The Coalition of Finance Ministers for Climate Action

Latest developments in upgrading DICE-2023: findings and implications for Ministries of Finance

ETH Zürich

Lint Barrage, Associate Professor and Chair of Energy and Climate Economics

A contribution to the 'Compendium of Practice from a Global Community of Ministries of Finance and Leading Organizations: Economic analysis and modeling tools to assist Ministries of Finance in driving green and resilient transitions'

Topic: Modeling tools relevant to Ministries of Finance

June 2025

Access the full Compendium at www.greenandresilienteconomics.org

This contribution was prepared at the request of, and with guidance from, the Ministry of Finance of Denmark as Lead of the Coalition's Helsinki Principle 4 initiative 'Economic Analysis for Green and Resilient Transitions' and its Steering Group, with input from its Technical Advisory Group. The views, findings, interpretations, and conclusions expressed are those of the authors. While many Coalition members and partners may support the general thrust of the arguments, findings, and recommendations made in this contribution, it does not necessarily reflect the views of the Coalition, its members, or the affiliations of the authors, nor does it represent an endorsement of any of the views expressed herein by any individual member of the Coalition.

Overview

The Dynamic Integrated model of Climate and the Economy (DICE) model is one of the most foundational and widely used integrated models of the climate, energy policy, and the macroeconomy. William Nordhaus developed the DICE model based on his earlier pioneering integration of greenhouse gas emissions, the global carbon cycle, climate system, and climate change impacts into an otherwise conventional ("Ramsey") growth model, and he was awarded the Nobel Memorial Prize in Economic Sciences for this work. Since its inception in the early 1990s (Nordhaus, 1992), the DICE model and its components have been used in countless studies and policy applications (Barrage 2019). In particular, the model offers the following to any interested user:

- A transparent and internally consistent framework (based on a standard Ramsey growth model) for analyzing interplays between the macroeconomy, greenhouse gas emissions, climate policies, and climate change.
- For example, the model can be used to quantify the social cost of carbon (SCC), which measures the present value of all future damages one additional ton of carbon dioxide emitted today is expected to cause. That is, the SCC measures the external costs that polluters impose on the rest of society through the consumption of, e.g., fossil energy resources. The SCC has fundamental policy relevance, for example, as the value that policymakers may want to attach to changes in carbon emissions in cost-benefit analysis of new policies (e.g., refrigerator efficiency standards), or to inform appropriate values for subsidy levels to clean energy, or perhaps most fundamentally, to inform carbon pricing policies that seek to ensure fossil energy resources are only consumed to the extent that their benefits outweigh their costs. The DICE model can also:
    - characterize cost-benefit optimal climate policy paths under different parameter choices
    - quantify cost-effective policy paths given policy targets (e.g., a global 2°C maximum temperature change limit)
    - characterize the costs and benefits of arbitrary policy paths under different parameter scenarios.
- Portable modules and quantifications for key elements of the climate change problem, including climate change damage functions, dynamic estimates of aggregate emissions reduction costs, a simplified carbon cycle-climate system representation, dynamic SCC estimates, and a flexible discounting module, inter alia.
- Publicly available and well-documented code, user manual, and data sources, which can readily be modified by users for their particular purposes.

Given that scientists' understanding and best practices with regard to many aspects of the climate change problem keep evolving, the DICE model has gone through repeated updates over the years. For example, recent climate science has found that global temperatures adjust more quickly to injections of carbon dioxide into the atmosphere than previously thought. Key innovations in DICE-2023 (Barrage and Nordhaus, 2024), the latest model update since the 2016 version (Nordhaus, 2017), thus include:

(i) A new carbon cycle-climate system representation based on updated climate science (including the FAIR model of Millar et al. (2017) and the latest Intergovernmental Panel on Climate Change Report (IPCC, 2023))
(ii) A new representation of non-CO2 greenhouse gas emissions and abatement
(iii) A new approach to discounting that explicitly incorporates uncertainty over future consumption growth and the risk profile of climate mitigation investments
(iv) An updated climate change damage function, i.e., an updated characterization of the GDP-equivalent global losses from a given level of global temperature change.

The updated damage function is based on three components: (i) a synthesis of 56 estimates across 33 published studies (expanding coverage of the damage function foundation to new research published since the 2016 DICE model), (ii) an adjustment for the costs of tipping points in the climate system based on estimates from Dietz et al. (2021), and (iii) a judgmental additional adjustment for further omitted impacts.[1] Altogether, these updates lead to a substantially higher SCC, a lower cost of maintaining the 2°C limit, and a lower cost-benefit optimal emissions and warming profile than in previous versions of the DICE model.

Strengths and limitations

The central strengths of the DICE framework include its simplicity, flexibility, and the portability of its modeling elements. The simplicity of the model also makes it comparatively easy to conduct extensive uncertainty and sensitivity analyses of the implications of various model elements for the results. By the same token, its simplicity can also be a limitation, as DICE abstracts from many complexities of modern macroeconomies. For example, the model uses a five-year time horizon and is thus not designed to study short-run macroeconomic frictions and fluctuations. The model also focuses on a representative consumer and final goods production sector. While a multi-regional version of DICE exists (the RICE model; Nordhaus 2010; Yang 2022) that permits analysis at the country- or regional level, the model is not designed for inference on some granular questions that may be relevant for MoFs, such as whether clean technology subsidies should be targeted upstream or downstream in industrial production networks, or what the distributional impacts of carbon pricing across consumer groups may be.

