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Chapter 2: Adopting a risk-based approach

Gary Yohe[1] and Robin Leichenko[2]

[1]Department of Economics, Wesleyan University, Middletown, Connecticut. [2]Department of Geography, Rutgers University, Piscataway, New Jersey

Address for correspondence: Gary Yohe, Woodhouse/SYSCO Professor of Economics, Wesleyan/UCS, Public Affairs Center 328, Wesleyan Station, Middletown, CT 06459. Voice: 860-685-3658. Gyohe@wesleyan.edu

Introduction

A significant message accompanying the call for greenhouse gas mitigation actions from the Intergovernmental Panel on Climate Change (IPCC) 2007 Fourth Assessment Report is the increasing need to identify a decision framework for climate change that encompasses both mitigation and adaptation. Through the IPCC, governments have begun to acknowledge risk management as a unifying theme for both climate change mitigation and adaptation. Their unanimous approval of this message underscores the importance of providing more information about climate risks (in addition to providing information about impacts and associated vulnerabilities) and suggests that consideration of risk plays a critical role in all facets of climate change decision making:

> "Responding to climate change involves an ***iterative risk management process that includes both adaptation and mitigation***, and takes into account climate change damages, co-benefits, sustainability, equity and attitudes to risk" (IPCC, 2007c; our emphasis).

These words make clear that governments throughout the world now understand that managing the risks associated with climate change will be a central theme for present and future planning and policy decisions. For climate change adaptation, particularly in a large city like New York, a risk-based approach can serve as a valuable guide to policy and action. A critical aspect is that it can promote support of expenditure of evermore scarce city resources to reduce risks from both high-probability events and low-probability events.

This chapter reviews the common underpinnings of a response portfolio that includes both mitigation and adaptation, although the focus of the New York City Panel on Climate Change (NPCC) is on adapting in order to protect existing and anticipated infrastructure. This dual approach of mitigation and adaptation to climate policy is essential, and risk management concepts can be applied side-by-side to both types of responses. First of all, the ability of both developed and developing countries to adapt to climate change can be overwhelmed by unabated climate change (IPCC, 2007b), so mitigation is essential. The implications of mitigation on the timing and severity of local vulnerabilities must be understood so that adaptation can proceed effectively and efficiently. Alongside mitigation, adaptation also needs to be a priority because the climate is already changing, and mitigation responses may not begin to moderate projected climate changes for several decades. (See Chapter 3 for a fuller discussion of climate science.) Mitigation and adaptation are therefore equally essential.

2.1 Adopting a risk-based approach to climate change

To ensure consideration of both simultaneously, we cast adaptation and mitigation into a common framework within which consideration of long-range goals and their translation into short-term

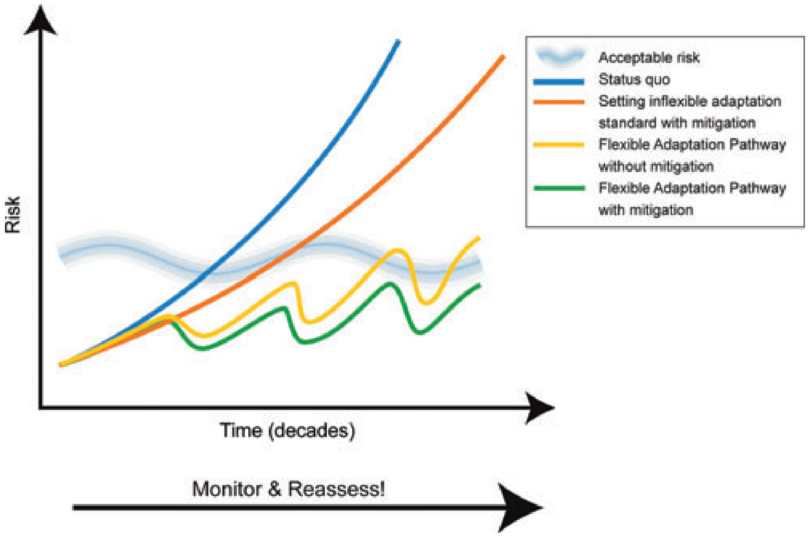

Figure 2.1. **Flexible adaptation and mitigation pathways. Adapted from City of London, "The Thames Estuary 2100 Plan," April 2009.**

objectives can be accomplished. To make a risk management approach to climate change adaptation operational, we must craft iterative and flexible adaptation plans whose relative efficacy can and will be influenced by investment in mitigation.

