Towards a Tipping Point in Responding to Change: Rising Costs, Fewer Options for Arctic and Global Societies

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Abstract Climate change incurs costs, but government adaptation budgets are limited. Beyond a certain point, individuals must bear the costs or adapt to new circumstances, creating political-economic tipping points that we explore in three examples. First, many Alaska Native villages are threatened by erosion, but relocation is expensive. To date, critically threatened villages have not yet been relocated, suggesting that we may already have reached a political-economic tipping point. Second, forest fires shape landscape and ecological characteristics in interior Alaska. Climate-driven changes in fire regime require increased fire-fighting resources to maintain current patterns of vegetation and land use, but these resources appear to be less and less available, indicating an approaching tipping point. Third, rapid sea level rise, for example from accelerated melting of the Greenland ice sheet, will create a choice between protection and abandonment for coastal regions throughout the world, a potential global tipping point comparable to those now faced by Arctic communities. The examples illustrate the basic idea that if costs of response increase more quickly than available resources, then society has fewer and fewer options as time passes.

Keywords Climate change costs · Prevention · Response · Politics · Economics · Village relocation · Forest fires · Sea level rise · Arctic

INTRODUCTION

The Arctic provides climate regulation services to the Earth. Snow and sea ice reflect sunlight. Permafrost seals large quantities of carbon in the ground. As the Arctic warms, the area covered by snow and sea ice is decreasing, and more solar energy is absorbed by the Earth. Permafrost

thaws, releasing carbon dioxide and methane into the atmosphere. Both changes are substantial positive feedbacks to global warming, meaning that the changes themselves lead to further changes in the same direction. Recent preliminary estimates of the magnitude of these feedbacks (Goodstein et al. 2010) suggest that, relative to its preindustrial state, the Arctic is generating climate forcing equivalent in 2010 to about 3 gigatons of CO₂, or 42% of carbon emissions from the United States.

These feedbacks have consequences. First, they exacerbate the impacts of carbon emissions by magnifying the resulting warming. This means that for emissions reductions to work, they must counteract not only the direct effects of previous emissions, but also the magnified effects due to positive feedbacks. Second, positive feedbacks magnify the costs of warming by increasing the rate and extent of impacts from sea level rise, extreme weather events, ecological changes, and so on. Goodstein et al. (2010) estimate the global social costs of reductions in, sea ice, and permafrost to be US \$61–371 billion from 2010 alone. Cumulatively, the costs by the end of the century may be US \$2.4–24.1 trillion. These estimates do not incorporate the possibility that Arctic warming will trigger accelerated melting of the Greenland ice sheet, an issue discussed further below.

The magnitude of these costs leads to the questions we address here: What are the implications for society of the rising costs of preventing or responding to global warming, in the Arctic and beyond? Are there likely to be tipping points (major changes that cannot be easily undone but instead create a new stable system) in the political-economic response to global warming? If so, what would those tipping points look like?

We begin by examining how rising costs affect the type of response—at the individual or community level—as

well as the availability of resources to address the warming itself. Then we show how trade-offs in potential responses lead us towards political-economic tipping points, including two examples in Alaska (village relocation, wildfires in the boreal forest) and one that illustrates how a changing Arctic can impact the broader earth system (rapid sea level rise due to melting of the Greenland Ice Sheet).

We conclude by considering the implications of the existence of political-economic tipping points in the human relationship with the earth system. Despite the ability to foresee problems and potential disasters, political will to take preventive action is often lacking. Where changes in the earth system cannot be easily reversed, the failure to prevent impacts (or the unwillingness to bear the costs of preventive action) leads to a tipping point: the abandonment of a town or region, changes to the characteristics of an ecosystem and human use thereof, and the shift of costs from society and governments to individuals and households. As this shift occurs, preventive action becomes less likely, and the social system and the earth system become increasingly likely to move towards a new state.

RISING COSTS, LIMITED RESOURCES

The global annual expenditure of US \$61–371 billion to address the costs of climate feedbacks from Arctic warming is not enormous in terms of the global economy, but neither is it trivial. It represents just one portion of the expenses associated with global warming. The annual costs are expected to increase as warming continues. If costs rise more quickly than the economy will grow, the standard assumption in the economics literature (Goodstein et al. 2010) then rising costs will eventually stress available resources, both for adaptation and mitigation policy.

