Economic History, Adaptation, and Uncertainty in Climate Change

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News of global warming or climate change has inundated the public in recent years. Every major newspaper has published multiple editorials or op-ed pieces on the topic, the broadcast media regularly discuss the issue and thousands of web pages and blogs provide information on definitions, facts, causes, and consequences. So, why are we adding to congestion on the subject? As readers will see, analysis of history has much to contribute, especially in understanding prospects for adapting to climate change.

The Intergovernmental Panel on Climate Change (IPCC) is the most widely regarded source of information on climate change (http://www.ipcc.ch/index.htm). Created in 1988 by the World Meteorological Organization and the United National Environment Programme, the IPCC does not carry out its own original research or collect climate data, but its panels of experts and interested parties assess the risks and evaluate the implications of climate change based on their reading of the scientific literature. The IPCC is organized into three working groups, which study The Physical Science Basis of Climate Change; Climate Change Impacts, Adaptation and Vulnerability; and Mitigation of Climate Change. Every few years the IPCC publishes assessment reports, the fourth of which arrived in 2007 in the form of a synthesis and reports by each working group.[1]

A. The Record and Projections

The most recent synthesis reports observed temperatures for the twentieth century and gives projections up to 2100 (IPCC, 2007, chapter 3). As one can see from Figure 1 below, the scenarios differ vastly depending upon the project rates of economic growth, population growth, and technologies, all of which affect the concentration of greenhouse gasses.[2] IPCC makes no predictions about the likelihood of these various

[1] IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

[2] A1 assumes very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2

outcomes but the range of plausible possibilities is enormous relative to average global temperature change in the preceding century.

Various global warming skeptics have cast doubt on the historical temperature record and the models used to project the future. Steve McIntyre, for example, notes that an increasing share of temperature stations were located in urban areas, which retain heat and induce and upward bias to recorded average temperatures. [3] He has recalculated the temperature record using level 1 (excellent) or level 2 (good) reporting stations, finding that the warmest years were 1934 and 1921 followed by 1998 and 2006. If the commonly-accepted temperature record is distorted, obviously projections based on this record will be deficient.

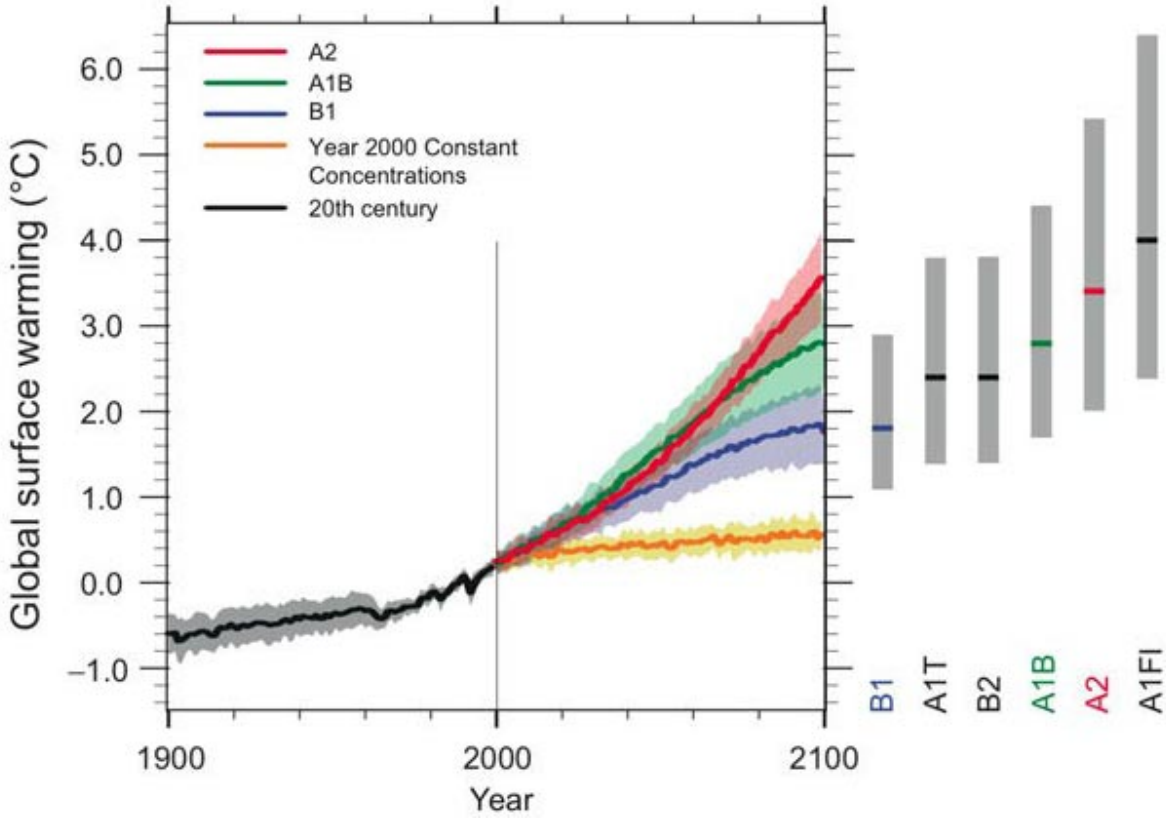

Figure 1: Multi-model global averages of surface warming (relative to 1980-1999) under alternative scenarios.
Source: IPCC (2007), p. 46.