Figure 2.1 offers a schematic portrait of several possible futures for interactive climate change adaptation and mitigation. It presents a societal "acceptable level of risk" as a wavy horizontal line, indicating the ever-fluctuating threshold of this concept. If we remain on a current risk trajectory with no regard to either mitigation or adaptation, depicted by the blue line, the acceptable level of risk is crossed relatively soon. The orange line represents setting inflexible adaptation standards done in conjunction with mitigation actions. While this is better than simply maintaining the status quo, it will still eventually result in crossing into a state of "unacceptable level of risk." The yellow line represents creating "Flexible Adaptation Pathways," a sequence of adaptation strategies policy makers, stakeholders, and experts develop and implement that evolve as our knowledge of climate change progresses. However, without mitigation actions, adaptation alone will likely not be enough to sustain society in an acceptable level of risk. The green, therefore, is better because it combines mitigation actions along with Flexible Adaptation Pathways to create a future scenario in which we will remain below an "acceptable level of risk" indefinitely. This concept is based on work done by the City of London and the UK Environment Agency for the Thames barriers (Lowe, *et al.*). Further information about Flexible Adaptation Pathways is provided in the Adaptation Assessment Guidebook (AAG) in Appendix B.

2.2 Definitions and fundamentals

Benefit-cost approaches (e.g., Nordhaus, 1991), which entail detailed financial calculations of the advantages (benefits) and harms (costs) associated with specific efforts to address climate change, have been a mainstay of economic analyses of climate policy for nearly two decades.[1] In recent years, though, many authors and commentators have argued that comparisons of benefits and costs are not really appropriate in the climate arena. Practitioners within both the public and private sectors have come to recognize that some benefits (and even some costs) cannot be monetized.[2] They have also recognized problems with specifying appropriate discount rates in order to calculate present-day values for dollars that will be spent or saved in the future. Other problems include coping with pervasive, persistent, and multidimensional uncertainty and accommodating the profound distributional consequences of climate change.

As a result, a risk management approach to confronting climate change has emerged as a complementary analytic tool that is designed to ameliorate or at least account for many of the limitations of traditional cost-benefit analysis (IPCC, 2007c).[3]

Risk management approaches to decisions begin with a statistical definition:

> *Risk = the probability of an event multiplied by some measure of its consequence.*

Risk-based approaches have gained favor among many decision makers because their direct application can be supported on the basis of the same economic-efficiency criteria (i.e., the maximization of goods and services provided to society at any given level of resource expenditure), which support other approaches to economic analysis. Risk management is also a technique that policy makers, stakeholders, and finance directors in both public and private sectors understand and adopt on a regular basis.

The key insight for all stakeholders is that risk management techniques show how diversification and risk-spreading mechanisms can improve social and/or private welfare in situations of profound uncertainty. Diversification cannot eliminate risk completely, and that is why the risk-spreading value of insurance is so important. Indeed, insurance is the primary means by which residual risk can be spread across a wider population so that no one person or small group of people face disproportionate exposures to losses (see Chapter 6 for further discussion of the role of insurance in responding to climate change). At the most fundamental level, first principles of economic efficiency support the pursuit of robust responses to uncertain circumstances—responses that work reasonably well across a wide range of possible futures even if they do not work optimally for any single outcome.[4] Since uncertainty is ubiquitous in regard to climate change and its impacts, it is not surprising that deliberations about how to respond are now couched explicitly in terms of risk. Moreover, a risk-based approach gives policy makers a method for evaluating hedges—that is, investments undertaken to reduce or eliminate certain risks.

The IPCC (2007c) builds on this understanding among its stakeholders when it asserts that risk management tools and approaches should be used in public discussions regarding what to do about climate change. At present, such discussions are often stuck in an unproductive standoff between strained claims of certainty ("the verdict is in, now is the time for significant action regardless of cost, it won't cost much anyway, etc...") and impassioned invocations that generic uncertainty justifies inaction ("climate change is uncertain, we lack proof, mitigation is too expensive, research and development alone will solve the problem, etc..."). Sensible decisions and prudent management of risks require actions that work in the murky arena between these two extremes. Risk management acknowledges that coping with uncertainty will play an important role in both the identification of policy objectives and the design of specific policy initiatives.

