Risk and Precautionary Approaches to Climate Change: Conceptual and Empirical Lessons from the Insurance Industry

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The concept of option value provides insight in weighing the countervailing risks of doing "Too Much Too Soon" or "Too Little Too Late" in addressing climate change. Option value represents profit potential to the insurance industry when it is positive, which occurs if people's willingness to pay exceeds expected actuarial losses. Climate change could increase both the mean and the variability of actuarial losses. This paper reviews literature relating climate change to the insurance industry and summarizes empirical estimates of damage payments by private insurers. Public data on long-term trends in weather-related disaster and emergency relief payments are cited.

INTRODUCTION AND BACKGROUND

This paper focuses on the risk aspects of climate change as part of a larger research project conducted for the Legislative Citizens Commission on Minnesota Resources (LCCMR, 2010). The overall project was directed by the University of Minnesota, Natural Resources Research Institute. According to the project 2007 LCCMR Workplan, the overall purpose was "to quantify climate, hydrologic, and ecological variability and trends, along with economic impacts of environmental fluctuation on water resources, and to identify indicators of future climate change effects on aquatic systems." This economic component presented economic conceptualizations of climate change as a policy challenge and empirical findings on "economic impacts of environmental fluctuation on water resources."

The Scientific Context for Climate Change Impacts on Minnesota Water Resources

According to USEPA Office of Water 2008"Climate change will have numerous and diverse impacts, including impacts on human health, natural systems, and the built environment. Many of the consequences of climate change relate to water resources, including:

- warming air and water;
- change in the location and amount of rain and snow;
- increased storm intensity;
- sea level rise; and
- changes in ocean characteristics." USEPA Office of Water (2008), page 51.

The Minnesota Pollution Control Agency (MPCA) climate change website states: "Minnesota is already experiencing impacts from climate change, and will continue to experience impacts to our ecosystems, natural resources, and infrastructure." The MPCA website quotes the US Global Change report (2009) which highlights key midwest impacts:

- During the summer, public health and quality of life, especially in cities, will be negatively affected by increasing heat waves, reduced air quality, and increasing insect and waterborne diseases. In the winter, warming will have mixed impacts.
- The likely increase in precipitation in winter and spring, more heavy downpours, and greater evaporation in summer would lead to more periods of both floods and water deficits.
- While the longer growing season provides the potential for increased crop yields, increases in heat waves, floods, droughts, insects, and weeds will present increasing challenges to managing crops, livestock, and forests.
- Native species are very likely to face increasing threats from rapidly changing climate conditions, pests, diseases, and invasive species moving in from warmer regions.

Specific Findings on Climate Change Impacts on Minnesota's Water Resources

Major trends in Minnesota's climate have important implications for water resources (Skaggs and Blumenthal, 2009). Those highlighted below are most relevant for this paper given their potential socio-economic significance due to impacts on water resources.

1. Changing character and quality of precipitation: there is an increasing proportion of annual precipitation coming in summer thunderstorms and these have more spatial variability than other precipitation events,
2. Warmer winter minimum temperatures,
3. Higher summer heat indices due to higher humidity and higher ambient air temperature,
4. Increase in the number of freeze/thaw days

Dedaser-Celik & Stefan (2009) analyzed trends in streamflow in Minnesota since 1946 using gauges from five different river basins across the state. The trends observed matched many predicted by other climate change literature such as increased high flow due to increased runoff. While extreme flood events have not increased, flows over a wide range of recurrence intervals have either increased over time or remained the same. These researchers did determine that rivers located in areas with higher rates of precipitation showed increases in streamflow.

Findings from the component of the project on streamflow indicate that the Minnesota River Basin and the Red River of the North have larger increases in streamflow than the other three basins in the state. Even though extreme precipitation events are likely to be randomly located across the state, it would be a wise investment to protect against such disasters in the most vulnerable locations. This would be a sound application of the Precautionary Principle and risk aversion discussed further below.

The overall project also investigated potential impacts of climate change on water quality. This paper focuses on the risks of changes in water quantity, not quality because the scope relates to insurance concepts. While changes in water quality also increase risks, these risks are of more public in nature than the risks related to infrastructure damage and other losses captured by the insurance industry or emergency management activities.

CONCEPTUAL FRAMEWORK FOR INFERRING ECONOMIC IMPACTS

Potential economic impacts of climate change must be understood within the conceptual framework about what people value. Environmental economics identifies two major conceptual components of value: use values and passive-use value. The theory and practice has developed toward the conventional wisdom that only recognizing use values in evaluating environmental effects would lead to substantial underestimation of value to the public.

In terms of water resources, some of the major use values revealed in market transactions are: recreational fishing, commercial fishing, commercial transportation on waterways, agricultural irrigation, infrastructure damages from flooding (drinking water, wastewater, and stormwater facilities, roads, bridges, culverts, and other structures), flood damages to crops, forests and other lands with commercial yields, hydroelectric power generation, water-borne diseases, and insurance costs.

