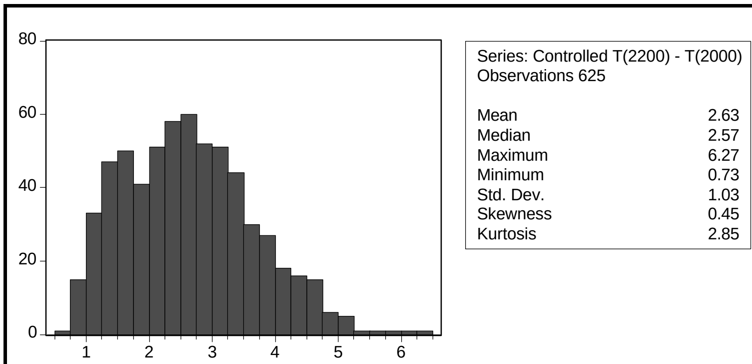


Figure 4. Distribution of temperature increases over next 200 years with "optimal" carbon taxes to slow climate change. Horizontal axis is the estimated increase in global mean temperature (ºC) from 2000 to 2200.

In summary, in the uncertainty analysis, the probability of hitting the threshold at which the thermohaline circulation shuts off is estimated to be 9 percent in the case where there is no climate change policy and is reduced substantially to around 1 percent in the case of optimal climate change policies.

[11] The runs to generate the distribution of temperature increases draw from earlier studies of the uncertainty about future climate change, particularly Nordhaus and Yohe [1982], Nordhaus [1994], and Nordhaus and Popp [1996]. The basic distribution of temperature change comes from the runs for Nordhaus and Popp. These use a Monte Carlo simulation of seven uncertain variables to generate a distribution of the major uncertain variables. The estimates are tabulated only for the first 100 years. These fit a model with independent increments reasonably well, so the estimate of the uncertainty is calibrated to the distributions from those runs.

Summary

28. The present note investigates alternative approaches to estimating the economic impact of abrupt climate change. There are a number of different methodologies suggested here. None of these is uniformly better than the others, and each has a niche in illuminating the major issues. Particularly fruitful areas of potential research are sectoral studies and time-series approaches, neither of which has been used for this purpose to date.

29. In terms of current knowledge, three tentative conclusions seem warranted. First, the major concern with climate change for high-income countries like the United States is from the potential for abrupt and unforseen climate change. The economic impacts of abrupt change are likely to be significantly larger than foreseen routine climate change; estimates provided above suggest that the costs of rapid change could be 2 to 10 times larger than routine climate change.

Second, because the sources of abrupt climate change are poorly understood, it is difficult at present to link economic policies to abrupt climate change. One source of rapid change that has been linked to human sources is the change in thermohaline circulation. The modeling results here indicate that the "best-guess" trajectory for the global economy puts the rate of change and the amount of temperature change over the next 200 years well below the threshold for triggering a reversal of the THC. However, given economic and geophysical uncertainties, there appears to be a non-trivial probability that the threshold will be crossed in the next 200 years, although that probability can be substantially reduced if sound policies to slow global warming through such measures as carbon taxes are used.

Third, it must be emphasized that knowledge about the impact of abrupt climate change is extremely thin. There are virtually no climatic scenarios to work with; there has been virtually no study of the economic impacts; and all the work has taken place for high-income countries, such as the United States. This is clearly a fruitful area for collaborative research between physical and social scientists, and much more research will be necessary before a secure understanding of the processes is attained.

Finally, from a social point of view, we must emphasize the crucial role of getting the geophysical facts right. Estimating the economic and social impacts, and designing and selling the appropriate policies, is virtually impossible without a clear and convincing scientific prognosis of the nature and timing of the climatic events.

References

Edmonds, J. A., J. M. Reilly, R. H. Gardner, and A. Brenkert [1986]. *Uncertainty in Future Energy Use and Fossil Fuel CO_2 Emissions 1975 to 2075*, Department of Energy, DOE/NBB-0081, December.

Fankhauser, Samuel [1993]. "The Economic Costs of Global Warming: Some Monetary Estimates," in Kaya et al. [1993].

--------- [1995]. *Valuing Climate Change*, Earthscan, London.