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describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change. No likelihood has been attached to any of the SRES scenarios. See IPCC, 2007, chapter 3.

[3] McIntyre, Steve (October 4, 2007). "Gridding from CRN1-2". Climate Audit. http://www.climateaudit.org/?p=2145.

We are not climate scientists and here we do not engage the debate over the scientific plausibility of the reported temperature record and projections based upon it. We do know, however, that the climate system is enormously complex and difficult to model. Even if one believes the model, or a synthesis of models, widely accepted by climate scientists, the future is highly uncertain because many of the moving parts in these models are difficult to project. How reliably can we forecast economic activity, population growth and technological change, for example? And especially the process of global political decision making that will influence these outcomes? In sum, it is prudent to act as if change is on the way but we should prepare for many alternatives.

Our capacity to adapt to climate change is even more important in light of past regional variability. The temperature record and the forecasts of Figure 1 appear placid because they average out or smooth local variation. Figures 2-5 disaggregate the record of temperature change from hemispheric to regional levels, and by comparing the charts by decreasing level of aggregation one can see that fluctuations increase. Temperature change over the past century or so has been highly variable at the regional level around the globe. Mean annual temperatures in Australia, for example, have generally increased since 1910 but the amount of warming and the trends in maximum and minimum temperatures has been far from uniform across the continent. The largest increase in minimum temperature occurred in the Northeast while the largest increase in maximum temperature took place in the Northwest.

Experience suggests that the effects of climate variability, and the corresponding need for adaptation will be regional or local due to patterns of specialization induced by resource endowments, transportation links, and supplies of labor. The forces that drove local climate variation in the past, whatever they may be, are likely to continue and will not be negated by other processes that provide the foundation for global warming. Therefore the models required to forecast regional climates are far more complex and the projections more uncertain relative to those operating at the global level. Hundreds of regional projections exist, of course, but their standard errors are enormous. We argue that flexibility and adaptability are the best insurance for the planet and its various regions in our uncertain future. It therefore becomes important to know how successful we have been in this dimension in the past.

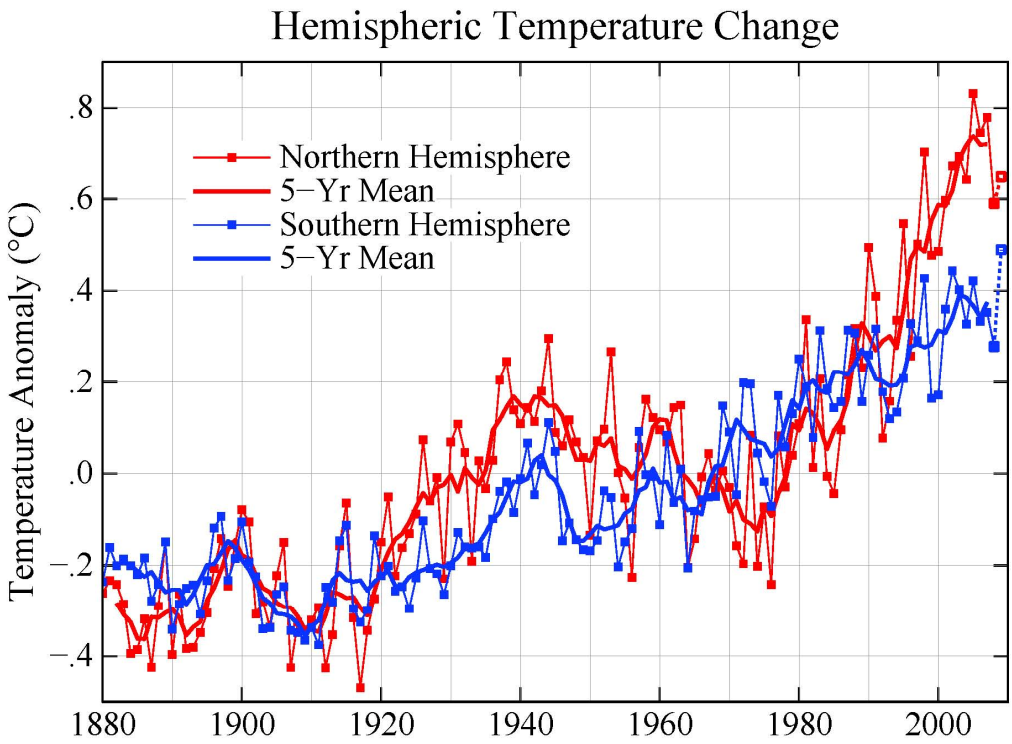

Figure 2. Annual Mean Temperature Change for Hemispheres
Source: http://data.giss.nasa.gov/gistemp/graphs/