Some of the major non-market values that could be impacted are: water quality, fish habitat, preservation of "natural" distribution of cold-water species such as lake trout and cisco, preservation of native aquatic plants, and preservation of "natural" levels of surface waters.

Option Value as a Conceptual Framework for Understanding Damages Due To Climate Change

In the extensive literature on option value, the concept is consistently defined as the difference between option price and expected consumer surplus, where option price is the maximum willingness-to-pay to maintain the option of future consumption. The concept is used to explain why people willingly purchase insurance and pay a premium that exceeds the expected loss. Hence option value is referred to as a risk-aversion premium. The conceptual framework for the application of option value to protecting against climate change impacts is adapted from the model in Freeman (1985).

Equivalent surplus, ES, is defined as the willingness-to-pay to avoid certain damages to water resources from climate change. But given climate change poses a risk of impacts greater than zero but less than 100% certain, efforts to reduce the impacts of climate change must be seen as lowering these probabilities. Similarly climate change can be conceptualized as increasing risks by increasing the dispersion of likely future states of the world. Even if the expected values for qualities and quantities of Minnesota water resources are assumed to remain unchanged, the widening of the extreme outcomes increases the riskiness of the world in the future. Given society is made up of individuals who typically are risk averse, increased risk due to climate change causes a loss in well-being.

The theoretical discussion of option value in the economics literature associates risk-averse preferences with characteristics of the typical individual's utility function. Specifically the utility function is assumed to be concave downward, i.e. exhibiting diminishing marginal utility of income. Departures from these and other theoretical assumptions lead to different conclusions about the sign and importance of option value. Boardman, et al. (2006) provides an informative overview of this debate.

Indeed the debate in the theoretical literature on option value has also played out in the economic analysis of climate change. The Stern Review (2006) provides seminal analysis of potential global economic impacts of climate change. It has been a catalyst for further scholarship on this topic. Stern relies heavily on option value as a component of the economic value of reducing the threat from climate change. Others have concurred with this conclusion while still others vehemently disagree. A key point of disagreement with the conclusion that option value should be counted as a positive benefit of reducing the threat of climate change is the view that individuals are also averse to the risk of losing income by spending on climate change mitigation that may turn out to be unnecessary.

But this argument misses the point that the trade-off in risks uses income as the unit of account. Money is the common denominator for balancing the risks of "doing too much too soon, or too little too late." The income equivalent to reduce environmental risk is already in the form of this monetary expenditure. The count money again as a risk of unneeded expenditure would be double counting. The WTP of risk-averse individuals exceeds expected loss because they see the risk of environmental damage as warranting the risk of spending money, even if unnecessarily.

The reasoning some authors use to conclude that climate change mitigation will not generate economic benefits in the form of option value would also be flawed when applied to the insurance industry. This reasoning would wrongly imply that individuals would quit buying homeowners insurance. In reflecting back on a year where no insurance claims needed to be filed, would a risk-averse individual attach greater risk to spending on insurance unnecessarily because no damages occurred? The repeated expenditure for insurance demonstrates that individuals benefit from the sense of security from a loss (even if it has low-probability), and weigh avoidance of that loss more heavily than the chance that they could have gotten by without purchasing insurance. The insurance industry depends on individuals having preferences in weighing risks that are manifested in WTP being more than the actuarially expected loss. That risk-aversion premium is the source of profits to the insurance industry.

The discussion above applies to a simple case where option value serves to maximize expected utility when risk is introduced to a previously riskless situation (see Freeman, 1985.) A more realistic characterization of the risks imposed by climate change is to add greater extremes to an already risky world. The simple case portrays climate change as introducing risk to the future quality and quantity of water resources. In reality, the future of Minnesota's water resources is already risky, without the added threat of climate change. So the more complex scenario would model climate change as widening the dispersion of likely future states of the world.

The literature on impacts notes that some environmental changes could be negative and some positive. If the negative changes outweigh the positive, there will be a socio-economic loss due to climate change, both due to lower expected income and lower expected utility due to aversion to greater risk. But the case of widening the distribution also shows loss from climate change even if the positive effects are equal to the negative effects in both magnitude and probability, so that expected income is unchanged. In this scenario loss from climate change is not due to a decline in expected values, but rather due to the preference to reduce the risk inherent in more dispersed outcomes. In other words the risk increase due to climate change can be modeled such that the expected value of the resource remains unchanged but the dispersion is more extreme. Here a risk-neutral individual would sense no loss from this greater dispersion because the expected loss is unchanged, so would have no option value. But using Freeman's framework where most people are risk averse, they would attach substantial option value to insure against the wider dispersion between the best-case and worst-case scenarios.