IPCC [1998]. Intergovernment Panel on Climate Change, *IPCC Workshop on Rapid Non-Linear Climate Change*, Report on a Workshop, 31 March - 2 April 1998.

Katz, Arnold J. and Shelby W. Herman [1997]. “Improved Estimates of Fixed Reproducible Tangible Wealth, 1929-95,” *Survey of Current Business*, May, pp. 69.

Nordhaus ,William D. [1992]. "An Optimal Transition Path for Controlling Greenhouse Gases," *Science*, vol. 258, November 20, pp. 1315-1319.

---------- [1994a]. "Expert Opinion on Climatic Change," *American Scientist*, January-February, vol. 82, pp. 45-51.

----------- [1994b]. *Managing the Global Commons: The Economics of Climate Change*, MIT Press, Cambridge, MA., 1994.

----------- [1998a]. “New Estimates of the Economic Impacts of Climate Change,” Yale University, processed, October 13.

Nordhaus, William D. and Joseph Boyer [1998]. *Roll the DICE Again: The Economics of Global Warming*, mimeo, December 15, 1998.

Nordhaus, William D. and David Popp [1997]. "What is the Value of Scientific Knowledge? An Application to Global Warming Using the PRICE Model," *The Energy Journal,* vol. 18, No. 1, pp. 1-45.

Nordhaus, William D. and Gary Yohe [1983]. "Future Carbon Dioxide Emissions from Fossil Fuels," in National Research Council [1983].

Statistical Abstract [1997]. *Statistical Abstract of the United States,* U.S. Government Printing Office, Washington, D.C.

Overpeck, Jonathan and Robert Webb [1998]. “Abrupt Climate Change, Climate Surprises, and Society: A PAGES/CLIVAR Perspective,” mimeo, NOAA, September.

Overpeck, Jonathan [1996]. “Warm Climate Surprises,” *Science*, 29 March, pp. 1820-21.

Manabe, S. and R. J. Stouffer [1993]. "Century-Scale Effects of Increased Atmospheric CO_2 on the Ocean-Atmospheric System," *Nature*, vol. 364, July 15, pp. 215-218.

Stocker, Thomas F. and Andreas Schmittner [1997]. “Influence of CO2 emission rates on the stability of the thermohaline circulation,” *Nature*, 28 August, 1997, pp. 862-865.

Survey of Current Business [1994]. “Integrated Environmental and Economic Accounts,” April.

Toth, Ferenc, Gerhard Petschel-Held, and Thomas Bruckner [1998]. “Kyoto and the long-term climate stabilization,” Potsdam Institute for Climate Impact Research (PIK), mimeo.

Yohe, Gary, James Neumann, Paul Marshall, and Holly Ameden [1996]. "The economic cost of sea level rise on U. S. coastal properties from climatic change." *Climatic Change*, 996, 32, pp. 387-410.

Yohe, Gary W. and Michael E. Schlesinger [1998]. “Sea-Level Change: The Expected Economic Cost of Protection or Abandonment in the United States,” *Climatic Change*, vol. 38, pp. 337-342.

Table 1

Vulnerability of Current U.S. Economy to Climate, 1994

Sector	*Gross Domestic Product Output (billions)*	*Percent of Total*	
Gross Domestic Product	**6931.4**	**100.0**	**100.0**
Major Potential Impact			**1.7**
Farms	82.2	1.2	
Agricultural services, forestry, fisheries	35.7	0.5	
Moderate Potential Impact			**4.2**
Water transportation	10.6	0.2	
Energy (c)	82.3	1.2	
Real estate: coastal property (a)	60.5	0.9	
Hotels and other lodging places	56.1	0.8	
Outdoor recreation (b)	81.2	1.2	
Negligible Impact			**94.1**
Mining	90.1	1.3	
Construction	269.2	3.9	
Manufacturing	1197.1	17.3	
Transportation, communications, and public utilities less moderate impact	513.5	7.4	
Finance, insurance, and real estate less moderate impact	1213.2	17.5	
Trade, wholesale and retail	1071.8	15.5	
Services less hotels and recreation	1205.4	17.4	
Government and statistical discrepancy	962.6	13.9	

Notes: "Potentially major impact" is more than 10 percent of output from 2.5oC global warming.
"Potential moderate impact" is between 2 and 10 percent of output from 2.5oC global warming.
"Negligible impact" is impact less than 2 percent of output from 2.5oC global warming.