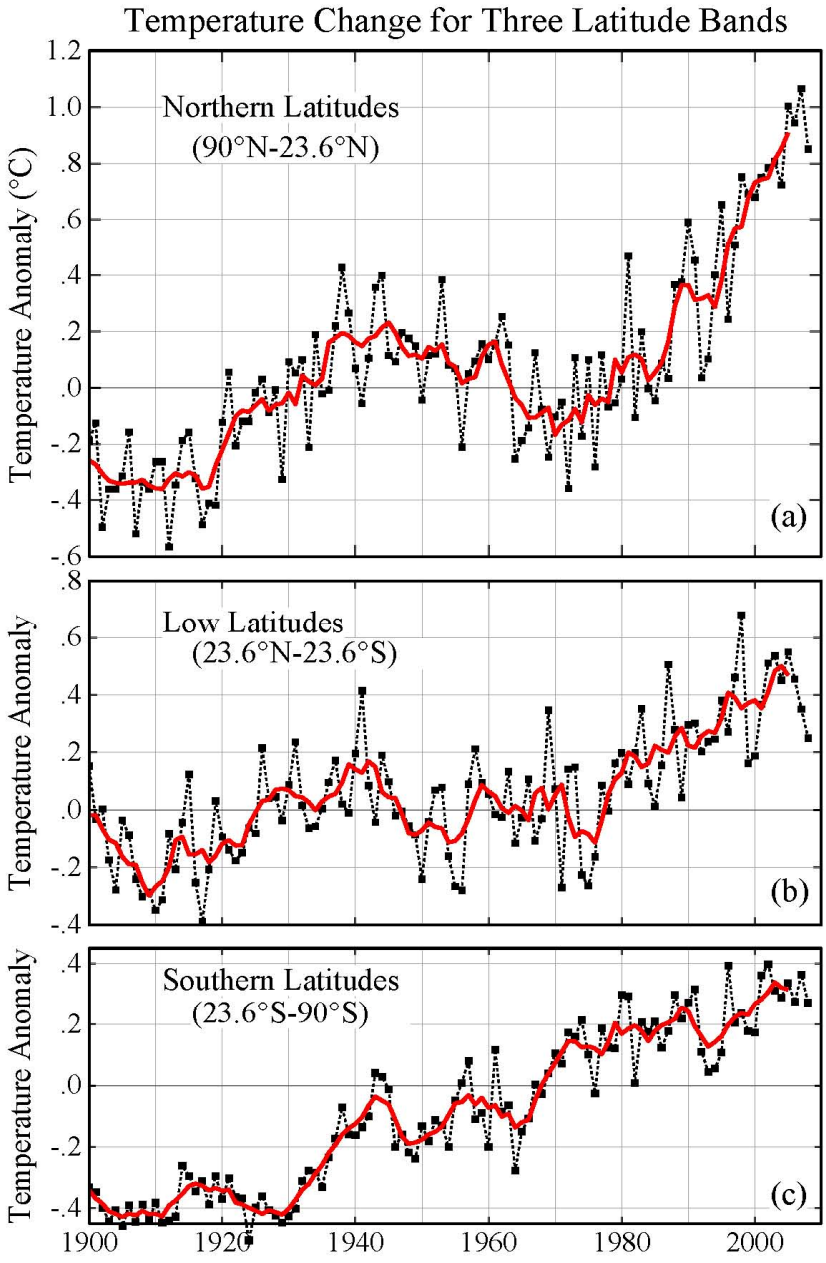

Figure 3. Mean Annual Temperature change for Three Latitude Bands
Source: http://data.giss.nasa.gov/gistemp/graphs/

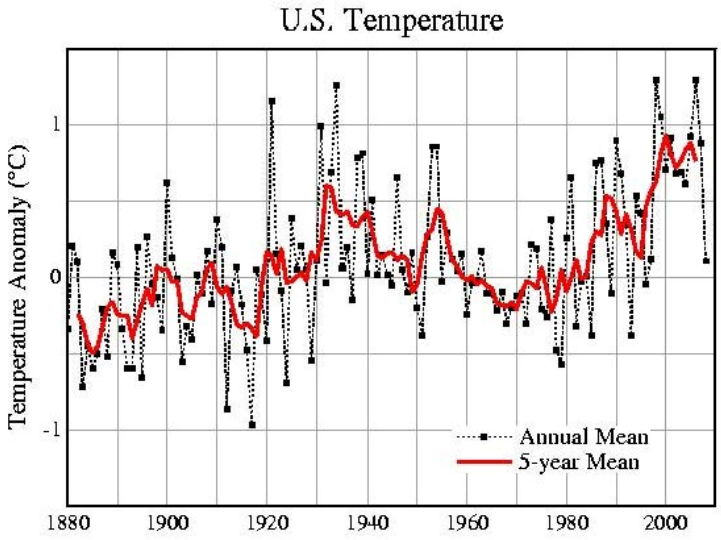

Figure 4. Mean Annual Temperature change in the United States
Source: http://data.giss.nasa.gov/gistemp/graphs/