Risk management for mitigation

Many questions about how to apply risk management knowledge in the climate arena still remain, but this knowledge is evolving rapidly. For example, the IPCC has concluded that it is "virtually certain" that the climate is changing at accelerating rates (IPCC, 2007a),[5] and there is "very high confidence" that anthropogenic emissions are the principal cause (IPCC, 2007a).[6] We know now that anthropogenic climate change is the strongest contributor to the conditions that created the 2003 heat wave across central Europe (IPCC, 2007b). This knowledge alone is sufficient to establish the reality and seriousness of the climate change issue. Even though substantial uncertainties persist about specific sources of risk, this knowledge is also sufficient to establish the need to respond in the near term in ways that will reduce future emissions and thereby ameliorate the pace of future change. In short, uncertainty makes the case for near-term action through hedging against climate risks denominated in terms of both monetary damages and other indicators, such as billions of additional people who might be facing hunger, water stress, or hazards from coastal storms.[7] It also follows that near-term mitigation actions should begin immediately if we are to minimize the expected cost of meeting the long-term objective to reduce the ultimate rate and magnitude of climate change.

Risk management for adaptation

Risk-based approaches clearly support the case for mitigation of greenhouse emissions. But questions remain about whether current understanding of the climate system can support a similar approach in

Table 2.1. Baseline sea level rise and mean annual changes (relative to baseline years) for New York City

	Baseline (1971–2000)	2020s	2050s	2080s
Sea level rise[a]				
Central range	NA	+ 2 to 5 in	+ 7 to 12 in	+ 12 to 23 in
Rapid ice melt[b]				
Sea level rise	NA	∼ 5 to 10 in	∼ 19 to 29 in	∼ 41 to 55 in

[a] Shown is the central range (middle 67%) of values from model-based probabilities, rounded to the nearest inch.
[b] "Rapid ice-melt scenario" is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies. See Chapter 3 for further details.

the area of climate adaptation. A limited number of risk assessments have already compared the costs of mitigation with the corresponding changes in climate risks, and more are appearing every month.[8] Taken together, these studies show that risk assessment can productively complement benefit-cost calculations.[9]

While a risk-based approach can certainly be applied to many types of adaptation decisions, the requisite data may not always exist. Identifying information needs and knowledge gaps is thus one reason why it is essential to begin a process of planning for and prioritizing across adaptation options as soon as possible. Table 2.1 shows climate hazards that contribute to risk expressed in terms of sea level rise projections, produced by the NPCC. One NPCC scenario for sea level rise, projected for three time slices, was derived from global climate models using the methods used in the IPCC (2007a). Because of uncertainties associated with that approach, the NPCC provided an additional scenario for sea level rise that reflected the potential for additional sea level rise contributions primarily from the Greenland and West Antarctic ice sheets.

Drawing lessons from other risk management arenas

Offering decision makers information about a possible future that has not yet been modeled satisfactorily may sound peculiar. Yet decision makers cannot simply ignore highly unlikely triggers that might lead to irreversible impacts of extraordinary consequence. It is reassuring, in this regard, to remember that the conduct of monetary policy by national governments frequently represents a real-world illustration of how hedging strategies have been employed against large risks whose likelihoods and/or consequences cannot be estimated. As noted by then Chairman of the Federal Reserve, Alan Greenspan, in his presentation to the American Economic Association (AEA) at their 2004 annual meeting in San Diego:

> ". . .the conduct of monetary policy in the United States has come to involve, at its core, crucial elements of risk management. This conceptual framework emphasizes understanding as much as possible the many sources of risk and uncertainty that policymakers face, quantifying those risks *when possible*, and assessing the costs associated with each of the risks . . . This framework also entails, in light of those risks, a strategy for policy directed at maximizing the probabilities of achieving over time our goals. . . policy practitioners under a risk management paradigm may, at times, be led to undertake actions intended to provide *insurance against especially adverse outcomes*" (Greenspan, 2004; emphasis added).

In other words, we must sometimes take into account low-probability but high-risk outcomes when developing risk management strategies *even in circumstances when we know little about likelihood*. Risk management strategies used in the monetary realm to cope with threats, such as deflation, have a direct parallel to the issue of climate change, where low-probability but high-consequence events represent a *very large risk*. A risk management approach to climate change supports the expenditure of some resources to reduce a significant risk (despite a low probability) in the future, such as designing contingency plans against permanent inundation of critical infrastructure due to rising sea levels related to rapid melting of the West Antarctic and Greenland ice sheets, as illustrated in Table 2.1. A hedging approach suggests that climate adaptation decisions can usefully be informed by consideration of risk.

2.3 Flexible Adaptation Pathways

Research and policy communities are beginning to acknowledge the ineffectiveness of instituting an inflexible set of climate policies, no matter how stringent. The multiple facets of climate change hazards, impacts, and adaptation strategies, as well as the uncertainty associated with each, limit our ability to create one standard timeless policy that will work for all situations. Rather, each aspect of climate hazards, impacts, and adaptation needs to be continually considered and re-evaluated as new information comes to light. An effective climate change policy is an iterative one that considers and incorporates this new information at regular intervals.

