Representing Dynamic Uncertainty in Climate Policy Deliberations

Author(s): Gary W. Yohe
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Synopsis

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This article highlights three sources of concern about the way that uncertainty in our understanding of the climate system is portrayed to decision-makers. These concerns include a continued reliance on the cost–benefit paradigm to organize their thoughts, the implicit acceptance of the notion that uncertainty will decline over time, and the persistent omission of adaptation as a significant source of uncertainty. These concerns are especially troubling if the cost–benefit approach to decision-making is emphasized at the exclusion of other methods that have been designed explicitly to accommodate uncertainty. A closing section, therefore, offers an alternative perspective borne from the efficiency properties of portfolio-based risk-management techniques. Uncertainty becomes a reason to act even in the near term to minimize climate and climate–policy risk instead of being a reason to delay action in the hopes that our understanding of the climate system will improve over time.

Because the unsettling ramifications of uncertainty are ubiquitous in global, national, and local discussions of climate change and climate policy, the research and policy communities are engaged in a mighty effort to comprehend what uncertainty means to their interactions and to the policy recommendations that they feel are appropriate. Early in 2005, for example, the Congressional Budget Office of the United States (the CBO) released a paper entitled "Uncertainty in Analyzing Climate Change: Policy Implications" in response to a request from the United States Senate Committee on Environment and Public Works (1). That article is a perfect illustration of this effort to cope with uncertainty. The authors relied heavily on the work of some of the world's most esteemed climate experts, like Nordhaus and Boyer (2), Tol (3, 4), and Jacoby (5), to produce a perfectly adequate review of many of the scientific and economic sources of uncertainty. Problems associated with the valuation of nonmarket goods and catastrophic changes were highlighted. So, too, were the difficulties involved in aggregating local impacts up to global-damage functions.

The most significant problem that the CBO faced, though, is that the research community's understanding of the implications of uncertainty is a moving target. Research perspectives change as understanding evolves, and so, papers like the one transmitted to the United States Senate are, at best, snapshots in time of what we know and what we do not know. Concerns can, therefore, be raised that the CBO paper misrepresents the state of scientific discourse on climate change and that it inappropriately narrows the decision-support context within which climate policy should be evaluated. Indeed, at least three major sources of concern can be identified. The next three sections take each source of concern in turn before a final section offers a suggestion on how the two communities might move forward more effectively.

EMPHASIS ON A COST–BENEFIT APPROACH TO CLIMATE POLICY

First of all, the entire CBO paper follows the traditional approach initiated by Nordhaus (6) in 1991 by casting its entire coverage of uncertainty in terms of the difficulty that uncertainty poses in calibrating the costs and benefits of mitigation while making only occasional references to other places where policymakers may "profit" from looking at "supplemental information" (pg. 33). Policy-makers in the United States are, thereby, instructed to think of mitigation in terms of aggregated costs and benefits while adding supplemental information only when ancillary issues like distributional consequences come to the fore. This advice comes at a time when the climate community is recognizing that the cost–benefit paradigm is ill-equipped to handle the profound uncertainties of the climate problem, in part, because the information that the CBO paper dismisses as supplemental is so critical in assessing how people will respond to climate-related stress. Perhaps most fundamentally, the applicability of the cost–benefit approach to climate is limited by its typical application to explorations of the implications of single policies considered almost in isolation. As a result, the approach can miss the profound value of exploring the possibility of simultaneously adopting a diversified set of policy responses.

The most recent discussions of climate policy in the literature have responded to this shortcoming by turning to a risk-management approach by which portfolios of policies can be evaluated in terms of their efficiency under uncertainty; see Yohe, et al. (7), for example. Built on the foundations of portfolio analysis in much the same way as modern monetary policy, this approach is not simply a restatement of the much-maligned precautionary principle (8, 9). It is, instead, a new application of a familiar tool borne of an efficiency-based analytical structure that was designed explicitly to accommodate ubiquitous sources of profound uncertainty—a structure drawn from investment theory, where the underpinnings of efficient diversification can be described rigorously.