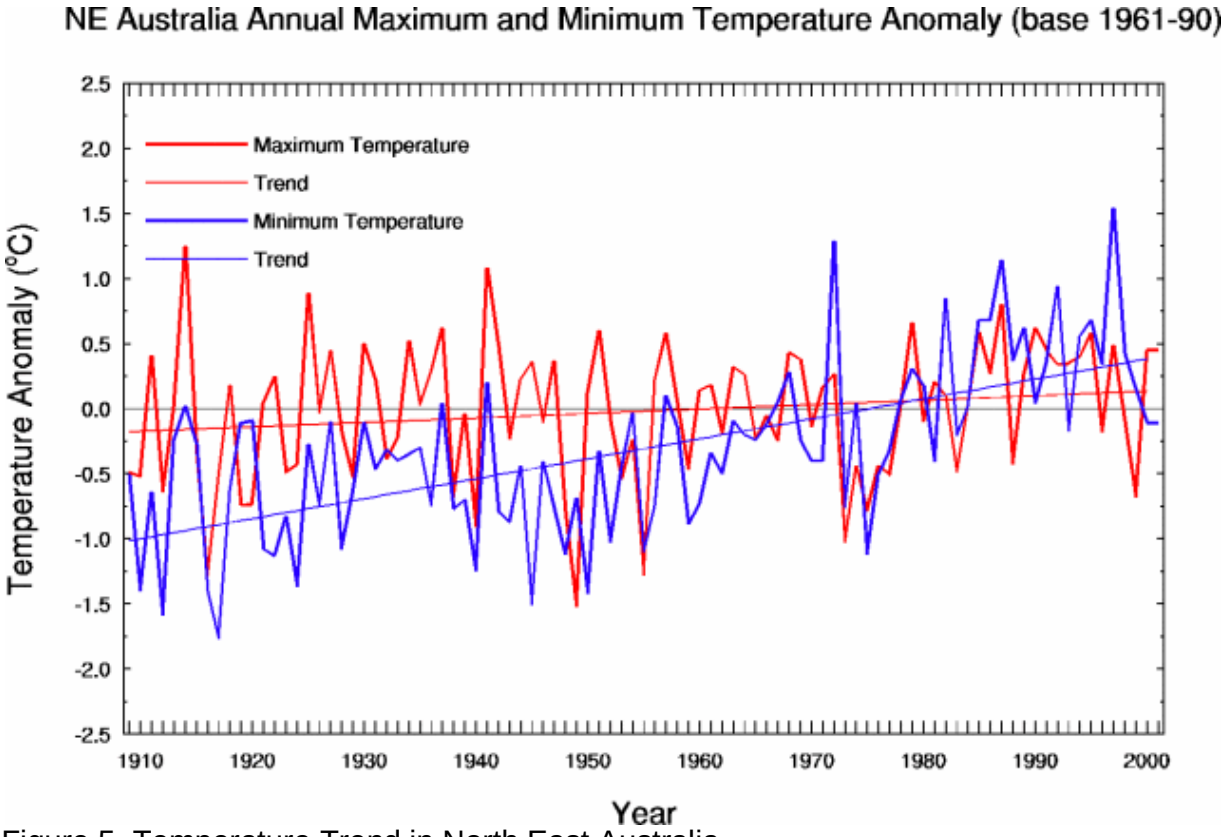

Figure 5. Temperature Trend in North East Australia
Source: http://www.bom.gov.au/climate/change/retrends.shtml

B. Overview

The inherent variability of regional climates in the past and projections of the future suggest that climate change poses serious and potentially dramatic challenges to the American economy. In part, the magnitude of these challenges depends upon the nature of the overall weather response to the buildup of green house gases GHG). As indicated in the following two chapters of this volume, there is considerable uncertainty as to the feedback mechanism between GHG accumulations and the climatic reaction. Accordingly, we may not know the nature of the problem before us for some time. In this case an understanding of the likely adaptability of the American economy will be important for forging any private/government action. Historical experiences can give us longer term assessment of just how well the American economy is positioned to meet climate change.

The economic impact also will depend on the time frame under which climate changes will occur. As with temperature projections, there is no consensus on a specific time period for major economic damages to materialize. One possibility is that they will be small and isolated for 20 - 50 years, after which they will be cumulatively larger. If this is correct, then it may make sense for modest emissions abatement programs

initially while the economy begins to adjust, more technology and learning are developed, and more information is generated.[4]

A major question, then, is how adaptable is the American economy? Agriculture will be particularly vulnerable if temperature and precipitation become more erratic with larger swings. Six of the chapters in this volume address agricultural responses to new weather conditions in American economic history. Indeed, the expansion of agriculture across North America in the 19th and 20th centuries encountered greater climatic variation than often is predicted by at least some climate change models (Olmstead and Rhode, 2008). And as we see agriculture was amazingly adaptive through new crop types, mixes, and methods of cultivation.

Health will be affected and two chapters address the issues. Here we also see responsiveness through demands for reduced air emissions as incomes rose and associated regulations to limit pollution were adopted. We also see that once individuals had access to information regarding health threats related to climate, they generally were able to respond effectively.

Electricity demand and pressure on utilities also likely will increase. The final chapter of the volume provides information on the size and heterogeneity of demand changes as temperature increases. This information is valuable for preparing for new energy sources if temperatures become hotter, especially in areas already warm and dry.

Overall, research in economic history reveals both how closely twined are climate, weather and the economy, and how remarkably resilient and adaptive is the economy. This is a valuable insight both because it suggests adjustments are likely to occur as new information, new learning, and new technologies emerge and because it augments contemporary climate change studies that typically rely upon either simulations or very limited data sets. Adaptation takes time and history is the best provider of information about how it has unfolded over time.

It also is important to note that the record of adjustment and flexibility described here is apt to underestimate the general responsiveness of the current and future economy. In the 19th and early to mid 20th centuries, the time period for most of the research presented here, information sources and transmission mechanisms were much more limited and costly than today. There were far fewer government, business, and agricultural organizations for coordination and mobilizing responses. Technology

[4] For a sense of the debate over the magnitude of the impact and the time frame involved, see National Academies of Sciences, 2008: Understanding and Responding to climate Change: Highlights of National Academies Reports, Washington D.C.; William Nordhaus, 2008, A Question of Balance: Weighing the Options on Global Warming, Yale U Press; Carolyn Kousky, Olga Rostapshova, Michael Toman, and Richard Zeckhauser, 2009, "Responding to Threats of Climate Change Mega-Catastrophes," World Bank Policy Research Working paper 5127, WB Development Research Group, Environment and Energy Team, Nov.

and knowledge were necessarily more primitive. It seems reasonable to conclude that if the economy could adapt in the manner described below in the past, it ought to be able to do so even more effectively in the future.