Sources and notes: Data are based on the U. S. National Income Accounts, Survey of Current Business, August 1996.

(a) Assumes that 10 percent of real estate is vulnerable to sea-level rise or other climate-change features.
(b) Hunting, fishing, boating, golf, and national park expenditures, less lodging.
(c) Estimate of energy use for heating and cooling as well as hydroelectric sources.

[ipictab1]

Source: Nordhaus [1998a]

Table 2

Impact of 2.5 degree warming on different sectors:

[Positive numbers are damages; negative numbers are benefits; impacts measured as percent of market incomes]

	TOTAL [2.5 degree]	Agriculture	Other vulnerable mkt	Coastal	Health	Non-market time use	Settlement	Catastrophic impact [2.5 degree]	Catastrophic impact [6 degrees]
United States	***0.45%***	0.06%	0.00%	0.11%	0.02%	-0.28%	0.10%	0.44%	2.97%
China	***0.22%***	-0.37%	0.13%	0.07%	0.09%	-0.26%	0.05%	0.52%	3.51%
Japan	***0.50%***	-0.46%	0.00%	0.56%	0.02%	-0.31%	0.25%	0.45%	3.04%
EU	***2.83%***	0.49%	0.00%	0.60%	0.02%	-0.43%	0.25%	1.91%	13.00%
Russia	***-0.65%***	-0.69%	-0.37%	0.09%	0.02%	-0.75%	0.05%	0.99%	6.74%
India	***4.93%***	1.08%	0.40%	0.09%	0.69%	0.30%	0.10%	2.27%	15.41%
Other high income	***-0.39%***	-0.95%	-0.31%	0.16%	0.02%	-0.35%	0.10%	0.94%	6.39%
High-income OPEC	***1.95%***	0.00%	0.91%	0.06%	0.23%	0.24%	0.05%	0.46%	3.14%
Eastern Europe	***0.71%***	0.46%	0.00%	0.01%	0.02%	-0.36%	0.10%	0.47%	3.23%
Middle income	***2.44%***	1.13%	0.41%	0.04%	0.32%	-0.04%	0.10%	0.47%	3.21%
Lower-middle income	***1.81%***	0.04%	0.29%	0.09%	0.32%	-0.04%	0.10%	1.01%	6.86%
Africa	***3.91%***	0.05%	0.09%	0.02%	3.00%	0.25%	0.10%	0.39%	2.68%
Low income	***2.64%***	0.04%	0.46%	0.09%	0.66%	0.20%	0.10%	1.09%	7.44%
Global [a]									
Output weighted	***1.50%***	***0.13%***	***0.05%***	***0.32%***	***0.10%***	***-0.29%***	***0.17%***	***1.02%***	***6.94%***
Population weighted	***2.19%***	***0.17%***	***0.23%***	***0.12%***	***0.56%***	***-0.03%***	***0.10%***	***1.05%***	***7.12%***

Source: Nordhaus [1998a]

Table 3

Impact of 2.5 degree warming on different sectors Measured at 1994 Output Levels

[Positive numbers are damages; negative numbers are benefits; impacts measured in billions of 1998 U.S. dollars]

	TOTAL [2.5 degree]	**Agriculture**	**Other vulnerable mkt**	**Coastal**	**Health**	**Non-market time use**	**Settlements**	**Catastrophic impact** [2.5 degree]	[6 degrees]	Item: 1995 GDP [billions of 1998 US $]
United States	**32**	4	0	8	1	-20	7	31	213	7,156
China	**2**	-3	1	0	1	-2	0	4	25	702
Japan	**19**	-17	0	21	1	-12	9	17	113	3,730
EU	**245**	42	0	52	2	-37	22	165	1,124	8,647
Russia	**-3**	-3	-1	0	0	-3	0	4	27	398
India	**20**	4	2	0	3	1	0	9	61	399
Other high income	**-6**	-14	-4	2	0	-5	1	13	92	1,436
High-income OPEC	**5**	0	3	0	1	1	0	1	9	276
Eastern Europe	**3**	2	0	0	0	-2	0	2	15	463
Middle income	**40**	18	7	1	5	-1	2	8	52	1,637
Lower-middle income	**25**	1	4	1	4	-1	1	14	95	1,384
Africa	**8**	0	0	0	6	1	0	1	5	205
Low income	**17**	0	3	1	4	1	1	7	47	634
Global										
1994 output levels	**2,285**	*36*	*13*	*87*	*28*	*-78*	*45*	*276*	*1,878*	*27,066*