THE IMPLICIT ASSUMPTION THAT UNCERTAINTY WILL DIMINISH OVER TIME

The CBO paper also gives the impression that uncertainty will diminish over time as our knowledge of the climate system improves—a second source of significant concern. Analysts are warned, for example, to "be careful to acknowledge the *lingering* uncertainties that cannot be meaningfully quantified in their analyses" (pg. 35; my emphasis). The problem here, of course, is that uncertainties do more than linger. They can easily expand over time even as scientific investigation progresses because increased understanding of, for example, the climate system, can lead to the discovery of important drivers of change that were previously unknown. Moreover, some uncertainties may never be resolved before a policy decision has to be made, and taking no action is as much of a decision as taking some action.

Two examples are sufficient to make this point. Estimates of the increase in the equilibrium global mean temperature associated with a doubling of atmospheric concentrations of greenhouse gases have been published by the Intergovernmental Panel on Climate Change (the IPCC) since it released its First Assessment Report in 1979 (10). These early authors put the range between 1.5 and 4.5°C, though there is some debate about the likelihood that they implicitly gave to values below 1.5°C or above 4.5°C; see Andronova, et al (11). Enormous effort has, in fact, been devoted to trying to reduce uncertainty about climate sensitivity over the past 25 y, but to no avail. Indeed, the most recent estimates have expanded the upper tail of the distribution beyond 9.0°C, and some see analysis of the historical record placing 25% of the likelihood above 6°C; see, for example, Andronova and Schlesinger (12).

Abrupt climate change, a topic covered briefly by the CBO, provides the context of a second example of persistent uncertainty. The Aspen Global Change Institute hosted a weeklong workshop in the summer of 2005 on abrupt climate change. Why, given that the National Academy of Sciences (13) published a report on this topic in 2002? In large measure, because the authors of that Academy report *all* agreed that there was enough new science and new social science to warrant a thorough reevaluation of what we know, what we don't know, and what uncertainty means when we want to decide what we should be doing in terms of policy over the near-term. The Academy authors recognized that scientific knowledge about the climate system is evolving quickly, and workshop participants concurred.

Discussions during the workshops on the state of knowledge about four possible sources of abrupt change [a weakening or collapse of the meridional overturning circulation (the MOC), changes in El Niño–Southern Oscillation (ENSO) patterns, melting of the Greenland ice sheet, and disintegration of the West Antarctic Ice Sheet] were confounded by competing explanations of process and exploratory (speculative) hypotheses of triggers, consequences, and likelihoods (14). Moreover, concern was raised about "Type III" errors—"barking up the wrong tree"—by devoting disproportionately large quantities of time and effort to studying one possible source (the MOC) and thereby underinvesting in examinations of other sources that may turn out to be more serious and perhaps more imminent. Perhaps most significantly, concerns were raised that current understanding and monitoring capabilities were incapable of providing timely warning that a dangerous threshold was about to be breached.

Surely recognition of the evolutionary (and nonmonotonic) nature of progress in scientific understanding across a range of potentially critical issues must be one of the most critical take-home messages of any consideration of the implication of uncertainty on policy deliberations, especially when some of the consequences of what are, at the present time viewed as unlikely events, could be so dire.

ADAPTATION IS A SIGNIFICANT SOURCE OF UNCERTAINTY

Turning finally to a third and perhaps most significant source of concern, it is unsettling to note that many policy discussions, including the CBO paper, do very little to recognize adaptation as a *source of uncertainty*. These discussions, therefore, ignore sources of uncertainty that the research community now holds to be as significant in clouding our ability to evaluate the potential benefits of mitigation as all of the problems that we have trying to understand the climate system taken together. Two recent papers by Jones (15) and Risbey (16) make this point explicitly, but the CBO authors only mention adaptation briefly in their subsection on agriculture and again at the end when they observe that humans will have to learn how to adapt because we are already committed to a certain amount of climate change. This sort of casual coverage of adaptation is completely inadequate.