This is not to say that we should be too sanguine about the ability of the economy to adapt to climate change. But the historical record, at least, is one that brings considerable optimism about the future responsiveness of the society to the important challenges of a climate that may change in unknown ways, raising uncertain costs—and possibly, benefits, for both current and future generations.

This record has not been presented in one place before and how the economy has responded to past climatic shocks has not been sufficiently integrated into contemporary debates over climate policy. The evidence reported here reveals that much can be learned not only about specific responses in the past, but also about the overall flexibility and ingenuity found in sectors of the American economy. Future climatic challenges will require similar innovation and elasticity perhaps in ways that have not been encountered before. But the research in this volume provides reasons for confidence and expectations for creativity that should not be overlooked as the economy moves to address a changing climate environment.

The chapters in this volume describe research findings regarding historical climate-related events as they have been faced in the American economy; the responses of individuals, organizations, and government institutions to those climate challenges; and assessments of their successes in addressing potential disruptions and in promoting the continued economic growth and welfare. The chapters also provide new data sources for measuring and evaluating how economic agents have adjusted to and progressed even in light of formidable environmental concerns.

This record of adaptation and progress has involved both individuals and organizations in the private sector—farmers, bankers, consumers, and firms, and government agencies at the state and federal level—agricultural experiment stations and extension services, the Bureau of Reclamation and Army Corp of Engineers, the National Weather Service, health agencies, and regulatory bodies.

C. The Uncertain Economic Implications of Climate Change

The first two chapters describe the environmental problems before us and the uncertainties involved in assessing the magnitude of climate change, in determining its long-term impact on the economy and society, and in formulating government policies and private strategies to address it. Chapter 2, “Additive Damages, Fat-Tailed Climate Dynamics, and Uncertain Discounting,” by Martin Weitzman, provides a theoretical framework for thinking about climate change. As Weitzman notes, climate change is so complicated, involving so many different disciplines and viewpoints that a model can only address one or two facets of the problem. His chapter focuses on the economic implications of unusually large structural uncertainties surrounding climate change extremes and why aggressive emissions mitigation policies might be justified. He argues that additive damages are appropriate for analyzing the economic impact of global warming in light of highly uncertain feedback mechanisms between GHG

accumulations and temperatures with possibly catastrophic results (losses of habitats and species; dramatic rises in sea levels; shrinkage of inhabitable regions and associated collapses in production and consumption).

With uncertain rates of time preference and discount rates approaching zero, these climate change damages and uncertain response mechanisms lead to very large expected present disutility. The social willingness to pay to avoid potential catastrophically-high temperatures in the future could be infinite, whereby society sacrifices all current consumption to prevent future warming. Because current CO_2 and CH_4 atmospheric accumulations appear to be at unparalleled levels and changing more rapidly than ever before, and the speed and magnitude of the global temperature response is so unclear with possible irreversible, self-enhancing feedback effects, Weitzman is doubtful that there are opportunities for learning, mid-course corrections, or adaptive adjustments of the types described elsewhere in this volume to respond to climate change.

Chapter 3, "The Impact of Warming in Climate Change Economics," by Robert Pindyck, also examines the issues raised by Weitzman, but with a different approach and a different conclusion. He incorporates distributions for temperature change and its possible economic impacts derived from studies assembled by the IPCC and from integrated assessment models (IAMs) into an analysis of climate change policy. He estimates the fraction of consumption society would be willing to sacrifice to ensure that future temperature changes are limited to some target level, say 2^0 or 3^0C.

He models the relationship between temperature change and the growth of GDP using a thin-tailed distribution for temperature change inferred from studies surveyed by the IPCC and a zero discount rate. Pindyck finds that the willingness to pay is less than 2 percent to avoid temperature increase greater than 3^0C over 100 years, a result that supports only moderate abatement policies. Pindyck's approach involves fitting parameters based on the existing state of knowledge regarding temperature change and its economic impact. In contrast to Weitzman, the analysis supports slower, more adaptive policies to address climate change that rely on new learning, new technologies, and market adjustments to lower costs and avoid the losses of more preemptive policies that turn out to be inappropriate or ineffective. This approach certainly would take advantage of the adjustment mechanisms described in the empirical work presented in this volume.

D. The Costs of Climate Change.

Because Weitzman and Pindyck point to the large uncertainties in assessing the potential costs of climate change, it is worthwhile to continue the volume with three papers that examine historical climate-related costs. Chapter 4 by John Landon-Lane, Hugh Rockoff, and Richard Steckel, "Droughts, Floods and Financial Distress in the United States," examines the relationships among weather, agriculture, and financial markets. There has been a long-standing sense, going back at least to Stanley Jevons (1884) and the notion that financial crises were linked to sunspots, that weather shocks as they curtained agricultural production could bring about bank failures and thereby disrupt the macro economy. Even though this linkage was noted by Keynes (1936) and

Friedman and Schwartz (1963), there has been little empirical work on the causal mechanisms and the overall magnitude of the impact.