Option value applies more widely to climate change impacts than just to water resources. In fact it addresses a fundamental aspect of the potential economic loss from climate change. Statisticians characterize distributions with measures of Central Tendency and Dispersion. Much of the concern about climate change impacts has focused on increases in measures of Central Tendency such as higher average temperatures or higher mean precipitation. But from a socio-economic perspective the potential damages linked to increasing dispersion, such as more extreme temperatures or precipitation patterns may be just as damaging to social and economic well-being. Given the probability of greater extremes, the concept of option value is crucial to understanding the economic impacts of climate change.

Review of the Literature Applying Option Value to Climate Change

A paper on the economic impacts of climate change by Heal and Kristrom (2002) is particularly thorough on the concept of option value and the Precautionary Principle. They extend the discussion of balancing risks in the previous section by including the aspect of irreversibility and endogenous learning. Heal and Kristrom state: "the preconditions necessary for the existence of an option value seem to be satisfied in the context of climate change. We expect to learn about the costs of climate change and about the costs of avoiding it over the next decades. And we expect that some of the decisions that we could take will have consequences that are irreversible. These are the hallmarks of decisions that give rise to option values associated with conservation. …But although these conditions are necessary for the existence of option values they are not sufficient. …there is another possible real option value at work here. If substantial sunk costs must be incurred to begin the process of abating greenhouse gas emission and avoiding or minimizing climate change, if the return to this investment is the avoidance of climate change, and if we learn about the value of this over time, then there is also a real option value associated with postponing investment in greenhouse gas abatement." Page 25

Precaution against an irreversible outcome that would destroy information is regarded in the literature as having quasi-option value. This argument assumes environmental damages are harder to reverse than the policies aimed to insure against them. This is referred to as asymmetric irreversibility. One view is that action should be taken to prevent potential impacts because by the time impacts are better known it may be too late. There is an opportunity for exogenous learning in waiting to see how bad damages become, but impacts may be irreversible by then. On the other hand, there could be endogenous learning enabled by taking action in that greenhouse gas abatement will teach us costs and these can be reversed later if we learn abatement is unnecessary. In fact, the EPA classifies pollution-control technologies distinguishing between the best that might be achievable through time versus those already in place. This classification invites an interpretation that endogenous learning can occur with these investments. Policies that generate endogenous learning are often comprised of what are commonly called "demonstration projects." Attempts to control pollution, or mitigate effects, are needed for endogenous learning to occur.

But an opposing view in the literature contends that pollution control commitments may also be difficult to reverse. Heal and Kristrom advocate that policies be designed to be flexible enough to be adjusted as new information is forthcoming. They provide a conceptual framework with dollar ranges and probabilities of damages and costs of action. (Heal and Kristrom, 2002 also discuss humans' preferred temperatures and disutility from weather extremes.)

Heal and Kristrom recognize role of the Precautionary Principle in the economics of climate change. A quote from the 1992 Rio Declaration (Article 15) is cited: "where there are threats of serious and irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." An opposing view is that precautions should be taken against premature expenditures on pollution control. Waiting to act until more is learned about the damages will also have an information value. This is described as the "learn then act" strategy. Heal and Kristrom note that "if we follow this strategy then the risk that society faces in the future will be greater" and that balancing these countervailing risks depends on the shape of the utility function and the level of "prudence" adopted by society. Page 26

Heal and Kristrom (2002) and Heal (2008) discuss uncertainties that are both ecological and economical. A major challenge to the Stern Review is the economic uncertainties that exist about future optimal discount rates, growth rates and technological advancement. However, it should also be noted that human behaviors and adjustments to information likely provide greater reversibility and are likely to be more flexible than ecosystem constraints. Unraveling ecosystem interconnections and irreversible threshold and cascade effects are potential consequences that need to be considered. In ecosystems, constraints such as the First and Second Laws of Thermodynamics and the Law of Conservation of Matter are immutable laws, in contrast to economic laws about behaviors and incentives.

The debate about whether option value would be positive for reducing the threat of climate change boils down to whether there is an income equivalent that expresses WTP as a risk-aversion premium. The conclusion of this analyst is that purchases of physical capital in the form of pollution control equipment - whether it be to reduce greenhouse gases or reduce other causes of potential environmental degradation – can be translated more readily into income equivalents than the consequences of losing natural capital. The same is true for the potential loss of human life.

Reducing the risk to water resources from climate change is one impact that could generate positive option value as a risk-aversion premium to individuals. An individual's willingness to pay an option price to protect water resources which is greater than expected losses is analogous to the individual motives for paying insurance companies premiums that generate profit. But an important distinction is that option value for protecting water resources accumulates to all individuals that are averse to these risks. So benefit accumulates simultaneously to all of these individuals due to policies that reduce these risks. This collective benefit fits the definition of a public good.