In its Third Assessment Report (the TAR), the IPCC recognized that adaptation must be integrated more fully into our analysis of climate change (17). The TAR argued that any system's vulnerability to climate change and climate variability (the benefit side to mitigation if it can be monetized) can be described not only in terms of its exposure to the impacts of climate and its baseline sensitivity to those impacts but also in terms of its adaptive capacity—i.e. its ability to reduce either exposure or sensitivity. This IPCC approach, while it has been criticized for being ambiguous in its description of the role of agency in defining vulnerability, quickly highlights the fundamental role of adaptive capacity in defining social–economic thresholds of tolerance to climate-related stress and focused immediate attention on the critical role that local circumstances play in determining a community's ability to adapt. Unfortunately, for those interested in expanding the cost–benefit paradigm to accommodate this reality, the IPCC came to the conclusion that "it is probably infeasible to systematically evaluate lists of adaptation measures" for various communities; and nothing has happened since to change anyone's mind.

This is not to say that nobody has been able to explore adaptation successfully. It is, instead, to say that these successes have been limited to site-specific and (development) path-dependent applications whose coverage is not sufficient to support global portraits of efficiency or even globally applicable perceptions of the most important underlying determinants of adaptive capacity, for that matter. Because the answers to questions like "What works where?" are fundamentally empirical, the take-home message here is simply that future research has a long way to go if it is to come to grips with the diversity of the socio-political-economic environments within which people all over the world will try to adapt to climate change; i.e. we have a long way to go before we will be able to characterize adequately the benefit side of a mitigation policy in terms of the economic value of damages avoided *net of the costs and including the benefits of efficient adaptation.*

A BROADER AND MORE INCLUSIVE APPROACH

A careful reading of the paper delivered to a United States Senate committee by the CBO in January of 2005 has uncovered three reasons for concern in the way that uncertainty is frequently characterized in the documents that inform our decision-makers:

i. The continued reliance on the cost–benefit paradigm to policy evaluation at the exclusion of all other decision-support paradigms.
ii. The pervasive assumption that uncertainty will decline over time as it lingers around the periphery of the underlying analyses.
iii. The persistent omission of adaptation as an equally significant source of uncertainty in evaluating the net economic consequences of climate change.

These concerns do not apply only to the CBO paper, of course, and their recognition in the research community has lead many to advocate the adoption a modern risk-based approach to climate policy. This approach, designed explicitly to accommodate uncertainty, allows policy deliberations to be organized in terms of risks (probabilities and consequences) rather than net benefits. Moreover, a risk-based approach can be used to portray mitigation and adaptation as two options in a policy portfolio whose efficacy can be evaluated notwithstanding multiple sources of persistent uncertainty (18).

Adopting the risk-management approach that is emerging in the climate literature can, more explicitly, allow decision-makers to contemplate mitigation over the near term for economic efficiency without waiting for a more thorough understanding of how the climate system works and how people, institutions, and societies adapt to externally imposed stress. Indeed, simply highlighting sources of risk identifies reasons to hedge against the potentially extraordinary costs of possible changes in the future climate *and possible changes in future climate policy*. That is to say, recognizing risk is a reason to spend a little in the near term to reduce the chance of significant and harmful climate change or to reduce the cost of making a policy adjustment in the future.

In this context, it is not enough to focus attention on simply maximizing the net returns of policy interventions. Policy portfolios must instead be diversified in an effort to minimize the variance of outcomes associated with a range of possible futures. Adaptation can work to reduce some of the damages associated with climate change, and a broad-based policy portfolio can come to grips with facilitating adaptation in locations where it is now difficult by understanding the roles played by determinants of adaptive capacity, even if its designers cannot explicitly characterize exactly what types of adaptation might be attempted. Perhaps most important, on the mitigation side of the debate, profound uncertainty cannot appropriately be used as a reason to delay climate policy by analysts tied to a cost–benefit approach. Indeed, uncertainty becomes *the reason* to do something in the near term under a risk-management approach because mitigation and adaptation can be complementary tools in a portfolio of policy options—tools that treat the disease and the symptoms at the same time.