The authors examine how drought has affected both bank failures and rates of return to bank equity in the U.S. Two major drought events are emphasized, a series of droughts between 1874 and 1896 in Kansas and droughts during the 1930s in Oklahoma. Both of these climatic events crippled agriculture, a major sector of the state economies. The Palmer Drought Severity Index (PDSI) has been constructed from meteorological data systematically collected by the U.S. Weather Bureau since 1900. Examining drought in 19th century Kansas requires that the index be reconstructed using tree ring data. These data are combined with measures of financial distress. The authors show that the early droughts, especially, resulted in drops in the rate of return to national bank equity and in bank failures as banks faced defaults on agricultural loans and mortgages.

Because of available data, it is possible to more systemically examine the linkage between drought and bank stress in Oklahoma during the 1930s. Surprisingly, despite the extent of the drought and the corresponding Dust Bowl in western and central Oklahoma, national bank rates of return reveal little effect. Much of the distress instead appears to have been with local, small state banks that did not have the institutional framework available to national banks for accessing funds and smoothing risk. Data for state bank rates of return, however, are not available for econometric analysis. The authors proceed, however, with other time-series analysis of the impact of the PDSI on national bank capital rates of return, farm foreclosure rates, and farm income between 1850-1976 and various subperiods for the U.S. as a whole and by region and subregion.

Generally, they find a positive relationship between the PDSI and rates of return—more rain, higher rates of return, with extreme drought and wet periods reducing rates of return. The effects are most pronounced in the period through 1940 and in the farming region of the Midwest. Similar results are reported for farm foreclosures and farm income. After 1940, however, the relationship between the financial sector and weather is much weaker. This suggests considerable adjustment through institutional changes via branch banking that allowed banks to better sustain localized drought-induced economic stress and through agricultural adjustments through a shift to new crops and new production methods. In sum, the authors find that weather events have had less economic cost since the mid 20th century than one might have imagined. They also suggest that organizational innovations that lowered the cost of accessing capital across banks during times of climate shocks was an important factor in mitigating financial, and overall macro economic distress.

Chapter 5, “The Effects of Weather Shocks on Crop Prices in Unfettered Markets: The United States Prior to the Farm Programs, 1895-1932,” by Jonathan Fox, Price Fishback, and Paul Rhode, also addresses the cost of climate-related events by examining the impact on agricultural prices. Because of current government intervention into commodity markets in many leading agricultural countries, it is more difficult to gauge the linkages between weather on contemporary agricultural prices. This was not the case in the early 20th century.

The authors assemble a 37-year panel of state data from the USDA for cotton, corn, wheat, and hay and from the National Climatic Data Center for temperature and precipitation, including the PDSI. They econometrically test for linear and non linear effects of temperature and precipitation on prices through time series analysis controlling for state and year fixed effects. They find that prices for cotton and wheat, two crops most traded internationally, were not sensitive to local state-level weather shifts. Prices for more locally-consumed commodities, corn and hay, however, were much more affected. Indeed, the effect of severe drought and high temperatures especially on corn crops helped to mobilize political action for federal government intervention to stabilize prices and farm incomes. Accordingly, in these cases, the costs of weather-related events depended in part on the extent of the market. Where markets were narrower, regional weather events had more pronounced costs and these in turn likely were a source of subsequent government intervention.

Chapter 6, "The Trials of Job: The Impact of Climate and Weather on Infant and Non-Infant Death Rates During the Great Depression," by Price Fishback, Werner Troesken, Trevor Kollmann, Michael Haines, Paul Rhode, and Melissa Thomasson, also examines the cost of climatic events. Contemporary discussion of climate change often points to its possible health implications. In this chapter, Fishback, et. al, present new data on mortality rates for 3,054 U.S. counties between 1930 and 1940, a decade that saw unusually severe droughts and high temperatures as well as economic collapse associated with the Great Depression. These conditions could be similar to conditions in many developing countries today should climate change disrupt the macro economy.

Combining data on mortality, temperatures, precipitation, and various socio-economic correlates, the authors examine both cross section and time series variation in temperature and precipitation and death rates across the over 3,000 counties during the 1930s. Respiratory and diarrheal diseases, as well as the prevalence of disease-carrying insects could be influenced by weather fluctuations, and infant children are particularly susceptible. Even so, the weather variables show little significant impact on the infant mortality. The most important explanatory factors are those associated with information—literacy and access to radios and magazines. These results are repeated in statistical tests where non-infant mortality is the dependent variable. The findings underscore the importance of improved information flows to promote public health as a way of reducing the effect of weather shocks on welfare. The authors acknowledge that their analysis focuses on weather fluctuations around the long-term climate norms and that shifts in climate may have bigger effects on mortality.

E. Evidence of Adaptation to Climatic Challenges.

As noted by Robert Pindyck in Chapter 3, moderate climate policy can benefit from adaptation in the economy that could reduce both the cost of climate change and efforts to mitigate it. Three chapters address adaptation by private markets and governments in American economic history. Chapter 7, "Responding to Climatic Challenges: Lessons from U.S. Agricultural Development" by Alan Olmstead and Paul Rhode, provides a long-term perspective for understanding how American farmers have

responded to new and challenging growing environments that in some cases involved greater temperature variations than are forecast in many contemporary climate change scenarios. Moreover, the adjustments Olmstead and Rhode chronicle took place prior to major understanding of plant genetics. Although the authors point out that they cannot say how future farmers, aided by new breakthroughs in plant science might respond to climate change, the historical record they present reveals the malleability of the agricultural enterprise that countered past expert predictions of failure. These predictions failed to see the impact of biological innovations that would transform commodity production.