Who will bear the costs of a warming planet? In general, governments (that is, the organized community at large) intervene on only a limited basis to cushion the blows of economic change, whether driven by technology shifts, outsourcing, or government actions like military base-closing. Consider, for example, modern examples of “collapse” such as Detroit, which like the Mayan cities discussed by Diamond (2005) has lost more than 65% of its population in the space of a few decades, including 25% in the last 10 years alone Gray (2011). Detroit has not received sufficient state or federal aid to stem its decline. There is little reason to think that government policy for climate-driven economic dislocation will be more generous.

Moreover, government’s resources are limited, and so cannot indefinitely offset or defray individual or household climate costs rising at a growing rate. This theoretical economic limit is almost certainly higher than the political limit for spending funds to address the impacts of warming.

In other words, what we can spend is likely to be higher than what we are willing to spend when the time comes.

There are two areas where governments at the local, state and regional level will provide some funds for adaptation. First, governments may mitigate extreme weather events through disaster relief. Second, governments may alter infrastructure and industrial, agricultural, forest management, and science and technology policies to accommodate changing climate patterns. Beyond these categories, however, the balance of economic costs will be borne by individuals and households in the form, for example, of higher prices for food and water, higher prices for or non-availability of insurance, the purchase of defensive technologies like air conditioners, or in extreme cases, household migration decisions, and potentially, the abandonment of towns or regions.

In the case of disaster relief, rising costs are already straining government budgets. By the end of July 2011, record breaking droughts in Texas and Oklahoma, record breaking floods in the midwest, and the record tornado season (not explicitly linked to climate change) had led to a record number of billion dollar disasters in the US, only eight months into the year (Kavanagh 2011). And even given massive federal relief efforts, intervention after Hurricane Katrina in 2005 could not forestall large-scale costs being born by individuals and households. New Orleans had lost 29% of its population by the 2010 Census (New York Times 2011).

We hypothesize that even in the two categories of disaster relief and climate-related infrastructure investment, as climate costs rise relative to GDP (at the regional scale) a tipping point will be reached at which government-funded adaptation will give way to costs borne largely if not exclusively by individuals and households. The tipping point will be the shift from willingness to pay to unwillingness, and thus lies at the intersection of politics and economy. It is this real-world tipping point that interests us here, and we now turn to three examples.

VILLAGE RELOCATION IN ALASKA

The question of village relocation in Alaska illustrates likely limitations in political will to spend money responding to impacts of climate change. Although some response will be necessary, one likely outcome would lead to a significant shift in the pattern of human habitation in rural Alaska, with individuals and households bearing the costs of climate change. Such a change would meet the criteria for a “tipping point.”

Coastal and riverbank erosion are common features worldwide. In Alaska, 184 of 213 Alaska Native villages (GAO 2003) are at risk from flooding and erosion,

exacerbated by rising sea level, loss of sea ice that helps protect coastlines, loss of permafrost that provides a solid footing, changes in riverflow patterns, and other symptoms of climate change. Four of these (Kivalina, Koyukuk, Newtok, and Shishmaref) urgently require relocation, whereas others are likely to require major adjustments or relocation in the not-too-distant future. The GAO report estimates the cost of relocating Kivalina to be US \$100–400 million, for a community of 377 people at the time the report was written.

Unlike typical communities elsewhere in the country, Alaska's Native villages have minimal local revenue, and instead have relied on federal and state subsidies for most purposes. The federal government was responsible for establishing many communities (often coalescing a number of family camps and settlements into one location) and with the state government has remained responsible for many costs of infrastructure, and has paid for relocations of some communities over time. This relationship is one aspect of the federal trust responsibilities to Native American and Alaska Native tribes and individuals, distinct from non-native communities (e.g., Case 1984).