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Gary W. Yohe
Professor of Economics
Department of Economics
Wesleyan University
238 Church St. Middletown,
Connecticut 06459 USA
gyohe@wesleyan.edu

Synopsis

Chance and Challenge for China on Ecosystem Management: Lessons from the West-to-East Pipeline Project Construction

The West-to-East Pipeline Project (WEPP), one of multiple key projects constructed in China, involves the construction of 4000 km of a 1016-mm-diameter pipeline. The trunk line starts from the head station at Luntai County, Xinjiang, China, and ends at the terminal station in Baihe, Shanghai, China (Fig. 1). It traverses various landforms as it crosses seven provinces, two autonomous regions, and the Shanghai municipality. Along WEPP, Gobi and deserts (1450 km), sand dunes (215 km), arid grasslands (160 km), oases (392 km), the Loess Plateau (563 km), forests (90 km), alluvial plains (826 km), and nine reserves (708 km) are traversed. Although the Chinese government takes great effort with environmental impact assessments and ecological restorations, few references are available that provide experience with such a big project. The ecological effects of WEPP construction are extensive and profound.

ECOLOGICAL DISTURBANCE OF WEPP

Construction of the pipeline involves a variety of human activities that may disturb soil systems, vegetation, surface river systems, and the landscape:

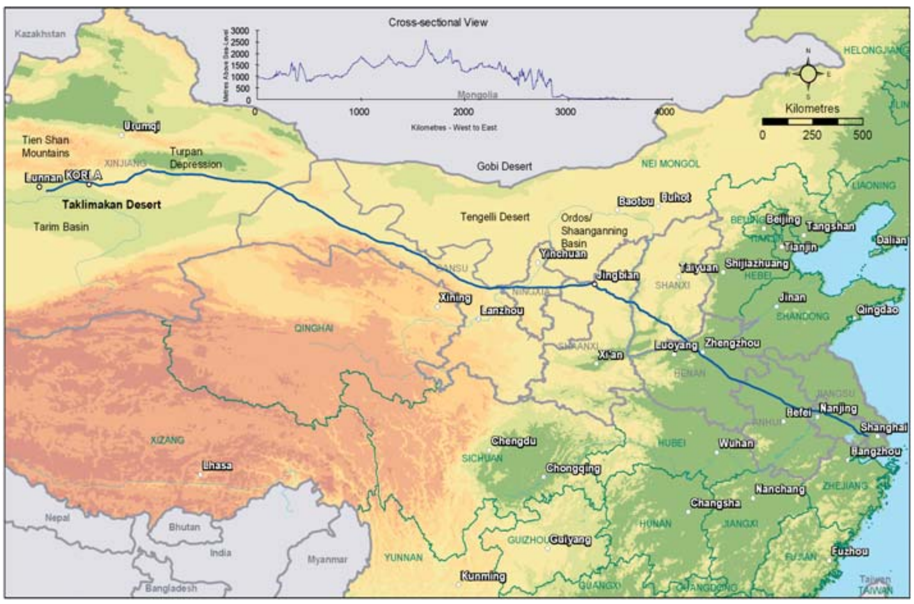

Figure 1. Route of the West-to-East Pipeline Project (WEPP) in China.

Pipeline construction; Typically, a working zone of 28 to 30 m for the trunk line and 20 m for branch lines was required to accommodate equipment, vehicle movement, and related human activities, along with storing trench waste and topsoil. In sensitive and fragile areas, such as nature reserves, historic sites, and steep slopes, the width of the working zone was reduced to minimize the construction footprint. Temporary and permanent land occupation involved 12 298 ha and 1277 ha, respectively (1).

Clearing; Clearing involves removal of vegetation and surface materials. The topsoil was stockpiled along the shoulder of the working zone to allow safe and practical construction access while preserving the topsoil for postconstruction reinstatement.

Trenching; The aggregate length of an open trench could be up to 8 km but was typically 1–2 km. The normal dimensions of the trenches were 2.2 to 2.4 m deep, with a 1.5- to 1.9-m-wide base, and a 2.6- to 5.2-m-wide groundbreaking width.

Material transportation; During pipeline construction, a large amount of material, both for project use and daily life, was transported. Transportation of materials by trucks or other means caused extensive disturbance to the surface landscape along the WEPP.

