POLICY RESPONSES TO CLIMATE CHANGE IN A DYNAMIC STOCHASTIC ECONOMY

Allocation: GLCPC/530 Knh
PI: Lars Hansen[1]
Co-PIs: Kenneth Judd[2], William Brock[3], and Thomas Hertel[4]
Collaborators: Yongyang Cai[1], Simon Scheidegger[5], and T. J. Canann[6]

[1]University of Chicago
[2]Hoover Institution
[3]University of Wisconsin
[4]Purdue University
[5]University of Zurich
[6]University of Minnesota

EXECUTIVE SUMMARY

We extended our Integrated Assessment Model (IAM) framework, called DSICE (Dynamic Stochastic Integration of Climate and the Economy), for evaluating alternative policy responses to future climate change. The new elements allow us to use stochastic processes to model risks in both the climate and economic systems, and to examine how robust our results are to uncertainties about parameters of those stochastic systems [1].

One substantive result of DSICE is that the social cost of carbon (SCC) is substantially greater when we include economic and climate risks in analyzing the impact of climate change on the economy. Moreover, the SCC is itself a stochastic process with significant variation. Our findings show that a single parameterization of DSICE, representing the most recent empirical macroeconomic analysis of economic growth, implies a stochastic process for carbon emissions with ~10% chance of emissions exceeding all of the Intergovernmental Panel on Climate Change (IPCC) emissions scenarios.

INTRODUCTION

Climate change will have significant impacts on human life, through altered agricultural productivity, changes in the demand for heating and air-conditioning, and changes in the flora and fauna valued by humans. Integrated Assessment Models (IAMs) aim to analyze the impact and efficacies of alternative policy responses to climate change. The benchmark IAM model is DICE [2]. It is frequently used to analyze economic policies for dealing with climate change in the United States Interagency Working Group on Social Cost of Carbon [3]. However, it ignores heterogeneity in the economy as well as uncertainty in economic conditions and the impact of warming on the climate. The perfect foresight modeling choices are often excused on the ground that computational limitations make it impossible to do better.

Our work on Blue Waters clearly showed otherwise. We construct computational frameworks merging the basic elements necessary for any such analysis—how the climate reacts to anthropogenic-induced changes in the atmosphere, how those changes affect the economy, alternative policies, how individual economic agents respond to uncertainties, and how policymakers should incorporate various uncertainties into their decisions.

METHODS & RESULTS

We are building a computational framework to address the issues discussed above. Cai, Judd, and Lontzek have used Blue Waters to develop a computational model, called DSICE [1], that allows shocks to the economic and climate systems and uses specifications for agent preferences consistent with empirical evidence of how much people are willing to pay to reduce risks about the future.

In 2015, Cai, Judd and their collaborators published two papers applying DSICE with Blue Waters support in prestigious journals: *Nature Climate Change* [4] and *PNAS* [5]. They found that the risk arising from potential tipping points substantially raises the optimal level of emission control, meaning that a low rate of discount should be used for climate damage when evaluating climate policies in the presence of tipping points.

In 2016, Cai and collaborators extended DSICE to study the impact of multiple interacting tipping points with Blue Waters support [6]. The article examines the solution of a dynamic stochastic programming problem with ten continuous state variables and five discrete state variables.

For policy analysis on climate change with multiple sectors, our goal is to solve competitive equilibrium and dynamic stochastic problems in high dimensions. In the past year, Cai and Judd used Blue Waters to develop a nonlinear certainty equivalent approximation method (NLCEQ) to solve them efficiently and in parallel [7].

To implement effective policy, ideas need to be complemented by analysis of what is possible, given the limitations placed on policy by social institutions. In the case of climate change, the key challenge is to find international agreements that sovereign governments can support. This is a problem in game theory; more precisely, one needs to find solutions using Nash equilibria in the dynamic interactions of various countries and their policy choices. These interactions can be modeled as supergames. Cai, Judd, and Yeltekin used Blue Waters to develop the algorithms that can solve supergames with states [8]. Cai, Hertel and Judd have also examined how the world demand for food, oil, and timber interacts to alter land use patterns [9].

WHY BLUE WATERS

Solving these high-dimensional dynamic stochastic problems is time intensive, but parallelizing dynamic programming methods allowed us to solve them efficiently [10]. In our benchmark example, we used up to 84,000 cores and it scaled almost linearly; a serial computation would take about 77 years [1]. We also developed NLCEQ to solve even higher-dimensional problems in parallel, e.g., a 400-dimensional dynamic stochastic problem [7]. Another algorithm, developed for solving a dynamic game with multiple players and many choices in Blue Waters [8], would take decades without parallelism.

NEXT GENERATION WORK

Our goal is to merge critical sectors, such as agriculture and forestry, with an energy balance climate model within a dynamic optimization model where policies are chosen to maximize an objective that accounts for different income groups and generations and reflects future uncertainty. DSICE has provided the beginning of this framework. Our next generation work will extend DSICE with Blue Waters to perform research on policy analysis with Bayesian learning, robust decision making, multi-sector integrated assessment of climate and economy under uncertainty, and geoengineering.

PUBLICATIONS AND DATA SETS

Lontzek, T.S., Y. Cai, K.L. Judd, and T.M. Lenton (2015). Stochastic integrated assessment of climate tipping points indicates the need for strict climate policy. *Nat. Cli. Change*, 5 (2015), pp. 441–444.

Cai, Y., et al., Environmental tipping points significantly affect the cost-benefit assessment of climate policies. *PNAS*, 112:15 (2015), p. 4606–4611.

Cai, Y., T.M. Lenton, and T.S. Lontzek, Risk of multiple climate tipping points should trigger a rapid reduction in CO2 emissions. *Nat. Cli. Change*, 6 (2016), p. 520–525.