The evidence on climate change impacts suggests that irreversible damages could occur. This implies an asymmetry in the countervailing risks of 1) premature action posing the risk of "Doing Too Much Too Soon" and 2) waiting until scientific evidence is better understood leading to the eventual regret of "Doing Too Little Too Late." Good policy formulation can provide flexibility to alter future pollution abatement investments. Human/social decisions should be more reversible than many environmental impacts; damages to ecosystems, loss of native species, loss of human life, etc. These risks are seen by this analyst as being less reversible, greater in magnitude and more difficult to monetize than expenditures on pollution control devices. If risks of irreversibility are asymmetric in this way, the risk-aversion premium weighs toward "Doing Too Much Too Soon."

SURVEY OF THE LITERATURE ON ECONOMIC IMPACTS OF CLIMATE CHANGE

Insurance Industry Perspectives

Over a decade ago, Michael Tucker (1997) provided a perspective on climate change action based on the market for insurance. "A convincing economic argument for taking action to prevent or ameliorate climate change has not developed because of both uncertainty about the degree of change and its timing.

Recent costly weather-related catastrophes with consequent negative impacts on the insurance industry has made the insurance industry a potential advocate for slowing what has been identified as a causal factor in climate change: emissions of greenhouse gases. However, rising costs of claims, without a longer-term trend of such catastrophic losses, will make it difficult to present a strong case for taking costly economic action." Tucker developed a technical, industry-specific argument regarding pricing of insurance to strengthen the case for action on climate change. He concluded that "economically justified higher insurance premiums" would result from "increasing levels of climate variability as embedded in the anticipated variability of damage to insured asset." While potential climate change impacts such as sea level rise are often conceptualized as not occurring until far into the future, Tucker's perspective of weather related damages brings the consequences into the present day, even in 1997.

In an article on global change, Berz (1999) speculates that "changing probability distributions of many processes in the atmosphere" will result in "serious consequences for all types of property insurance." "In areas of high insurance density the loss potential of individual catastrophes can reach a level at which the national and international insurance industries will run into serious capacity problems." Three insurance industry experts, Mills, et al. (2001) estimate a 15-fold increase over the period 1970 - 2000 in insured losses from catastrophic weather events (defined as exceeding $1 billion of damages.)

Following is a statement from the website of the Insurance Information Institute. "Catastrophes appear to be growing more destructive, but insured losses are also rising because of inflation and increasing development in areas subject to natural disasters. In 2005, the year of hurricanes Katrina, Wilma and Rita, catastrophe losses totaled $64.3 billion. Hurricane Katrina caused losses of $41.1 billion, the highest on record, about twice as much as Hurricane Andrew would have cost had it occurred in 2005. Seven of the 10 most expensive hurricanes in U.S. history occurred in the 14 months from August 2004 to October 2005. If, as suggested, hurricane-related losses grow by as much 40 percent over the next 20 years, a Katrina-like storm could cause $60 billion in losses, or significantly more if it struck a densely populated metropolitan area like Miami or New York City."

The evidence from the scientific literature does not lead to consensus about trends in hurricane frequency and severity. But these damage figures are of concern to many in the insurance industry and have broader implications for society as a whole.

In their paper on the economics of climate and insurance, Valerde and Andrews (2006) state: "As a key instrument and enabler of loss mitigation and risk transfer, the U.S. insurance industry lies at the nexus of several crucial dimensions of the climate change problem, especially as it relates to the potential implications of climate change for society and the global economy. Having sustained record-breaking natural catastrophe losses, insurers and reinsurers are openly—and, indeed, justifiably — questioning the potential linkage between anthropogenic climate change and extreme weather, looking at both the likely short-term implications for the industry, as well as potential long-term impacts on financial performance and corporate sustainability." page 1. "A fundamental question that we pose here, then, is whether the risks posed by global climate change are, in some way, structurally different than what has previously come to pass, thereby presenting insurers with new — and, some would argue, unprecedented— challenges, requiring a fundamental rethinking of the mindsets and methods that are used to manage these risks. Indeed, it may be the case that traditional underwriting and risk management methods are not adequate for this task." page 3. Despite the highly developed theory and practice of actuarial science, these authors are suggesting that the risks posed by climate change may present new and unprecedented challenges.

In an analysis of trends in the Canadian insurance industry, White and Etkin (1997) state: "At the same time that a scientific consensus has arisen that the world will most likely experience a changing climate in the near future, with more frequent extreme events of some weather hazards, the insurance industry, worldwide, has been hit with rapidly escalating costs from weather-related disasters. This conjunction of scientific belief and economic impact has raised the questions as to (1) whether more frequent extreme events have contributed to the rising insurance costs and (2) how will future climate change affect the industry? Based upon historical data, it is difficult to support the hypothesis that the recent run of disasters both world-wide and in Canada are caused by climate change; more likely other factors such as increased wealth, urbanization, and population migration to vulnerable areas are of significance. It seems likely, though, that in the future some extreme events such as convective storms (causing heavy downpours, hail and tornadoes), drought and heat waves will result in increased costs to the industry, should the climate change as anticipated."