Source: Nordhaus [1998a]

Table 4

Transient Costs of Sealevel Rise on Developed Properties

	Perfect foresight ----- Sealevel rise to 2100 -------			***Myopic*** ----- Sealevel rise to 2100 -------		
	10 cm	50 cm	90 cm	10 cm	50 cm	90 cm
	[millions of 1990 U.S. dollars per year]					
Year						
2050	8.1	90.6	218.7	8.3	110.4	284.4
2100	14.2	158.3	382.3	16.6	221.8	571.5

Ratio of myopic to perfect foresight

	----- Sealevel rise to 2100 -------		
	10 cm	50 cm	90 cm
Year			
2050	1.02	1.22	1.30
2100	1.17	1.40	1.49

Source: Yohe and Schlesinger [1998].

Table 5

Estimated Obsolescence of Capital from Abrupt Climatic Change

	Row	Capital Stock [billions, 1998 prices]	Lifetime (years)	Percent Climate Sensitive [%]	Loss of value for abrupt climate change, billions of 1998 dollars [using geometric depreciation and no foresight, where abrupt change takes place over years] 10	20	50	100
TOTAL		***24444.3***			***2131***	***1877***	***1410***	***1037***
PRODUCED ASSETS								
Made assets..	1							
Fixed assets	2							
Residential Structures	3	5867.8	60	10	457	356	168	48
Fixed nonresidential structures and equipment	4							
Natural resource related	5							
Environmental management	6							
Conservation and development	7	213.6	30	20	35	29	16	6
Water supply facilities	8	127.4	20	20	22	19	12	6
Pollution abatement	9							
Sanitary services	10	253.8	20	10	22	19	12	6
Air pollution abatement and control	11	62.7	20	10	5	4	2	1
Water pollution abatement and control	12	62.2	20	10	5	5	3	1
Non environmental	13							
Nonresidential structures	14							
Utilities	15	1444.1	50	5	48	32	10	1
Other	16	3855.7	40	5	150	117	55	16
Nonresidential equipment	17	2658.7	12	5	67	34	4	0
Inventories	18							
Government	19	263.1	1	10	0	0	0	0
Nonfarm	20	1179.9	1	10	1	0	0	0
Farm (harvested crops and misc. livestock)	21							
Corn	22	14.4	1	10	0	0	0	0
Soybeans	23	6.7	1	10	0	0	0	0
All wheat	24	3.6	1	10	0	0	0	0
Other	25	28.3	1	10	0	0	0	0
Developed natural assets	26							
Cultivated biological resources	27							
Cultivated fixed natural growth assets	28							
Livestock for breeding, dairy, draught, etc.	29							
Cattle	30	20.5	2	20	0	0	0	0
Fish stock	31							
Vineyards, orchards	32	3.0	5	50	1	0	0	0
Trees on timberland	33	460.7	40	50	203	179	123	66
Work-in-progress on natural growth products	34							
Livestock raised for slaughter	35							
Cattle	36	43.4	4	20	2	1	0	0
Fish stock	37							
Calves	38	8.1	4	20	0	0	0	0
Crops and other produced plants, not yet harvested	39	2.9	2	50	0	0	0	0
Proved subsoil assets	40							
Oil (including natural gas liquids)	41	190.0	1	1	0	0	0	0
Gas (including natural gas liquids)	42	172.7	1	1	0	0	0	0
Coal	43	238.3	1	1	0	0	0	0
Metals	44	194.4	1	1	0	0	0	0
Other minerals	45	62.2	1	1	0	0	0	0
Developed land	46							
Land underlying structures (private)	47	5910.4	200	10	576	562	522	460
Agricultural land (excluding vineyards, orchards)	48	663.9	200	50	324	316	293	259
Soil	49							
Recreational land and water (public)	50							
Forests and other wooded land	51	431.8	200	50	211	205	191	168
NONPRODUCED/ENVIRONMENTAL ASSETS	52							
Uncultivated biological resources	53							
Wild fish	54							
Timber and other plants and cultivated forests	55							
Other uncultivated biological resources	56							
Unproved subsoil assets	57							
Undeveloped land	58							
Water (economic effects of changes in stock)	59							
Air (economic effects of changes in stock)	60							