Spending up to US \$1 million per person to respond to one manifestation of climate change is clearly a major commitment, regardless of past practices and acknowledged responsibilities, and would set a precedent for future response. We can also look at this cost as a fraction of federal spending in Alaska. Assume that only one community per year will require re-location, and take the lower figure of US \$100 million as the average cost. Annual federal spending in Alaska is approximately US\$8 billion (Goldsmith and Larson 2003). This puts the relocation of one community at 1.25% of annual federal spending, exclusive of any other demands for climate change response in the state.

By itself, this figure is not inconceivable, but in the context of recent poor national economic performance, massive federal deficits, and a strong political push to cut federal spending, the addition of US \$100 million to benefit a few hundred people may be politically untenable. This is especially true if the relocation of one community implied a commitment of similar assistance to other communities. One indication that such political will is lacking is the fact that, in the 7 years since the GAO (2003) report was issued, no relocations have been completed, and only one has even begun. In this sense, we may already have passed the political-economic tipping point beyond which village relocation is unlikely to be largely paid for by governments.

Should communities that are eroding away not be rebuilt elsewhere, the distribution of people on the landscape will change. Residents of the vanishing villages will move to other communities or regional hubs or cities such as

Anchorage, perhaps bearing an appreciable share of the costs of doing so. It is unlikely that villages will be restored later on, making this a permanent shift, creating a new pattern of settlement regardless of future climate trends. While this course of events is still speculative, it appears more and more plausible, and has the characteristics of a tipping point. Other such examples can no doubt be found throughout the Arctic, with regard to various aspects of human habitation, livelihood, and behavior.

WILDFIRES IN THE BOREAL FOREST

Forest fires affect important economic and subsistence (traditional hunting, fishing, and gathering) resources and the habitat of many wildlife species (Chapin et al. 2003). Changes in fire frequency, duration, and severity have been forecast for many boreal regions due to a warming climate (Balshi et al. 2009; Flannigan et al. 2009), and indeed changes in the fire regime are already occurring in interior Alaska. The fire return interval has decreased and the fire severity has increased in interior Alaska in recent years, and there has also been an increase in the number of large fire years, with four out of the eleven largest fire years occurring between 2002 and 2009 (Kasischke et al. 2010). Consequently, a greater proportion of the landscape is being impacted by fire.

Black spruce (*Picea mariana*) is the dominant forest cover type in this region and is prone to frequent, stand-replacing fires. Fire and the successional processes in these black spruce forests have been viewed as a cycle of spruce self-replacement, with few changes in pre- versus post-fire vegetation composition. Yet, under current changes in the Alaska fire regime and expected future changes under a warming climate, this traditional view has been altered. Recent research has shown that the degree to which a fire consumes the soil organic layers (e.g., fire severity) and the duration of the fire return interval (e.g., the fire-free period) in these black spruce forests are key determining factors for whether the black spruce forests regenerate to a forest composition similar to the pre-fire forests or are replaced by a forest that is dominated by deciduous hardwoods (Greene et al. 2007; Johnstone et al. 2010) (Fig. 1).

Climate-related responses of the fire regime have implications for ecosystem services that are related to climate regulation and subsistence. In terms of climate regulation, forests and peatlands store large amounts of terrestrial carbon, and when released to the atmosphere, it may increase the atmospheric composition of CO₂ (Balshi et al. 2009). Furthermore, the alteration of the vegetation cover under climate related changes in the fire regime may influence the regional climate through changes in surface

Fig. 1 The landscape in **a** is dominated by a mixture of spruce and deciduous hardwoods. However, following severe fires, such as that shown in **(b)**, the spruce forests are more likely to be replaced by northern hardwoods, leading to a landscape that differs in vegetation composition compared to that of the pre-fire landscape. Photo by E. Euskirchen

albedo. This may actually result in a negative feedback to climate warming since the cooling effects from an increased surface albedo due to a greater proportion of young forest stands on the landscape may be greater than

the heating effects from the direct emission of greenhouse gases during fire (Randerson et al. 2006).

Changes in ecosystem structure due to changes in the fire regime may also have repercussions for the use of

subsistence resources. In particular, the suitability of these forests for wildlife habitat may be altered for caribou and moose, which serve as key subsistence food resources for indigenous people. Caribou typically prefer the black spruce woodlands while moose prefer early postfire successional forests that are dominated by young willow and aspen (Chapin et al. 2008). Consequently, as changes in the fire regime cause landscape-scale shifts towards more deciduous stands, the habitat for moose increases while that of caribou declines.