Olmstead and Rhode examine the regional climatic barriers that were encountered in the expansion of the agricultural frontier across North America and the collaborative innovations of farmers, agricultural experiment and extension agents, and seed companies in responding to them for wheat, corn and cotton.[5] The authors point out that between 1839 and 1929, U.S. wheat production increased by 10 times and production shifted to areas that were very different in climate and soil. New varieties, particularly hard red winter and spring wheat, improved yields and were more tolerant to extremes in heat, cold, and drought, while also being resistant to rust to other plant diseases. New dry farming techniques introduced by farm organizations and the USDA further allowed for production to be extended into areas that previously had been considered too inhospitable. Similar progress is described for corn and cotton.

The response of farmers to new seed types and the roles of private firms and government agencies in developing them is described in Chapter 8, "The Impact of the 1936 Corn-Belt Drought on American Farmers' Adoption of Hybrid Corn" by Richard Sutch. Sutch reexamines Zvi Griliches (1957) famous study of the adoption of hybrid corn. Griliches argued that diffusion could be described by a logistic function, whereby individuals learned from first adopters. As more parties considered the innovation, overall penetration would rise initially at an increasing rate to an inflection point, after that adoption would rise more slowly. Sutch's study shows that the process was far more complex and that there was critical involvement of both government and private companies.

Indeed, until the 1936 drought, Sutch argues that there was little or no economic advantage to hybrid corn over standard, open-pollinated varieties due to the high cost of seed and the need for more fertilizer and greater use of mechanization at a time of low corn prices. Hybrid corn seeds had been marketed commercially in the U.S. since 1925, with slow adoption. But the drought of 1936 revealed advantages of hybrid corn that previously had been unrecognized—its drought tolerance. This advantage led to more rapid adoption, especially in the more drought-prone western corn belt in 1937 and 38. Further, there was path dependence. Greater sales revenues financed R&D by private seed companies, particularly Pioneer Hi-Bred Seed that improved seed productivity in normal years, encouraging more adoption. A sudden climate event, the extraordinarily severe drought of 1936, served then as a tipping point by generating new information about the advantages of hybrid corn seeds. Additionally, Pioneer was founded by

[5] Alan Olmstead and Paul Rhode, 2008 Creating Abundance: Biological Innovation and American Agricultural Development, New York: Cambridge University Press.

Agricultural Secretary Henry A. Wallace, who used his position to encourage the diffusion of new seed types.

Sutch's analysis uses data from the Iowa Corn Yield tests of 1926-40 as well as Griliches' data and relies upon yield per harvested acre a measure of the severity of the drought in 1936. He tests the hypothesis that adoption of hybrid corn after 1936 was influenced by drought conditions. His analysis provides a more complete and interesting story about the development and dissemination of innovation and the important role of collaboration among farmers, firms, and government agencies as emphasized by Olmstead and Rhode.

Chapter 9, "The Evolution of Heat Tolerance of Corn: Implications for Climate Change," by Michael Roberts and Wolfram Schlenker, continues the analysis of technological change in seed types as responses to climatic shocks. They provide new evidence on the relationship between weather and corn yields by assembling data from 1901-2005 for Indiana, a major corn-producing state, on yields, temperature, and precipitation. Overall, they find that adjustment to extremes in temperature and precipitation evolved over time in a manner described in the previous chapter as new seed varieties, supplemental irrigation, and new production and management techniques were introduced.

Using both time series and cross section econometric analysis, Roberts and Schlenker, however, find that the evolution of tolerance for excessive heat has been less successful than that for swings in precipitation. They find that improvements in heat tolerance have been non linear, growing with the introduction of new hybrids in the 1940s and 1950s, peaking in 1960 and then declining due to the effects of very high temperatures on corn yields. The key question they raise is whether the next seed innovation cycle can bring both increases in average yields and heat tolerance as was the case from 1940-60. Otherwise, there may be little scope for response to higher temperatures while maintaining yields in areas where corn is currently grown.

The chapter concludes by briefly examining the distortions of current U.S. agricultural policies, land set asides and conservation programs, and the large, corn-based ethanol subsidy. The authors conclude that the subsidy shifts a third or more of the U.S. corn crop to ethanol away from food production. Removal of this subsidy alone could offset losses due to heat in corn production for food.

F. Government Policy and Adaptation to Variable Climatic Conditions.

The final three chapters address government policies and how they have affected the response to new climate conditions. Chapter 10, "Climate Variability and Water Infrastructure: Historical Experience in the Western United States," by Zeynep Hansen, Gary Libecap, and Scott Lowe, examines how a major policy initiative, massive investment in dams and related canals, largely for irrigation and flood control in the 20th century, affected crop yields and mixes during times of extreme drought and wetness. Because the water infrastructure constructed by the Bureau of Reclamation and the Army Corps of Engineers was importantly influenced by political constituent pressures (Pisani, 2002), it is possible that the infrastructure may have had little impact on

smoothing output, but rather served to expand production into areas where it otherwise might not have been possible.

To explore these issues the authors assemble a county level data set of 3,620 observations for five western states, Idaho, Montana, North and South Dakota, and Wyoming using census data for the 20th century. These states have similar temperature and precipitation patterns, crops and soil types, but the availability of irrigation varies widely. The crop data are for hay, wheat, barley, corn, and potatoes. The first two crops, especially, can also be dry farmed without irrigation. The dataset includes total planted acreage, total failed acreage, total fallow or idle acreage, and total harvested acreage by crop, along with information on topography, soil quality, water storage and distribution, temperature, and precipitation.