n.a. Not available
** The calculated value of the entry was negative.*
Note......Leaders indicate an entry is not applicable.
Source: Survey of Current Business, April 1994 with modifications and additions by author.

Table 6

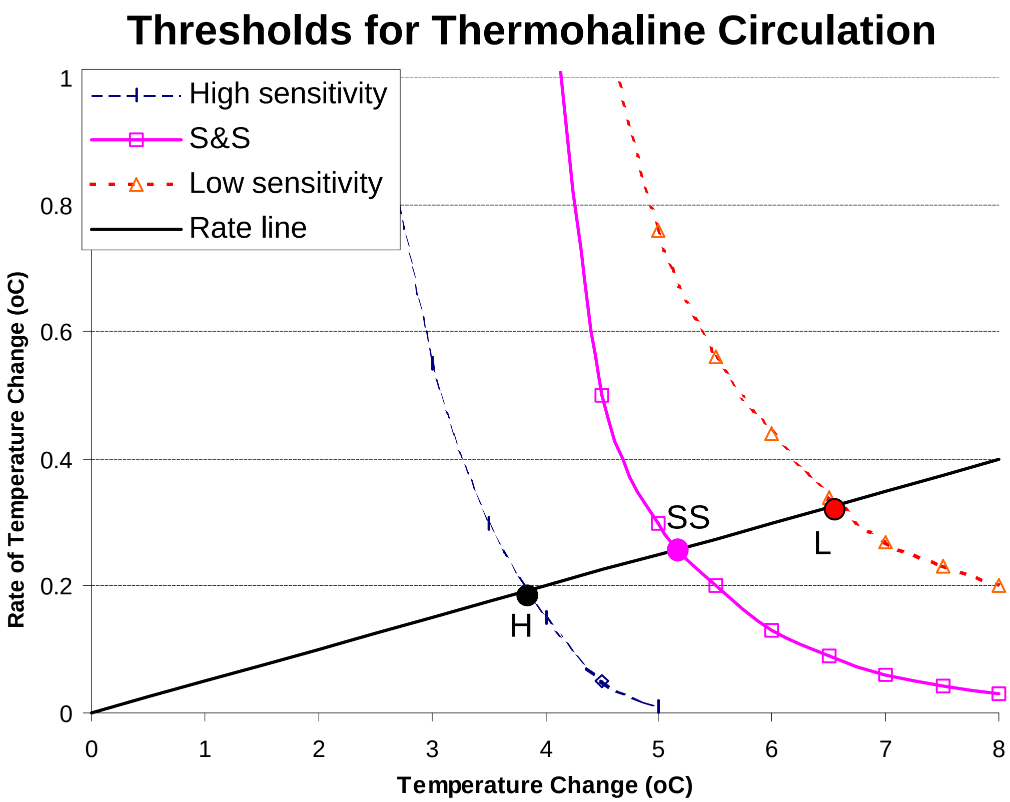
Summary of Estimated Capital Impact from Abrupt Climatic Change

	Loss of value for abrupt climate change, [using exponential depreciation and no foresight, where abrupt change takes place over n years			
	10	20	50	100
Total Capital Effect				
Billions of 1998 dollars	2,131	1,877	1,410	1,037
Percent of total	8.7%	7.7%	5.8%	4.2%
Annuitized value of loss as percent of GDP [a]	1.7%	1.5%	1.1%	0.8%

[a] Using an annuitization factor of 5 percent per year.

Source: Table 5.

Figure 2



Source: Toth et al. [1998]. The "rate line" is discussed in the text.