These resulting shifts in vegetation composition under a changing fire regime also signify increasingly complex decision making for government agencies with regard to climate regulation, and maintaining biodiversity and natural ecosystems within the landscape. At present landowners are allowed to choose the suppression level to be applied to their land. However, fire managers in interior Alaska have never had the resources necessary to suppress all wildfires, nor is complete fire suppression desirable for many habitats and species. Consequently, Alaska has been zoned into levels of suppression effort, where in approximately two-thirds of interior Alaska, fires are monitored, but generally allowed to burn. In the other portions of interior Alaska, where fires might pose a risk to local communities, they are actively suppressed (Chapin et al. 2008). However, it is becoming increasingly recognized that the strategy of letting fires actively burn in two-thirds of interior Alaska also poses a risk to local communities, and indigenous people in particular, due to the loss of subsistence opportunities resulting from changes in the fire regime. Maintaining the existing fire regime and landscape characteristics, however, requires far greater expenditure on fire prevention and fire fighting.

In reality, however, fire management agencies are experiencing budget shortfalls, closing remote forest fire fighting field stations, and focusing primarily on protecting more populated areas. Furthermore, fires in Alaska have typically burned from early June – July, at which time resources are moved to the other states, where the main fire season begins later than in Alaska. However, the area burned during late season fires has increased over the past two decades (Kasischke et al. 2010). Consequently, when fires burn longer in Alaska, the resources to fight later season fires can be even more limited since personnel and equipment have been moved to other states. Thus, there is a growing gap between what is required for the government to maintain lands and resources in the condition that the public expects, and resources available to the government to provide increased fire suppression needed to do so. Some difficult decisions may have to be made regarding which lands and buildings will be protected. The idea of letting landowners choose the level of protection they want,

regardless of cost, may be forced to change in policy as well as in practice.

We are approaching a landscape tipping point at the intersection of climate-driven change to the fire regime, and political-economic and practical limitations on the ability to manage that change by fire suppression. The almost inevitable result will be the creation of a different forest landscape, supporting different vegetation composition and abundances of animals, thereby requiring different strategies for human uses such as hunting, gathering, and forestry. The costs of such adaptation, including perhaps changes in the location and use of remote cabins on lands no longer protected from fires, will likely be borne by individuals.

RAPID SEA LEVEL RISE

One possible consequence of the warming Arctic Ocean that the Greenland ice sheet mass will cross a tipping point, starting a process of geologically rapid melt. Should this occur, in concert with comparable processes in the West Antarctic Ice Sheet, it would raise global sea level by more than ten meters. Tripathi et al. (2009) note that the last time the earth experience a sustained period of CO₂ greater than 400 ppm, the earth was 3–6°C hotter than preindustrial levels, and sea levels were at least 22 meters higher than they are today, implying that not only Greenland and West Antarctica were virtually ice free, but also significant portions of East Antarctica.

Nicholls et al. (2011) argue that sea-level rise this century, even assuming high end warming and the initiation of ice-sheet collapse, can likely be no greater than two meters. The authors examine the case of a sea-level rise of two meters over the next 100 years. They first explore the “optimists” viewpoint of “rational adaptation” policy, in which governments around the world construct sea-wall defenses and nourish beaches in populated or high tourism areas wherever the benefits of protective action are greater than the costs. Because coastal real estate, especially urban, is valuable, the model generates a lot of sea wall construction. Annual adaptation expenses (construction costs) are estimated at \$275 billion. This is 0.02% of global GDP, but much higher than 3% in some countries. To put the expenditure in context, the post-Katrina upgrades at New Orleans were \$15 billion, so the model assumes yearly global expenditures equivalent to 18 times what the US spent upgrading the New Orleans system over the course of 5 years. In this scenario, most displacement is avoided, with a relatively small number, 305 000 people, migrating over the course of the century as a result of loss of their homes.

If no protection were undertaken (the “pessimists” view), by contrast, the authors estimate that some 187 million people would migrate as a result of flooding, 2.7% of the global population. With a two meter sea level rise, and no protection, 1.2% of the earth’s land surface would disappear.