Watercourse crossings; Midsize and small rivers were crossed by digging trenches, and the big rivers, such as the Yellow River, the Yangtze River, and the Huaihe River, were crossed by either directional drilling or tunneling. In total, 24 trenches, three directional drillings, and two tunnels were used when crossing rivers. At the same time, many small gullies are crossed by WEPP. These altered the current surface river system.

ECOLOGICAL EFFECTS OF WEPP

Destruction of vegetation; All vegetation on 3717 ha (including 3172 ha desert vegetation) in the 28-m construction right-of-way (ROW) along WEPP was removed completely. Aside from the pipeline itself, approximately 1015 km of access roads and 34 processing stations were also built. Recovery of vegetation is difficult in arid and semiarid regions because of water shortage.

Disruption of surface soil; About 4645 ha of farmland were occupied temporarily. Apart from direct soil disturbance, the human activities broke the gravel stratum and surface desert vegetation in the arid regions, as well as changing the soil texture. If no protections are employed, desertification is a possibility because of disruption of the ecological balance.

Activation of sand dune and expansion of desertification; In arid areas, WEPP construction not only caused vegetation destruction but also aggravated wind erosion and desertification. First, vegetation destruction leads to degradation of desert communities and ecosystems. Second, the construction activated semifixed or fixed sand dunes (2, 3). Third, salt crust (often 0–30 cm) in saline desert (168 km) and gravel layer in Gobi are natural barriers preventing fine sands from deflating (3). When the pipeline traversed sand deserts, some fixed/semifixed sand dunes became reactivated, surface vegetation was destroyed, and the shifting sand dunes became more active. Further development of such processes would lead to the pipeline being uncovered or broken.

Alteration of surface water systems and hydrologic flows; Pipeline construction resulted in changes of the surface river system, which may have a temporal or permanent impact on aquatic ecosystems and water supplies, especially for local agriculture and aquaculture. As well, temporal disruption of runoff due to excavation, compaction of sites, and work camps may affect river systems and surface processes, such as mass movement and runoff.

Loss of wildlife habitat and diversity; Nine nature reserves were traversed by WEPP, including the Lobpo Double-peak Camel Nature Reserve in Xinjiang and the Wild Monkey Nature Reserve in Henan Province. The effect of habitat loss on wildlife is profound and will be studied in the future. When WEPP passed the lower Yangtze River, many ponds and wetlands were affected. Many aquatic wildlife species were also affected.

Acceleration of soil erosion and environmental hazards; Severe soil loss due to rainstorms was a major problem in the Loess Plateau. Because most places passed by WEPP contain loess soils in hilly areas where current soil erosion is severe, the construction of the pipeline will accelerate soil erosion, which, in turn, will affect pipeline operation if the ecosystem is not restored in time. At the same time, earth falls, soil creeps, debris slides/flows, and mudflows occurred during construction.

Decline of land productivity; In eastern China, construction of the pipeline completely destroyed the soil system and farm ecosystem. Even though a layer-soil refill was required of WEPP contractors, restoration of a mature soil system with high productivity will require many years.

ECOSYSTEM MANAGEMENT IN WEPP CONSTRUCTION

Before construction, a target "Green Project and Ecological Corridor Across China'' was proposed by the WEPP management agency. Ecological restoration and environmental conservation were primary considerations, and considerable money was invested in restoration during pipeline construction.

Environmental Impact Assessment

In compliance with state environmental impact assessment (EIA) laws, WEPP was authorized by the State Environment Protection Administration of China after it met the requirement of the EIA. The EIA assessed six aspects: the pipeline's impact on human life, safety, and health; soil and water conservation; wildlife habitat and biodiversity; the impact of geological hazards on the pipeline; and the impact of earthquakes on the pipeline.

Ecological Restoration Planning and Regional Security Design

Because WEPP is different from small pipeline projects, environmental protection and ecological restoration particularly concerned WEPP officials. A large program on "*Protection, Recovery, and Ecological Security Design along WEPP,*" and a special program on "*Ecological Conservation and Management Schemes for Nature Reserves along WEPP*" were initiated during construction. These programs offered a scientific foundation for building "A Green Project." To reach this target, a budget of about $90 million was used on soil erosion control and environmental conservation.

