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ANALYSIS

Integrating economic analysis and the science of climate instability

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Abstract

Scientific understanding of climate change and climate instability has undergone a revolution in the past decade with the discovery of numerous past climate transitions so rapid, and so unlike the expectation of smooth climate changes, that they would have previously been unbelievable to the scientific community. Models commonly used by economists to assess the wisdom of adapting to human-induced climate change, rather than averting it, lack the ability to incorporate this new scientific knowledge. Here, we identify and explain the nature of recent scientific advances, and describe the key ways in which failure to reflect new knowledge in economic analysis skews the results of that analysis. This includes the understanding that economic optimization models reliant on convexity are inherently unable to determine an "optimal" policy solution. It is incumbent on economists to understand and to incorporate the new science in their models, and on climatologists and other scientists to understand the basis of economic models so that they can assist in this essential effort.

Keywords: Climate instability; Abrupt climate change; Methane hydrates; Clathrates; Dynamic Integrated model of Climate and the Economy (DICE); Economic optimization

1. Introduction

Early analysis of climate change by economists evaluated the transition between two climate equilibriums, or at most, two climate paths that smoothly changed over time from today's climate to one characterized by a doubling of atmospheric concentrations of CO_2 and other warming gases since the pre-Industrial Revolution (Mendelsohn et al., 1994; Manne and Richels, 1991; Gaskins and Weyant, 1993, and references therein). Cline (1992) was the first to extend the analysis beyond a doubling, with CO_2 emissions that were derived from simple models of economic growth (Manne and Richels, 1990; Nordhaus and Yohe, 1983; Reilly et al., 1987). Cline input the CO_2 emissions into a simple climate submodel that is used in the

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natural science literature for long-term analysis of the relationship between warming gases and temperature.[2] Cline then presented a sensitivity analysis of the benefits and costs of avoiding climate change with respect to the discount rate that converts future damages and costs into present values. Nordhaus (1992, 1994) developed an economic growth model (called "DICE") that endogenously calculated the interest rate, coupled with a sophisticated climate submodel, where the social discount rate used for benefit cost analysis of policy alternatives was based upon the endogenous rate of return on capital. Nordhaus' (1994) climate submodel is based upon a model published in the early 1980s that has the feature of climate equilibrium, in which an increase in CO_2 will eventually return to initial conditions (Schneider and Thompson, 1981).[3] While Nordhaus (1994, p. 26, note 4) acknowledged that his equilibrium climate submodel is not applicable to a greater than doubling of CO_2 equivalent gases, his model continues to be the basis for economic analysis beyond a doubling and is extended to analyze abrupt climate change. The science of climate change has advanced considerably in the last quarter of a century as these economic models were developed; yet the new understanding has not been incorporated in economic analysis of climate change.

Paleoclimatic and paleoceanographic studies completed during the past decade demonstrate that Earth has experienced dramatic and abrupt environmental change, at scales and rates not experienced during recorded history (Dansgaard et al., 1993; Mayewski et al., 1997; Alley et al., 2003). Scientific understanding of the nature of past climate change has been continuously advanced as climatic transitions are investigated at ever higher resolution and by application of new analytical techniques. These advances create a challenge for economic models in that specific climatic transitions that were only recently considered to be abrupt, but simple, steps of cooling or warming, have been discovered to actually consist of intervals of rapidly flickering climatic oscillation. Numerous rapid warming and cooling steps during the last 60,000 years have been 1/3 to 1/2 as large as the entire difference between the coldest glacial and warmest Holocene intervals, yet took only decades to years to occur (Alley et al., 1993; Alley and Clark, 1999; Severinghaus and Brook, 1999). Past decadal-scale increases in local temperature were more than 10 °C at high latitudes, as great as 7 °C at mid-latitudes, and 1–2 °C in the tropics (Alley and Clark, 1999; Hendy and Kennett, 1999; Lea et al., 2003). Both conventional and new hypotheses attempting to explain the forcing and amplifying mechanisms of such past climate instability have implications for future climate instability related to anthropogenic releases of greenhouse gases.

One broadly accepted explanation of climate instability invokes switching of the North Atlantic deep ocean thermohaline circulation that keeps Europe warm and distributes heat from the tropics to higher latitudes. A shutdown or slowdown could cause a step into glacial cooling (Broecker, 1997), whereas resuscitation of circulation patterns similar to those of today could produce rapid warming steps (Ganopolski and Rahmstorf, 2001). A more recent explanation is the "Clathrate Gun Hypothesis" (Kennett et al., 2003). Briefly, they hypothesize that relatively minor changes in thermohaline circulation warmed intermediate-depth ocean waters, causing instability of methane hydrates at depths of 400 to 1000 m, triggering collapse of continental slopes and massive releases of methane (a powerful greenhouse gas in short time frames) that reached the atmosphere. This hypothesis implies that future global warming events can be greatly amplified by the release of vast quantities of methane stored in the sea floor and arctic permafrost.

Past climate change was initiated by relatively small changes in the amount and distribution of solar insolation caused by cyclical changes in Earth's position relative to the sun ("orbital forcing") or by other, still undetermined, forcing agents such as variations in solar output, interplanetary dust, volcanism, etc. (Hays et al., 1976; Imbrie et al., 1992). The magnitude and rate of the resultant climatic changes, however, do not relate linearly to changes in the forcing function, because Earth's climate functions by stepping between a number of semi-stable operational modes of the connected atmosphere/hydrosphere/cryosphere system (Broecker and Denton,

[2] See Hall (2001, p. 127) for a derivation of Cline's climate submodel, showing that it is equivalent to the climate model used by McElwain et al. (1999) to analyze climate at the Triassic–Jurassic boundary.

[3] See Nordhaus (1994, p. 33).