Many uncertainties about the earth's climate system are so profound that they may never be resolved in a timely fashion. A key climate change science example is climate sensitivity, which is defined as the increase in global mean temperature associated with a doubling of greenhouse gas concentrations from pre-industrial levels. Current understanding puts the range of this critical parameter between 1.5°C and more than 5°C, and it is now widely accepted that substantial and timely reductions in this range through advances in fundamental scientific understanding are quite unlikely.[10] Roe and Baker (2007) show, for example, that "the probability of large temperature increases" is "relatively insensitive to decreases in uncertainties associated with the underlying climate processes." Allen and Frame (2007) further argued that it is pointless for policy makers to count on narrowing this fundamental uncertainty.

Other layers of uncertainty around climate change planning to consider are those associated with impacts, adaptations, adaptation policies, and societal factors. Climate hazards will have various impacts on critical infrastructure, some of which are more well documented than others. For example, increased heat will pose larger strain on the energy grid, but the thresholds for sustained pressure are dependent on several factors ranging from the relative prevalence of alternative energy sources to the demand for air conditioning on any given day. There are also uncertainties around adaptations that will be influenced by unforeseen technological advances or potential unintended co-benefits related to other environmental stresses. Adaptation strategies will continue to be refined as lessons are shared among stakeholders and municipalities. Knowledge regarding strategy development is another uncertainty in climate change adaptation planning, since initial efforts are just getting under way, and evaluations have not yet been done. Finally, there are uncertainties regarding future social factors that will influence climate change adaptation planning, such as population trends and economic conditions.

As a result of these layers of uncertainty, a policy response that delays immediate action in favor of waiting for the results of a "crash research program" to narrow the range does not appear to be viable. Moreover, decision makers and resource managers should not anticipate that inflexible long-term climate change policies will be set in place any time in the near future. Therefore, it follows that we must begin to construct a process by which interim targets and objectives for both mitigation and adaptation will be informed by long-term goals in ways that appropriate adjustments will be as efficient and as transparent as possible.[11] This is a simple conclusion that makes sense, but issues abound as soon as one begins thinking about how to make it operational.

As urban managers think about designing responses to climate change that incorporate hedging decisions, the role that flexibility plays under conditions of uncertainty is critical. Indeed, many policy alternatives would be equivalent in a world of perfect certainty.[12] In the real world, however, more flexible polices are generally much more robust than less flexible policies when uncertainties are important (Box 2.1). Yet, there are limits to this advantage. Flexibility in one arena can impose costs elsewhere that must be compared with the associated efficiency gains.

Box 2.1 Designing iterative climate policy—the car on a dangerous road analogy

Parson (2008) divides the problem of designing an iterative process for climate policy into two categories.[13] In the first, likened to guiding a car down a dangerous road when the driver understands how the steering wheel and brakes work, he assumes that well-defined and well-understood levers are available for implementing short-term policies and making appropriate mid-course corrections. In the second, the driver either does not have a steering wheel and brakes or, only slightly less unsettling, will not understand how they work without some preliminary experimentation during the early part of the trip. In such a case, trying some modest experiments with an eye toward understanding the policy-lever mechanism would certainly be prudent.

Even in the world of the first category, assuming that policy makers are equipped with good steering and brakes related to climate change, the situation is not so straightforward. Effective monitoring mechanisms and a transparent adjustment processes must be established to (1) monitor progress toward interim targets for both mitigation and adaptation, (2) monitor the robustness and appropriateness of long-term goals, and (3) determine how frequently to undertake adjustments on the basis of what information can be expected and when it might be distinguished from statistical noise. Responding too frequently or too aggressively is extremely expensive, yet responding too infrequently or too cautiously can also impose costs.

Unfortunately, the second case that assumes imprecise or even very preliminary understanding of how the policy levers might work (especially together) is probably a better description of the state of knowledge. All of the issues raised above pertain, therefore, but an entirely new set of monitoring mechanisms now designed to provide evidence of exactly how, why, and when policies do and do not work must be added to the list. In this context, some adaptive management (trying policy experiments designed explicitly to elicit maximum information about the policies themselves) could be important components of fruitful near-term response portfolios. The National Research Council (2009) provides a thorough description of this technique.

