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CLIMATE POLICY IN A DYNAMIC STOCHASTIC ECONOMY

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EXECUTIVE SUMMARY

There are significant uncertainties in both the climate and economic systems. Integrated Assessment Models (IAMs) of the climate and economy aim to analyze the impact and efficacies of policy responses to climate change. The research team developed and solved new computational IAMs, with more than 10-dimensional continuous state space, that incorporate a spatial temperature system, climate tipping points, economic risks, carbon capture and storage, and/or regional economic activities. The team then analyzed the optimal policy under uncertainty and risks and how such a policy impacts economic activities. They found that tipping points and sea level rise significantly increase the social cost of carbon (SCC), but efficient adaptation and carbon capture and storage can significantly decrease SCC, while ignoring spatial heat transfer leads to nonnegligible bias. Moreover, they have solved dynamic stochastic cooperative and noncooperative equilibria and find that noncooperation leads to much lower carbon taxes and then to a much higher temperature in the future.

RESEARCH CHALLENGE

A major characteristic of leading IAMs is that their geophysical sector determines the mean surface temperature, which in turn determines the damage function, and then damages are related to the mean surface temperature of the planet. However, climate science shows that under global warming, the temperature at the latitudes closer to the poles will increase faster than at latitudes nearer to the Equator. This effect is called polar amplification (PA). Moreover, most countries in the tropic area are poorer and more vulnerable to climate change than rich countries in the higher-latitude regions. Furthermore, PA will accelerate the loss of Arctic sea ice, leading to a potential meltdown of the Greenland and West Antarctica ice sheets, which then could cause serious irreversible sea level rise. All of these factors call for a more realistic and regionalized IAM.

Most existing IAMs are perfect foresight forward-looking models, assuming one knows all of the future information. However, there are significant uncertainties in the climate and economic systems. For example, PA will increase the likelihood of tipping points that may significantly change the Earth system and economic productivity. On the other hand, technological progress such as carbon capture and storage as well as more efficient adaptation may reduce potential climate damage significantly. International cooperation or noncooperation will lead to significantly different solutions. All of these uncertainties call for a richer and more dynamic stochastic IAM, which is computationally challenging.

METHODS & CODES

Cai, Brock, Xepapadeas, and Judd [1] developed a model of dynamic integration of regional economy and spatial climate under uncertainty (DIRESCU) that includes spatial heat and moisture transport from low latitudes to high latitudes, sea level rise, permafrost thaw, and tipping points. To model spatial heat and moisture transport, they disaggregated the globe into two regions: region 1 is the region north of latitude 30°N to 90°N (called the North), while region 2 is the region from latitude 90°S (the South Pole) to 30°N (called the Tropic-South). The research team adapted the computational method in DSICE [2], developed by Cai and Judd in past years using Blue Waters, to solve DIRESCU in a cooperative world. They also studied the regional climate policy under noncooperation between the North and the Tropic-South by developing an iterative method to find feedback Nash equilibrium in DIRESCU.

Cai and Judd [4] extended DSICE to study the impact of carbon capture and storage on climate policy in the face of economic risks and also with a climate target constraint: If the global average surface temperature increase is above 2° or 1.5° Celsius, then the Earth likely will incur significantly larger damages. The researchers adapted the computational method in DSICE again to solve this constrained model.

These computational methods are parallelized using the master–worker structure—the master assigns N tasks for workers to solve in parallel and then gathers the results of these tasks from workers. In principle, they follow the parallel dynamic programming method developed by Cai, Judd, and their co-authors [3]. The code shows high parallel efficiency and an almost linear speedup from 30 to 5,000 nodes.

RESULTS & IMPACT

In the past year, the DSICE paper [2] was accepted by the *Journal of Political Economy* and has been cited more than 190 times according to Google Scholar. The paper is the first in the literature to solve such a high-dimensional dynamic stochastic IAM in the face of both economic and climate risks. Its largest example would take several decades to run on a single-core machine, but the research team solved it in less than eight hours using 3,459 nodes on Blue Waters. The paper shows that the social cost of carbon (SCC)—the present value of the marginal damage to economic output caused by carbon emissions—is substantially affected by both economic and climate risks. Moreover, SCC is itself a stochastic process with significant variation.

DIRESCU [1] and Cai and Judd [4] are two research projects continuing from last year's Blue Waters project. This year, the team made significant revisions. In DIRESCU, they developed a computational method to solve the feedback Nash equilibrium, which is well known to be computationally challenging, particularly for high-dimensional dynamic stochastic games. The researchers studied many cases in DIRESCU [1] and Cai and Judd [4], where each case used thousands of node hours of Blue Waters.

WHY BLUE WATERS

The research team's parallel computational package requires low-latency communications because it uses the master–worker structure and needs frequent communication between the master and workers. The problems are large. For example, DIRESCU has 10 continuous state variables and one binary state variable as well as eight continuous decision variables and a horizon of over 500 years. It corresponds to solving a Hamilton–Jacobi–Bellman (HJB) partial differential equation with 10 or 11 state variables in a cooperative world, or a system of two HJB equations in a noncooperative world. Blue Waters allows the researchers to solve these large problems efficiently.

PUBLICATIONS & DATA SETS

Y. Cai, K. L. Judd, and T. S. Lontzek, "The social cost of carbon with economic and climate risks," *J. Political Econ.*, 2019, doi: 10.1086/701890.