The evidence on worsening trends in weather-related damages has continued to grow over the last decade. The World Wildlife Fund for Nature and Allianz Insurance Company issued a report (2009) on tipping points from climate change and damage potential. The report notes that "The phrase 'tipping point' captures the intuitive notion that "a small change can make a big difference." As a concept for understanding risks, the tipping point invites comparisons to the argument by Valerde and Andrews that the insurance industry may need to develop a new paradigm. Tipping points in ecosystems, ecological goods and services and in the planet's life support systems could force tipping points in many human-social institutions, including the insurance industry.

Damages to Public Infrastructure

The economics literature on risk-aversion should inform decisions on climate change. The potential damages from climate change are the types of risks that people typically wish to guard against. Most citizens place a value on risk reduction and are willing to pay for the insurance value this yields. As noted above, public policy that reduces the risks described above is a public good to all those who have risk-averse preferences. It is a collective value derived from the sort of individual value many people place on private insurance. Fundamental aspects of climate change involve risks that are better understood in the context of option value.

Some studies at the national or international level aggregate findings that originate at the spatial scale of states. Research for the National Weather Service has categorized weather-related damages by state. A study by Pielke, et al. (NOAA, 2002) estimates the monetized damage estimates from National Weather Service records for each state. This information is aggregated from separate datasets. Information from local regions was added to statewide data in some cases. Damage information spans from 1925 to 2000. Despite some data limitations that are explicitly noted, the document contains useful information. For example, flooding in Minnesota cost over $900 million in 1993 and $700 million in 1997. The annual damage figures for MN span from 1955 to 2000. Current and constant dollar estimates are provided in Table 1.

Research by Lettenmaier, et al. (2008) examines the current relationship between climate change and water. This study projects the near term impacts of global climate change on water resources in the United States for the next 25 to 50 years. Major aspects included are streamflow, evaporation, drought, precipitation, runoff and water quality. Minor focus areas include land use and ground water impacts. In the analysis of streamflow, trends from 393 stations in the US were plotted on maps with statistically significant increases reported in the central portion of the United States, including source stations in Minnesota. Evaporation rates are examined and where net decreases occur plausible explanations are offered, such as being due to increased cloud cover.

Droughts are anticipated to occur more frequently in the West and Southwest. A wetter climate overall is found to occur based on data from 1915 to 2003. Droughts are not projected to affect the central portion of the United States. Regional analysis is conducted for the central portion of the US, which includes Minnesota. Two separate studies have indicated an overall increase in precipitation in this region.

In relation to increased precipitation, runoff rates are explored using USGS statistics on runoff trends from 1901 to 1970. Projecting these trends into the future suggests an overall increase in runoff in the central US. Within this region, there is likely to be an increase in runoff in the Upper Mississippi basin.

POTENTIAL ECONOMIC EFFECTS OF CHANGES IN MINNESOTA'S WATER RESOURCES

Potential Economic Impacts from Changes in Water Flows

While the literature on global changes, including US federal government research (2009), indicates higher lake levels in the Midwest, except perhaps the Great Lakes, research on MN lake levels thus far yields mixed results. Lake levels appear to be less susceptible to immediate pulses of water from precipitation and snowmelt than are rivers and streams. The vulnerabilities of rivers and streams to flash-flooding is not an immediate concern for lakes. This is not to say that fluctuations in lake levels are not a concern in MN, but the evidence thus far points to water levels in rivers and streams warranting more attention.

As noted above, Heinz Stefan and his colleagues (2007, 2008, 2009) have studied water levels in lakes, rivers and streams. The streamflow analysis was based on data from gauging stations in the five major river basins of the state. In general, this evidence is consistent with impacts predicted in the literature. Results vary between the five basins, but generally the data indicate higher median flows and higher 90th percentile flows. Methods of describing riverine flows utilize measurements of time spans, such as 1-year, 10-year, 20-year, 100-year and 500-year floods. Ten-year floods should occur every ten years so should have a one in ten chance of occurring in any given year. One-hundred year floods should have only a one-percent chance of occurring and 500-year floods should have a probability of only two tenths of one percent. The work by Stefan and associates indicates that these floods are happening more frequently than the odds predict, especially for the 10-20 yr. floods. The statistics are less meaningful for the most extreme events associated with the most severe damages: 100-year and 500-year floods.

Even though the most extreme flow levels do not exhibit strong statistical changes, the increased baseline (median) flows and more frequent 10 to 20-year flood events could be evidenced by a trend toward increasing infrastructure damages. The evidence from the data must be couched in terms of limitations of data availability in terms of temporal and spatial scales: i.e. too few years of water levels are available to show long-term trends and too few flow measures have been taken within watersheds at the levels of tributaries or smaller in the five major basins. Downscaling of data may be necessary to enhance understanding of flooding patterns. Catastrophic events such as the southeastern MN flood of 2007 that severely damaged Rushford, MN and the surrounding area must also be recognized even though data availability may make it hard to place these extreme events in context. The economic evidence below does include these extremely damaging events even though they may be difficult to define in terms of evidence of climate change.