As illustrated in Box 2.2, the ongoing global financial crisis offers some important lessons about how to respond iteratively to climate change using a risk-based approach. The enormous uncertainty regarding understanding of the climate system, impacts, adaptation, and our socio-economic future means that climate policy must deal with correspondingly enormous complexity. The complexities include improving knowledge of what can be monitored, what is causing climate impacts, how those impacts can impose significant vulnerability on natural and human systems, and how well the responses actually work. Conflicting explanations of climate science are akin to those in economics. This means that decision mechanisms must cope with competing indices of change as they try to monitor what climate impacts are occurring and what they mean in terms of economic and social vulnerabilities in the future.

As noted explicitly in IPCC (2007c), the thresholds of dangerous interference across key vulnerabilities cannot all be calibrated in terms of a common metric. It follows that the thresholds of "dangerous anthropogenic interference" that are to be the basis for action drawn from Article 2 of the United Nations Framework on Climate Change (IPCC 2007c) are still not well defined.[14] Nonetheless, we know that the risks of climate change are potentially large even if we cannot estimate all probabilities or calibrate all potential consequences in monetary terms. We also know that the possibility of a "bail-out" is quite low.

Box 2.2 Lessons for climate policy from the 2008–2009 global financial crisis

Domestic and international banking and financial systems offer some examples of macroscale iterative policy making, such as have been proposed for climate change responses (e.g., Stiglitz and Walsh, 2005). Central banks, for example, frequently set trajectories for growth in the money supply when they expect normal economic activity over a foreseeable future—a time period that defines when the next round of trajectory decisions will be taken. Since they do not have exact control over the money supply, however, they also surround these trajectories with cone-shaped boundary thresholds—thresholds that trigger well-defined but immediate responses in advance of the anticipated time frame should the money supply climb above or fall below the intended range (see Fig. 2.2). Central banks can also monitor exchange rates in exactly the same way.

In both cases, actors across the economy know how the central bank will conduct its analyses in anticipation of making scheduled policy adjustments.

They can anticipate much of what will happen during those adjustments and begin to make appropriate changes in their own behaviors in advance of the policy change. These actors also understand what the banks will do if unanticipated adjustments are initiated by crossing the trigger threshold. They can detect early warning signs so that they can begin to respond in advance of these more unexpected events. Transparency in the process can, in other words, lessen the costs of planned or unplanned policy adjustments (i.e., the backseat passengers are not as vocal as they would be otherwise).

The experiences of these monetary structures suggest at least three guidelines that can be applied to climate change policies: (1) keep long-term target options open as long as possible by setting decision-triggering thresholds, (2) work to minimize the adjustment costs of regularly implemented adjustment periods, and (3) minimize administrative complexity in both adjustment processes by making them as transparent and as predictable as possible.

Events in the financial markets that marked the second half of 2008—including dramatic reductions in stock valuations, government takeover of banks, and temporary freezes in credit markets—clearly indicate that difficulties can still arise, especially when the assumption of well-defined policy levers and well-understood monitoring mechanisms breaks down. Central banks may have been monitoring the money supply, inflation and exchange rate fluctuation, but they were not keeping track of complexity in financial instruments that spread enormous risk across a range of unsuspecting and otherwise debt-burdened citizens and institutions. Difficulties of this sort are perhaps even more ubiquitous and dangerous in the case of climate change.

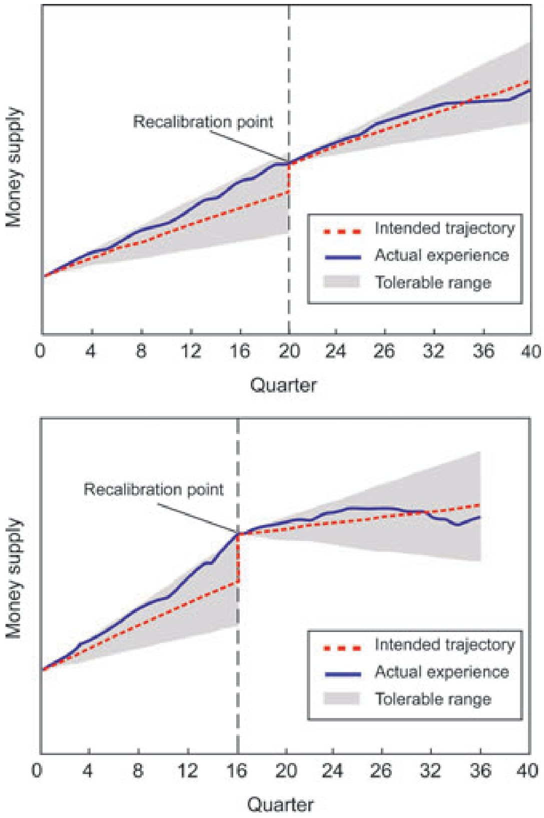

Figure 2.2. **Representative iterative adjustments in the growth of the money supply.**