Integration of Quality Management and Environmental Supervision

An advanced management system integrating Quality, Health, Safety and Environment (QHSE) was employed during pipeline construction. In general, within the petroleum industry, the QHSE management system is only a framework, and many standards and regulations need to be enumerated by the contractors. During WEPP construction, a third organization was invited to supervise ecological restoration separate from supervision of the construction.

Assessment of Ecological Restoration After Pipeline Construction

Although assessment of construction projects after construction is complete is required by the Chinese government, it has not often been implemented. However, a postassessment of the environmental impacts and ecological restoration was conducted by WEPP. During this assessment, problems that occurred during construction were identified and addressed over time.

CHANCE AND CHALLENGE OF ECOSYSTEM MANAGEMENT IN CHINA

Gaps in Understanding of Ecological Restoration and Security between Different Communities

Through interviews, we found that views on ecological restoration and security vary between WEPP officials and ecologists. Most engineers viewed their responsibility as including only environmental impacts within the WEPP working area, whereas ecologists were concerned about the environmental impacts, ecological restoration and security, and ecosystem functioning of a larger sphere that often contained areas outside the WEPP working area. Because most ecological effects are diffuse, intangible, potential, and profound (4), they are often ignored by entrepreneurs. Vegetation restoration in the disturbed regions alone is not sufficient. For safety of the pipeline operation, vegetation restoration on a larger scale is required. Although much effort was made by WEPP personnel in restoring vegetation within the working area of the Loess Plateau, many geological hazards, such as earth falls, debris slides, and soil erosion happened along the WEPP in 2004. These occurrences caused some trouble to the operation of the WEPP. However, realizing large-scale ecological security requires the cooperation of local and central governments because the areas outside the ROW are not controlled by WEPP.

Integration of the EIA and Ecosystem Restoration

Calls for environmentally sustainable development have put pressure on construction projects to integrate ecological concerns into planning and decision-making. In many countries, a description of the likely key effects of the project on the environment is required before the project is approved. The description covers the direct effects and any indirect, secondary, cumulative; short, medium, and long-term; permanent and temporary; positive and negative effects of the project. The EIA indicates the potential impacts of the development rather than offering practical planning for ecological restoration. Scientific planning for ecosystem restoration is required for ecosystem management, particularly in a large project.

Quantitative Assessment of Ecological Effects

After some geological accidents happened along WEPP in the Loess Plateau in 2004, WEPP officials recognized that the security of the WEPP involved the ecological restoration of the adjacent area. However, no one could adequately describe how much effect the pipeline had on adjacent regions or the degree of environmental hazards to the pipeline. WEPP has included a lot of ecological restoration and soil erosion control, however, environmental hazards still trouble the WEPP operation. Making a quantitative assessment of the environmental impacts of the WEPP and the ecological restoration required is imperative for both the government and environmentalists.

Encouraging Investment by Entrepreneurs in Environmental Conservation and Ecological Restoration

One problem is how to resolve the conflict between ecological restoration and entrepreneurial profit. The WEPP Company has invested a great deal of money in soil and water conservation and ecological restoration, primarily to implement the goals in the “Green Project and Ecological Corridor across China.” Developing policies that encourage private companies to invest in environmental conservation is important to China, as well as to the other developing countries.

REMARKS

As one of largest projects conducted in the 21st Century in China, WEPP plays a significant role. The effects of WEPP on regional ecosystems and the effects of geological hazards on the pipeline should be addressed by the project owner and local officials. This helps to keep the pipeline operating safely. However, to realize this goal, cooperation from several different communities will be required.

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Liding Chen and Qichen Gao
Key Lab of Systems Ecology Research Center For Eco-nvironmental Sciences Chinese Academy of Sciences P.O. Box 2871 Beijing 100085, China
liding@mail.rcees.ac.cn;
Chenliding@sohu.com