Another nuance of the merging of evidence on streamflows and damages relates to the higher base flow levels, especially in late winter and spring as snow melt enters the major basins. This pattern worsens risks of spring flooding in ways that may be too difficult to discern from data available thus far. Higher base flows and greater snow melt create worse vulnerability to early spring rains putting rivers and streams even higher above flood stage. The extreme flood event in the Red River Valley in 1997 was unusual given the record snow depths of that winter, but increased likelihood of rain at this time would exacerbate the problem. The 1997 floods show up in the damage records below.

It is essential to recognize that many variables are changing through time and in directions that would indicate historical trends for more flood damages for some trends and less for others. One factor suggesting that historical trends would be toward more damages is simply the inflation of the value of the resources and materials that are lost. Increasing development also places more valuable assets in harm's way. These and other changes make dollar amounts difficult to compare over the years. Policy has been in place for some time to invest in prevention of future damages by making scheduled replacement of transportation infrastructure (roads, bridges, culverts, etc.) to withstand high flow events. Furthermore when damages occur and emergency repairs are needed these too are being done to provide a buffer or guard against the failure of infrastructure repeating itself. This policy should lead to a decrease in damages over time. Historical trends are difficult to interpret given outcomes on damages result from a combination of influences, some positive and some negative. Multiple variables that influence infrastructure damages are in flux in MN so that the data on damages must be interpreted with caution.

Non-transportation infrastructure also merits attention. Some of the most expensive repairs are needed when drinking water facilities are overcome, especially if in conjunction with inundation of wastewater treatment plants. Precautions for human health concerning emergency water supply and long term repair make this category of damages very costly when they occur. The evidence in MN would indicate that these catastrophic damages are not increasing as dramatically as more numerous washouts of less costly infrastructure such as secondary roads and culverts associated with 10 to 20-year flood events. The data on damages reported below warrants explicit mention of some basic arithmetic: total damages amass just as much through many incidents of low to moderate cost as with fewer incidents of high cost. The former, if not the latter, would appear to be occurring more frequently in MN as a result of climate change.

Before moving on to a discussion of damage figures, greater dispersion of flows, including more extreme low flows should also be mentioned. Project findings on generally higher flows should not mask the possibility of economic costs of extreme low flows during extended droughts. The basins that show the most significant changes in flow are the Red River of the North and the MN River. Concerns over dependable water supply in the Red River of the North (Fargo, ND – Moorhead, MN and Grand Forks, ND - East Grand Forks, MN) have led to research and policy discussions as to these vulnerabilities and possible remedies. Again climate change makes this situation more risky.

Damage figures below are presented in order of most general categories of infrastructure to data more specific to transportation at the end. Table 1 provides figures for Minnesota from a NOAA study (2002) that reports the history of U.S. flood damages from 1955 to the most recent year, 2000. The report re-examines data back to the 1920s but only details damages state-by-state from 1955- 2000. The most informative column shows damages standardized in 1995 dollars, in thousands. This shows that from 1955 – 1970 there were three years with damages in the tens of millions of dollars and two in the hundreds of millions. From 1971 – 1984 (1980-82 missing) there were three years with damages in the tens of millions of dollars and three in the hundreds of millions. From 1985 – 2000 there were three years with damages in the tens of millions of dollars and the two years with the highest damages 1997 and 1993. The latter had damages in excess of $1 billion in constant 1995 dollars.

The MN Department of Public Safety's Division of Homeland Security & Emergency Management summarized damage information over the decade of the 1990s. The summary is more enlightening than the totals above being the damage figures are broken down into informative categories. The report "A Decade of Minnesota Disasters: A Historical Look at Minnesota Disasters in the 1990s" notes that the specter of climate change places increased importance on changing weather patterns and the increase in storm occurrence and intensity. The report focuses on weather related damages in Minnesota throughout the 1990s. According to the report, these damages are increasing and during the 1990s there were 14 presidential declarations of major disasters. Most of the damages were the result of flooding, ice storms, snow removal, straight-line winds, tornadoes, and heavy rain. From these disasters Minnesota taxpayers spent $827 million and the cost to insurance companies was more than $2 billion.

The report also ranks MN hazards by category of loss that occurs. It is based on data from the Minnesota Hazard Mitigation Plan. The rankings are a composite of: likelihood of occurrence, frequency, and historical impacts as natural hazards affecting the state. On average per year, blizzards are the top cause of deaths, ice and sleet are highest for injuries causes, and floods cause the most economic impact. Table 2 lists the 14 declared disasters in Minnesota for the 1990s, including totals by year. Some years had multiple declared disasters. A report for the last decade is not yet available but Table 3 categorizes the disasters since 2000.