Regularly scheduled "mid-course corrections," similar to the "recalibrated" points depicted in Figure 2.2, can be envisioned for an iterative climate adaptation process. This is shown in Figure 2.1 where the "corrections" might come in the form of updated climate information, new technological advancement, or a new policy that would serve to readjust the risk trajectory back to an acceptable level. If the climate hazards that create vulnerabilities change as anticipated, then no adjustment would be required. If they are observed to be moving more quickly than expected (but still within a range of tolerability), then some effort to slow the pace of change or reduce sensitivity would be implemented in due course as scheduled. If, however, they are observed breaching the threshold of tolerable pace, then earlier adjustments would be required. In Figure 2.1 these are represented as the dips in the "saw-toothed" trajectories.

This Flexible Adaptation Pathways concept was put into practice in the form of an iterative decision tree for protecting London from coastal storms calibrated against sea level rise, shown in Figure 2.3. It shows that the Greater London Authority has identified a series of escalating responses that begin with raising defenses along the Thames River but nonetheless include the possibility of constructing a new barrage at the river's mouth. For modest sea level rise, a sequence of responses has been deemed possible even if maximum anticipated sea level rise grows gradually over time. For more severe cases with significantly higher flooding risk earlier in the century, however, larger and more expensive

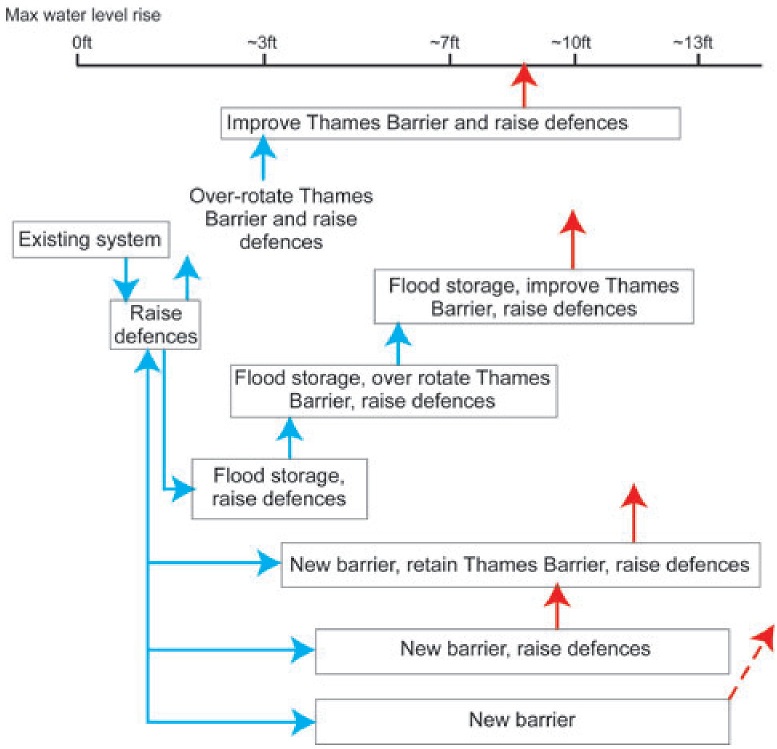

Figure 2.3. Iterative adaptation strategies to protect London from coastal storms. Source: Greater London Authority.

construction projects including early commitment to a new barrage are thought to be necessary. Decisions about timing and monitoring have yet to be finalized, but the Authority clearly envisions an iterative process whose ultimate evolution will be contingent on how the future unfolds. Their capacity to do so is, in every case, enhanced by strength in the underlying determinants of adaptive capacity, including explicit recognition of causal links, well-defined understanding of the need to spread what could be significant risks, and consolidated social capital embodied in a central planning and decision-making institution. Such a risk management approach to the climate change adaptation process is also being applied in the case of New York through the NPCC and Task Force process, based on its own geographic setting, climate risks, and adaptive capabilities.

2.4 Application of a risk-based approach for New York City

The City of New York is following a risk-based approach as it develops plans to help protect the infrastructure in and around the city from increasing vulnerability to climate change. The City's risk management approach simultaneously combines both mitigation and adaptation. Mitigation goals have already been adopted within PlaNYC, including reduction of the City government's greenhouse gas emissions by 30% below 2005 levels by 2017, and the City has conducted emissions inventories for a number of infrastructure sectors (City of New York, 2009). The City has been motivated in its work on mitigation and adaptation by the perception of risk.