Beyond the loss of real-estate to rising waters, increased sea-level will expose more cities, more capital assets, and more people to New Orleans-style events, previously expected to occur only once in every 100 years. With no permanent inundation, that single storm still caused more than \$100 billion in property and other types of damage, and forced the evacuation of more than 1 million people. A recent study by the Organisation for Economic Co-operation and Development (OECD) suggests that only a half a meter of sea-level rise—towards the lower end of projections—will, by 2070, put more than 70 million people and \$8 trillion in additional assets at risk of exposure to 100 year storm surges (Nicholls et al. 2008). With more than 100 major cities exposed, we should expect that incremental exposure to translate into substantial human and capital losses on average once a year.

Which view—the optimist or the pessimist—is more likely? The failure of New Orleans to prepare for the well-known dangers posed by a Katrina-like hurricane challenges the assumption of rational adaptation. Necessary preventive measures had been identified but not acted upon (Freudenburg et al. 2009). The inference from our analysis is that we would likely see a socioeconomic tipping point, where an initial commitment to coastal protection gives way in the face of rising costs to abandonment, with these tipping points becoming more likely in higher end warming scenarios. Nicholls et al. (2011) note that this is a possibility: “It is certainly plausible that extreme events can trigger a cycle of decline and ultimately coastal abandonment.”

Global sea level rise, and especially rapid sea level rise, will be a tremendous infrastructure challenge for local, national and regional governments. It seems likely that rather than being mitigated through assumed efficient government policy, a large percentage of the costs will be borne by private individuals and households. In this way, the Alaska village experience may be a foreshadowing of the global response, driven in part, by the collapse of the natural cooling services provided by the intact Arctic cryosphere.

DISCUSSION: SCALE AND TIMING

As Earth warms, there will be many political-economic tipping points, at a variety of scales. The common feature they have is that they involve the loss of one or more options for the future. The relocation of villages in Alaska illustrates the point on a small geographical scale. Climate costs already exceed many times the village GDP, and

relocation would be a significant portion of current federal spending in Alaska. If we are unwilling or unable to prevent the loss of villages, we have passed a tipping point and entered a new state where the only available response is simply to move people (or let them move themselves) to existing towns or cities, accepting as inevitable the resulting strain on individuals and on the resources of the communities that must accommodate a population influx. Although the basic policy decision may be taken in the short term, the varying degrees of susceptibility to flooding and erosion among Alaska Native communities mean that movements to towns and cities will take place over decades as one village after another becomes uninhabitable.

Boreal forest fires will have impacts on a similar scale. Fire-fighting is a cost borne by governments, with some local efforts to protect homes and other personal property. At the landscape level, significant resources are likely to be needed to retain current fire regime characteristics and the resulting vegetation patterns in Interior Alaska. These resources, however, are unlikely to be available, and an ecological shift is likely to take place, forcing humans to adapt as well.

Similar examples can no doubt be found elsewhere in the Arctic. Russia and Canada have extensive boreal forests, and must address similar questions of landscape change. Greenland has seen major economic changes due to the shift from abundant cod to abundant shrimp off West Greenland, yielding a different economic model and changing the fortunes of several towns (Hamilton et al. 2003). The viability of reindeer herding in Scandinavia may be affected by more frequent winter rains and ice build-up on the ground, making it difficult for animals to reach the lichen they depend on in winter (Huntington and Fox 2005). Further investigation is needed to determine the presence and nature of tipping points in these systems, but it is unlikely that Arctic political-economic-ecological tipping points are limited to Alaska.

Rapid sea level rise, on the other hand, is a global problem. Here, both the stakes and the costs are higher, as many major cities and hundreds of millions of people are affected. Although mitigation may be technically feasible and economically possible, the example of New Orleans suggests that political will may be lacking, and thus government-supported mitigation may yield to adaptation and relocation paid for by the individuals affected. Here, too, we see a tipping point in human habitation, as the coastal areas that have been attractive to people for centuries become inundated, and in human response to climate change, as collective efforts to address the causes of climate change or to mitigate its impacts fail, leaving individuals to bear the costs of adaptation and response.