The authors examine variation in agricultural production and crop mix before and after the water infrastructure was installed, and across counties with and without such infrastructure during times of excessive drought and precipitation. Various econometric techniques are employed to address endogeneity. They find that agriculture within counties with water storage and distribution facilities generally was better able to deal with climate variability, smoothing output and crop mixes in times of drought and heavy precipitation, relative to agriculture in counties without such facilities. The results underscore how important the water infrastructure has been for long-term adaptation strategies to respond to highly variable climatic conditions.

In Chapter 11, "Did Frederick Brodie Discover the World's First Environmental Kuznets Curve? Coal Smoke and the Rise and Fall of the London Fog," Karen Clay and Werner Troesken examine the incidence of coal smoke in fogs in and around London and the pattern of such fogs over time. Brodie attributed these fogs to intense coal smoke emissions between 1871 and 1903. After that, however, he argued that the fogs largely ended. Clay and Troesken analyze to see if this claim is correct, why the pattern of fogs existed, and address related health effects of the so-called "killer fogs." In doing so, they reconsider Brodie's limited data and assemble additional information on coal consumption/capita; gas and electricity use; abatement legislation; and mortality from respiratory diseases.

The authors construct a reverse event study, using spikes in mortality to predict severe fogs and then compare those predictions against other evidence regarding their occurrence. As indicated by Brodie, the authors find that between 1855 and 1910 there were recurring fogs, but none after 1900. With this information they then conjecture why the fogs declined after 1900. The smoke density in London fell for a variety of reasons: the city's population became more dispersed; the inhabitants became richer; and associated regulations, such as the 1891 Public Health Act instituted fines for dense smoke emissions, promoting a shift to the use of gas and hard coal that burned more cleanly. Clay and Troesken conclude that Brodie was correct in his assessment of the source of London's killer fogs and that city had to reach a threshold level of income and technological advancement before it could address the problem of coal smoke.

The final chapter, "Impacts of Climate Change on Residential Electricity Consumption: Evidence from Billing Data," by Anin Aroonruengsawat and Maximillian

Auffhammer, does not directly address government policy, but it provides information critical for formulating policy in the energy sector. The chapter describes analysis of an unusually complete panel data set on for California from 2003-2006. Supplementing these data with weather data and census information by zip code and controlling for household, month and year fixed effects, the authors examine the electricity consumption response to changes in temperature across 16 climate zones. Flexible temperature response functions are estimated by zone, and they find heterogeneity in the response.

The greatest impact occurs in areas with the largest number of high and extremely high temperatures—in the central and southeastern parts of the state where electricity demand could rise as much as 55 percent by the end of the century. The authors also explore the impact of other variables on electricity consumption, including the percent of households using heating as fuel, the percent using gas, urban location, and age of the structure. Overall, the study finds larger and more non linear impacts on electricity consumption from temperature extremes than had been previously found. The authors caution that the study does not allow for changes in consumption due to price shifts, movements to different locations, or other structural modifications that might reduce potential increases in demand.

The types of adaptation to climate that are described in this volume have received less attention in the economics literature than have policies for mitigation of emissions. More concern has been directed to the design of optimal carbon taxes and implementation of cap and trade systems, including carbon credits. Because of the global nature of the GHG externality, however, any effective mitigation effort necessarily requires international collaboration. Otherwise, emissions reductions in some regions will likely be offset by increases elsewhere and the overall stock of GHG may continue to rise, generating further climate change.

This point emphasizes the importance of international collective action to address climate change. The record, however, is not an encouraging one. The United Nations has been active on this front, beginning with the 1992 United Nations Conference on Environment and Development in Rio de Janeiro and the 1997 United Nations Framework Convention on Climate Change in Kyoto, followed by various UN Conferences of Parties in Buenos Aires, 2004, Bali, 2007, and Copenhagen, 2009. Yet, there has been little concrete, coordinated global action to reduce emissions. Disputes over the science, over the magnitudes, nature, speed, and distribution of climate change across the planet, and more critically, over the distribution of the costs of addressing it have blocked meaningful action.

These problems of mobilizing collective action regarding the global climate change externality appear not to be much different from those encountered with other environmental or resource externalities. In fact, experiences in effectively confronting overharvest, overextraction, and excessive pollution in common pool fisheries, water resources, oil and gas reservoirs, and local air quality reveal that distributional conflicts are the norm. Disagreements over the size of the problems to be addressed and the assignment of the costs and benefits of mitigating it inhibit cooperation.

Delay in response until a crisis occurs is the usual pattern. A crisis—the collapse of the resource stock or severe health consequences from air pollution, provide new information about the immediacy and size of the problem. This information causes the cost-benefit calculations to change and distributional concerns become displaced by agreement on the need to address the problem. At that time, more effective collective action takes place.[6] If this empirical pattern holds true for international climate change negotiations, as seems likely, then more attention should be placed on adaptation because meaningful global mitigation of GHG emissions is unlikely to occur before there is a major crisis to galvanize international collaboration. By that time, however, the stock of GHG may be of sufficient size that major climate changes will follow in any event. Accordingly, adaptation is key and an understanding of the potential responsiveness of the economy is essential. Our volume addresses this pressing need.

[6] Gary D. Libecap, 2007, "Open Access Losses and Delay in the Assignment of Property Rights," 50 University of Arizona Law Review 379.