2.5 Conclusions and recommendations

The major conclusion to be drawn from this brief review of current thinking about how to respond to the various risks associated with climate change is summarized most succinctly in the initial quotation from IPCC (2007c). To paraphrase:

> Responding to climate change *requires* adopting a *risk management approach* by which both adaptation and mitigation can become part of an *iterative process* that recognizes explicitly the

> need for midcourse corrections as our understanding of the underlying science and its translation into climate variability as well as climate impacts evolves.

Any iterative, or Flexible Adaptation Pathways, process must recognize with equal care the multiple dimensions of climate hazards, impacts, adaptations, economic development, and other social factors. These include technological advancements, programs designed to achieve socio-economic goals that are expressed in terms of sustainability and equity, and the efficacy over time of efforts to slow the pace of anthropogenic sources of climate change. This is true in general, and it is true for New York City.

To incorporate this process into their routine operations, governments and other institutions must work to establish cooperative mechanisms by which they can track, analyze, and project key manifestations of climate change, impacts, and adaptations to reduce both exposure and sensitivity to those impacts, and the inevitable interaction of these responses with other private and public initiatives.

Much of the literature devoted to responding to climate change has focused on the potential for climate change mitigation, particularly on options that seem to be win–win opportunities for city managers, because they work to reduce greenhouse gas emissions and generate economic cost savings. Adaptation to climate change has been more difficult to motivate in part because proponents have had to navigate contested political terrains and because many options have offered little in the way of immediate benefits. The results of the NPCC work show that a very different picture may be emerging. To some degree, a risk-based approach changes the underlying decision calculus because, at the very least, it leads immediately to consideration of adaptations that complement existing risk and hazard management strategies.

This synergy strongly suggests that decision makers develop a process by which climate protection levels derived from existing standards and codes and defined through the lens of maintaining socially tolerable levels of risk are translated into new design decision-support tools and revised design parameters (CPL, Appendix C). However, this process needs to recognize that it is operating in a dynamic environment that will evolve over time. As a result, design standards, like those that reflect the risk of operating within a 100-year flood zone for coastal and inland storms, may be adjusted systematically to accommodate and even to anticipate changing climatic conditions.

Iterative processes for adaptation operating in a dynamic environment should try, whenever possible, to define Flexible Adaptation Pathways. Policy makers can identify tipping points in natural and social systems, perhaps described in terms of critical thresholds of irreversible or particularly deleterious impacts, based on scientific research. These can be an essential part of designing these pathways, but only if they can be expressed in terms of timely "triggers" that determine when an adaptation measure is required. This represents a suite of possible future studies centered on the notion of evaluating the outcomes of the risk management approach and the potential of enhancement of existing design standards and policies as part of an effective adaptation strategy.

New York City has embraced this conclusion and, perhaps more importantly, has recognized that Flexible Adaptation Pathways will be feasible only if climate change monitoring programs are established (see Chapter 7). These programs, designed with the help of ongoing consultation with experts, will track and analyze the trajectories of change for key climate change variables, their associated impacts, and the efficacy of existing adaptation processes in the context of evolving scientific knowledge.

Armed with this knowledge, concentrated attention can, on the one hand, be paid to near and medium-term impacts caused by incremental changes in, for example, temperature and precipitation. Meanwhile parallel attention can be paid to the possibility that low-probability but high-consequence events may occur (or become more likely). It is in implementing responses along this second tract that it is necessary (1) to identify, characterize, and understand nonlinear tipping points and impact triggers, and (2) to devise decision pathways that suggest when and how to adopt different types of adaptation measures. In turn, these conditions will require constant, dynamic evaluation. It will be responsible for New York City stakeholders to evaluate the ongoing change and the effectiveness of their risk management–based responses in order to seize opportunities and make corrections.

Endnotes

[1] Circular A-4 (White House, 2003), the federal directive under which cost-benefit analyses have been undertaken to evaluate the effectiveness of climate change policies, was distributed by the Office of Management and Budget to update long-standing instructions for environmental assessments that defined the standards for "good regulatory analysis"—exercises that work from statements of need and explorations of alternative approaches to produce evaluations of the "benefits and costs—quantitative and qualitative—of the proposed action and the main alternatives. . ." The Circular suggests how to identify areas where government action may be required, but it warns against unwarranted intervention in the marketplace by leading with an explicit "presumption against economic regulation." Most of the text, though, is dedicated to illuminating "best practices" for circumstances in which this presumptive hurdle has been overcome. It begins by highlighting benefit-cost and cost-effectiveness analyses as the "systematic frameworks" within which to identify and to evaluate the likely outcomes of alternative regulatory choices. The Congressional Budget Office (2005) amplified these points.