Another set of limitations arising from the tractability is that the model makes numerous simplifying assumptions that, in the broader literature, are well understood to be consequential. For example, the evolution of technology and emissions reduction costs are taken to be exogenous, i.e., not affected by climate policy. While the model allows both autonomous energy efficiency improvements in the economy over time and assumes that clean technology costs will continue to fall in the future, the rate of change in these key variables is taken to be both fixed and known. The costs of mitigating carbon emissions are also taken to be a proportional and contemporaneous fraction of GDP that increases nonlinearly in climate policy stringency. Population growth is similarly taken to be fixed and unresponsive to either climate change or climate policy (though mortality impacts of climate change are valued in the damage function). Finally, climate change damages are assumed to be quadratic in the global mean surface temperature change. While this assumption is in line with other estimates for modest temperature change, it should be emphasized that evidence on damages is very limited for higher levels of warming and that a quadratic damage function does not reflect potential concerns about threshold damages.

Relevance to Ministries of Finance/key policy questions addressed

The DICE model is relevant to MoFs in at least two key ways.

- *As is*, the DICE/RICE models can be used to inform decisions about economic strategy and policy, including aspects of fiscal policy. Concrete examples include the model's outputs for the SCC, which can inform carbon pricing policies and have also been used widely in public cost-benefit analyses and in setting subsidy rates such as for zero-emissions electricity (see Greenstone et al., 2013; Barrage 2019). The model can also be used to help inform long-run macroeconomic and fiscal projections of the global or regional GDP impacts of different climate policy scenarios. Endogenous[2] model outputs include GDP, climate change

1 It should be noted that the literature synthesis underlying DICE-2023 results in substantially lower damage estimates than another recent review by Howard and Sterner (2017). However, conditional on discounting assumptions, the DICE-2023 estimates of the social cost of carbon align closely with those of other independent recent climate change impact estimation efforts such as those underlying the GIVE and Climate Impacts Lab models' applications in the U.S. Government's SCC calculations (EPA, 2022; see also the discussion in Barrage and Nordhaus 2024). Importantly, the DICE model can also be run with different damage functions.

2 "Endogenous" model outputs are those that are determined by the choices of agents in the model and that vary across scenarios. So, for example, depending on what level of climate policy is set, the DICE model calculates different trajectories of world GDP, future climate change, etc.

damages, mitigation expenditures, consumption/investment, carbon prices, the SCC, industrial carbon emissions, land-use carbon emissions, abatable non-CO_2 emissions, global mean surface temperature change, and carbon concentrations.
- DICE-2023 model *elements* can be incorporated into other MoF-relevant frameworks to inform questions that DICE is not specifically designed to answer, such as the implications of physical climate change and energy policy on public budgets and debt levels in the context of fiscal policy models (see, for example, Barrage 2024, 2020). DICE elements have also been used in models of short-run economic fluctuations such as DGSE or New Keynesian frameworks (see the review by Annicchiarico et al., 2022) that may include additional outcomes such as inflation.

Use in practice

Everything necessary to run and use the DICE model is freely available online.[3] The provided resources include a User's Manual for DICE-2023, the GAMS model code, a simplified Excel version, and the paper describing the DICE-2023 model, as well as relevant Appendices and background papers that provide details on further key issues such as data sources. Any further questions about using the DICE model (Barrage and Nordhaus 2024) can be addressed to the author.

Lessons and challenges

One challenge for MoFs may be that they do not have a GAMS license or GAMS programming expertise. In these cases, the Excel version and User's Manual of the model may be useful. That is, while basic GAMS programming skills are required to run the standard version of DICE, anybody with an understanding of Excel or basic macroeconomics can utilize the Excel model version and DICE model equations as described in the documentation. There are some additional caveats associated with the use of the Excel version, as noted in the model documentation. Some scholars have also produced and made publicly available MATLAB code for older versions of DICE.[4] While the 2016 DICE version misses some important updates on the carbon cycle, damages, non-CO_2 forcings, and discounting, it may still be useful. Given how widely used the DICE model is, there are many resources available for potential users. Of course, the results must be interpreted with the standard caveats in mind, as this class of models make many simplifying assumptions and are based on quantifications that are often subject to major uncertainties.

Conclusions and recommendations

The DICE-2023 model offers MoFs a transparent and accessible tool that can be used for many applications in core climate-macroeconomic modeling. The model—along with its multi-regional cousin, the RICE model—can be used for applications such as estimating the SCC (under a range of parameter assumptions), estimating cost-effective or cost-benefit optimal climate policy, and characterizing the costs and benefits of different global (and, with RICE, domestic) policy paths. The RICE model has also been used for applications such as quantifying different design options for "Climate Clubs" (Nordhaus 2015). DICE-2023, in particular, offers updated representations of the carbon cycle and climate system, of climate change damages, of non-CO_2 abatement, and of risk-adjusted discounting. While the model is thus greatly simplified, its various components can also be integrated into more conventional macroeconomic models used by MoFs for a variety of purposes, such as fiscal or DSGE models, as has already been done by many scholars and for many policy applications.

3 : https://bit.ly/3TwJ5nO
4 See, for example, https://github.com/dlemoine1/DICE-2016R-Matlab

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