TABLE 1
FLOOD DAMAGE
(in 1000s of Current and Constant 1995 Dollars)

Year	Deflator	Current $	Constant 1995 $
1955	0.20163	0	0.000
1956	0.20846	11	52.768
1957	0.21539	9,128	42378.941
1958	0.22059	17	77.066
1959	0.22304	50	224.175

1960	0.2262	212	937.224
1961	0.22875	552	2413.115
1962	0.2318	1,290	5565.142
1963	0.23445	26	110.898
1964	0.23792	0	0.000
1965	0.24241	97,603	402636.030
1966	0.24934	4,300	17245.528
1967	0.25698	0	0.000
1968	0.26809	1,197	4464.918
1969	0.28124	67,168	238828.047
1970	0.29623	4,350	14684.536
1971	0.31111	15	48.214
1972	0.32436	64,318	198292.021
1973	0.34251	242	706.549
1974	0.37329	16,939	45377.588
1975	0.40805	139,726	342423.723
1976	0.43119	0	0.000
1977	0.45892	7,870	17148.958
1978	0.49164	65,000	132210.561
1979	0.53262	13,140	24670.497
1983	0.70214	310	441.507
1984	0.72824	5,000	6865.868
1985	0.75117	500	665.628
1986	0.76769	1,501	1955.216
1987	0.79083	27,800	35152.941
1988	0.81764	555	678.783
1989	0.84883	17,600	20734.423
1990	0.88186	3,032	3438.187
1991	0.91397	1,280	1400.484
1992	0.93619	1,760	1879.960
1993	0.95872	964,050	1005559.496
1994	0.9787	1,867	1907.633
1995	1	3,750	3750.000
1996	1.01937	460	451.259
1997	1.03925	743,218	715148.424
1998	1.05199	2,529	2404.015
1999	1.06677	466	436.833
2000	1.09113	43,112	39511.332

(Note: constant 1995 dollars divide current $ by the implicit price deflator according to the U.S. Bureau of Economic Analysis, 2001. No estimates for 1980-1982.)

TABLE 2
FEMA DECLARED DISASTERS IN MN DURING THE 1990S

1. FEMA 1288 DR MN (1999) Total Cost $11.1 million
2. FEMA 1283 DR MN (1999) Total Cost $52.2 million
3. FEMA 1225 DR MN (1998) Total Cost $1.5 billion
4. FEMA 1212 DR MN (1998) Total Cost $246.1 million
5. FEMA 1187 DR MN (1997) Total Cost $85.4 million
6. FEMA 1175 DR MN (1997) Total Cost $545.0 million
7. FEMA 1158 DR MN (1997) Total Cost $82.4 million
8. FEMA 1151 DR MN (1997) Total Cost $20 million
9. FEMA 1116 DR MN (1996) Total Cost $48 million
10. FEMA 1078 DR MN (1996) Total Cost $6.7 million
11. FEMA 1064 DR MN (1995) Total Cost $18 million
12. FEMA 993 DR MN (1993) Total Cost $215.1 million
13. FEMA 946 DR MN (1992) Total Cost $32.5 million
14. FEMA 929 DR MN (1991) Total Cost $11.7 million

Totals by Year: Sum for Decade $2,874,200,000

Year	Totals	Year	Totals	Year	Totals
1999	63,300,000	1995	18,000,000	1991	11,700,000
1998	1,746,100,000	1994	0		
1997	732,800,000	1993	215,100,000		
1996	54,700,000	1992	32,500,000		

TABLE 3
DAMAGE TOTALS FOR FEMA DECLARED DISASTERS 2000-PRESENT: DESCRIPTIONS AND TOTALS

	Description	Public Assistance Total	*Total
4/19/2010	Flooding (estimates)	**$ 17,907,069**	**$ 20,593,129**
03/19/2010	Flooding	**$ -**	**$ -**
04/09/2009	Severe Storms and Flooding	**$ 38,221,852**	**$ 47,526,068**
03/26/2009	Severe Storms and Flooding	**$ 726,393**	**$ 726,393**
06/25/2008	Severe Storms and Flooding	**$ 8,238,063**	**$ 9,176,828**
08/23/2007	Severe Storms and Flooding	**$ 43,753,443**	**$ 85,439,673**
06/05/2006	Flooding	**$ 9,123,910**	**$ 9,634,389**
01/04/2006	Severe Winter Storm	**$ 10,465,370**	**$ 11,089,558**
10/07/2004	Severe Storms and Flooding	**$ 5,037,343**	**$ 9,712,096**
06/14/2002	Severe Storms, Flooding and Tornadoes	**$ 33,943,265**	**$ 50,376,450**
05/16/2001	Flooding	**$ 46,526,867**	**$ 56,712,017**
06/27/2000	Severe Storms, Flooding and Tornadoes	**$ 14,840,929**	**Declared**

*Total includes only the federal and state share of funding paid under the Stafford Act. Other federal funds, special state appropriations, and local funds are not included. The difference between Public Assistance payments and the total is Individual Assistance Program payments and Hazard Mitigation Grants

CONCLUSIONS AND IMPLICATIONS FOR FURTHER RESEARCH

Conclusions

The economics literature on risk-aversion should inform decisions on climate change. The potential damages from climate change are the types of risks that people typically wish to guard against. Most citizens place a value on risk reduction and are willing to pay for the insurance value this yields. Public policy that provides this is a public good to all those who have risk-averse preferences. It is a collective value derived from the sort of individual value many people place on private insurance.