[2] Critiques of relying too heavily on limited benefit-cost analyses include Tol (2003) and Yohe (2004, 2006).

[3] The foundations for the results that follow can be found in Raiffa and Schlaiffer (2000). While understanding of the factors that create risks have long been a mainstay in the natural hazards literature (e.g., Wisner *et al.*, 2004), this literature is primarily focused on identifying technological, institutional, socio-economic and political factors that influence the vulnerability or resilience of individuals or socio-ecological systems to extreme events (Leichenko and O'Brien, 2008).

[4] Risk analyses have demonstrated how the decisions we make are critically dependent on the subjective prior distributions with which we weight the relative likelihoods of future outcomes and have thereby demonstrated how aversion to risk influences the value of information. Economic efficiency establishes criteria by which we could potentially achieve maximal welfare from a limited number of resources by most effectively allocating their employment across wide ranges of competing demands.

[5] According to the IPCC conventions, "virtually certain" implies that there is more than a 99% probability that an outcome will occur (IPCC, 2007a).

[6] "Very high confidence" means that there is at least a 9 out of 10 chance of being correct (IPCC, 2007a).

[7] Hedging involves sacrificing some economic value relative to the optimum across most of the possible futures facing a society to reduce either the likelihood or the consequence of a possible future that is far less benign.

[8] Mastrandrea and Schneider (2004), for example, used the DICE economic model from Nordhaus and Boyer (2000) to assess the costs of avoiding dangerous climate change as defined by assumptions drawn from the IPCC's Third Assessment Report. Webster *et al.* (2003) used an integrated model of intermediate complexity to quantify the likelihood of global warming in 2100, beginning with projections of population, economy and energy use. Jones (2004a, 2004b) and Wigley (2004) both presented frameworks that probabilistically relate CO_2 concentrations at stabilization with equilibrium temperature, but treat neither the costs of mitigation nor the benefits of avoiding damages. Brian O'Neill edited an entire volume of papers designed to explore the role of learning in setting long-term mitigation strategies; see O'Neill (2008) for his overview paper. Schlesinger *et al.* (2006) adopted a more focused approach by tracking the likelihood of a collapse of the Atlantic thermohaline circulation (the THC) over the next one or two centuries under a variety of mitigation assumptions using three alternative representations of underlying uncertainty in climate sensitivity and in three fundamental parameters of a simple, reduced-form ocean model. Zickfeld and Bruckner (2008) followed with an investigation of the implications of alternative emissions corridors on the same THC risk profile using an alternative ocean model. In each of these cases, the idea was to create risk profiles and to explore their sensitivities to various levels of mitigation.

[9] The studies portray cumulative probability distributions of key vulnerabilities based on subjective judgments of the relatively likelihoods of various outcomes or ranges of critical parameters.

[10] IPCC (2007a) reports, for example, that "the equilibrium climate sensitivity is a measure of the climate-system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations. It is *likely* to be in the range 2°C to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values."

[11] See, for example, Yohe *et al.* (2004).

[12] See, for example, Weitzman (1974) where the difference between a price control and a quantity control (read tax and "cap-and-trade" quotas) emerge only when business can respond to changes in their environment that lie beyond the capacity of the regulator to monitor. Under perfect certainty (symmetric information), there is an equivalent price for every quota. Under uncertainty, the price allows more business response than the quota (a benefit for business), but consumers suffer from the resulting variability in supply. The choice between the price and the quantity control therefore turns on whether the benefits to business exceed the costs to consumers.

[13] His thoughts, in this regard expressed in the broader context of constructing international policy agreements, can be found in Parson (2008); reference to adaptive mitigation is found on pages 3 and 4.

[14] As noted on page 40 of IPCC (2007c), Article 2 of the UNFCCC states that: "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." The Synthesis Report continues by noting that "determining what constitutes 'dangerous anthropogenic interference with the climate system' (in relation to Article 2) involves value judgments" that science cannot make. It suggests that "science can (nonetheless) support informed decisions on this issue, including by providing criteria for judging which vulnerabilities might be labeled ***key***." Chapter 19 in IPCC (2007b; our emphasis) offers a set of such criteria.

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