In theory, slow transitions leave plenty of time for policy reversals. Even if the village that is abandoned today

is never re-settled, tomorrow's vulnerable villages may have access to sufficient resources to allow successful relocation. In this case, the tipping point is highly localized and may not represent a substantial societal shift.

But another trajectory is also plausible. If relocation resources are scarce, a policy of protecting only the large regional towns may make sense, rather than spreading scant funds across many villages. In this case, the recognition that all villages cannot be protected could translate into even more rapid abandonment as available resources are concentrated in a few places and even relatively minor needs such as a new runway are no longer feasible for the smallest communities.

Regardless of who bears the cost, responding to climate change is not optional (e.g., Stern 2007). As the environment changes, society and its members will have to respond. The nature of that response may vary, but the basic fact of response remains. For eg., when faced with sea level rise, we can attempt to build barriers and dykes to hold the water away from areas of importance such as large cities. Or we can re-locate cities and towns to higher ground. Or individuals could be left to find their own solutions, which would likely lead to considerable conflict as refugees move into already inhabited lands. In any case, the response will happen one way or another.

Preventing change, on the other hand, is optional. There is no requirement to do anything, even if preventive action would save considerable money in the long run or alleviate widespread human suffering. Taking preventive action requires political will, and requires a willingness to spend money on problems that have not yet arisen. Prevention can be difficult to justify, because it is often difficult to pinpoint the savings that were realized. For example, funds to respond to forest fires are much easier to obtain than funds to prevent fires. When a fire is burning, there is strong political support for action. When no fire is burning, there are many competing demands for available funds, and it is hard to calculate the amount saved by preventive action, thus making it difficult to justify afterwards.

In spite of these difficulties, prevention is often the smartest policy, and societies do undertake preventative expenditures (e.g., Stern 2007). The use of vaccines to prevent infectious diseases is one example, as many societies require or encourage vaccination to reduce risks and costs of epidemics or even individual illness. In the case of global warming, however, as the impacts of warming increase, the costs of responding will increase too, leading to a second hypothesis. Under the assumption that these costs increase more quickly than available resources, this means that responding to change may well come at the cost of preventing change. As a greater proportion of resources is devoted to response, fewer and fewer resources will be available for prevention (Fig. 2).

Fig. 2 If response costs increase more quickly than the size of the economy, the resources available for prevention decrease over time, resulting in fewer available options for society

An example of this interplay in action was seen in Australia in 2011. Flooding, likely due to changes in precipitation related to global climate change, caused extensive damage with substantial costs. In response, the Australian government cancelled an AU \$500 million clean energy program (attempting to prevent or reduce climate change), re-directing the funds to flood relief (Climate Progress 2011). This decision was of course a choice by the Australian government and Australian society, because the problem was not an inability to pay for both clean energy and flood relief, but a political choice not to do so. Nonetheless, the absolute ability to pay is of only theoretical interest.

Australia's re-allocation of funds away from clean energy and towards flood relief means that the development of clean energy alternatives is at best postponed until funds are no longer needed for flood relief. The decision to spend money on responding to change rather than preventing change marks a shift in attitude and an acceptance that prevention is not feasible. Perhaps the Australian example is an aberration, or perhaps it is the way of the future, in which the option of prevention is one we no longer choose (a matter of political will) or are not longer able to choose (economic reality, regardless of political will). If that is the case, we have indeed passed a major tipping point as a global society.

In the case of rapid sea level rise, sea wall construction will also lay claim to such a large share of national wealth in some countries that it is likely to crowd out climate stabilization investments, as well other governmental and private sector expenditures.

The exact nature of whatever stable climatic-ecological-societal system awaits us is impossible to predict. Tipping points themselves are difficult to predict (Scheffer et al.

2009), and can often occur without warning (Hastings and Wysham 2010). Even the absence of a tipping point is not necessarily good news, since considerable impacts may occur anyway. The process of change will be disruptive regardless. As society approaches political-economic tipping points of the kind discussed here, we should be aware of the consequences of passing points of no return, and think carefully before we lose too many more of our options for the future.

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