Economic efficiency and equity goals are relevant to decisions about climate change. Risks from climate change could be reduced through emission reductions and/or adaptive strategies such as enhancing ecosystem integrity and resilience, precautionary design of infrastructure, etc.) If avoiding potential damages is deemed to generate net benefits and/or enhance equity, ways of achieving these goals at least cost should be pursued. Increasing the prevalence of best land-use practices applied in many watersheds may be a cost-effective way to offset ecological stress on Minnesota's water resources.

Flood Damages

An adaptive strategy to climate change would be to identify settings with the greatest vulnerability to catastrophic failure such as loss of life and property if structures fail. Most of the MN topography does not cause as great of danger of flash flooding as in more mountainous areas. The severe flood in southeastern MN in 2007 demonstrates that the topography of that part of the state makes it more vulnerable to severe flash floods. Elsewhere in Minnesota, overland flooding is more likely to occur rather than the deep rush of water with floods in hills and valleys. A two-pronged approach to risk management would inventory watersheds for greatest vulnerability to damages from flash floods according to two characteristics: 1) geomorphology conducive to flash floods and 2) human and natural environments that put highly valued assets and human life in harm's way.

Findings from the component of the project on streamflow indicate that the Minnesota River Basin and the Red River of the North have the largest increases. Even though extreme precipitation events are likely to be randomly located across the state, it would be a wise investment to protect against such disasters in the most vulnerable locations. This would be a sound application of the Precautionary Principle.

The longest yearly record for weather-related damages in MN comes from figures reported in a NOAA study (2002) that re-examines damage figures from 1925-2000 using constant 1995 dollars. From 1955-2000 occasional weather events caused damages in the tens of millions of dollars. Damages in the hundreds of millions of dollars also occurred over this time period. By far the two years with the highest damages were 1997 and 1993. The floods of 1993 caused damages in excess of $1 billion in constant 1995 dollars.

The MN Department of Public Safety's Division of Homeland Security & Emergency Management provided summarized damage information over the past two decades. According to the report "A Decade of Minnesota Disasters: A Historical Look at Minnesota Disasters in the 1990s" these damages are increasing with 14 presidential declarations of major disasters over the decade. Most of the damages were the result of flooding, ice storms, snow removal, straight-line winds, tornadoes, and heavy rain. The disasters of the 1990s cost Minnesota taxpayers $827 million and more than $2 billion to insurance companies.

Examination of transportation infrastructure as a major category of damages revealed that numerous weather-related events have occurred in the last two decades that caused damages to roads, bridges and culverts in the millions or tens of millions of dollars, per event.

Implications for Further Research

The larger MN research project identified future needs for data at scales appropriate to understanding climate change impacts in Minnesota. Much of the discussion in the research community at the national and state level is emphasizing the need to "downscale" data to allow meaningful analyses for smaller geographic areas, such as states. Needs to improve scale are:

1. Spatial Scale: consensus on need for "downscaling." Scaling Down Global and Regional Patterns to State Level and
2. Temporal Scale:
   A. Data to Determine variations over long enough time span and
   B. Hydrologic Data to Determine variations in Stream Flows that occur within 7-day period, such as extreme flows within a 24-hour period.

One major example of limitations due to too short of time span is described in an earlier project summary. It pertains to projecting biological responses to changing climate. Fish populations and other biological communities will be affected by warmer water temperatures, and altered thermal regimes, changes in flow regimes, total flows, water level, and water quality. These changes will affect the health of aquatic ecosystems, with impacts on productivity, species diversity, and species distributions. The paucity of historic data makes it difficult to assess past changes and predict biological responses to climate change.

The overall project, and the economic component, generated useful information as an indication of where the state might be headed in terms of climate change. It also indicates how much remains to be done in order to generate more precise empirical evidence. A great deal is being learned about how climate change may impact the future and what options exist to address it. Climate change has implications in time scales longer than most institutions are equipped to handle. Research design and policy formulation needs to reckon with these long time horizons in determining actions today that will benefit the future.

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*This paper includes analysis that is part of a larger study conducted on behalf of the Legislative-Citizens Commission on Minnesota Resources titled "Minnesota's Water Resources: Impacts of Climate Change- Phase II." Author's contact information: pwelle@bemidjistate.edu, (218) 755-4103, fax (218) 755-4107. Research assistance on the larger study was provided by Rabi Vandergon and Brett Nelson.