



CLIMATE ECONOMICS

Opportunities for advances in climate change economics

Target carbon's costs, policy designs, and developing countries

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There have been dramatic advances in understanding the physical science of climate change, facilitated by substantial and reliable research support. The social value of these advances depends on understanding their implications for society, an arena where research support has been more modest and research progress slower. Some advances have been made in understanding and formalizing climate-economy linkages, but knowledge gaps remain [e.g., as discussed in (1, 2)]. We outline three areas where we believe research progress on

climate economics is both sorely needed, in light of policy relevance, and possible within the next few years given appropriate funding: (i) refining the social cost of carbon (SCC), (ii) improving understanding of the consequences of particular policies, and (iii) better understanding of the economic impacts and policy choices in developing economies.

REFINING THE SCC. The SCC is an estimate of the damages caused by emitting carbon. Formally, the SCC estimates the monetized change in social welfare over all future time from emitting one more tonne of carbon today, conditional on a specific trajectory of future global emissions and economic and demographic growth. An understanding of the SCC is used in developing regulations directly or indirectly linked to climate change and is vital to building political support for domestic climate policies worldwide (3, 4). The SCC is usually estimated using an integrated assessment model (IAM), although other methods,

POLICY such as expert elicitation, are being explored. Widely used values for the SCC have been criticized, with particular skepticism surrounding the empirical basis used by IAMs to project climate damages and, thus, the SCC (5). We highlight five promising research directions to refine SCC estimates, which might then improve how they are used in policy (6). First, a better understanding of the economic impact of extreme climatic events is required. Economists can build on advances in our physical understanding of these low-probability, high-damage events (7) to study how changing likelihoods could affect damage estimates. Second, research is needed on how to represent potential damages that are poorly captured in typical economic output measures. Such “nonmarket” damages, which include potential costs of increased civil conflict, changes in human health, and biodiversity loss, could be sizeable (8) but are omitted from current damage estimates or are represented in an ad hoc way (e.g., as a simple multiple of market damages). Research should explore new methods for measuring key nonmarket outcomes [e.g., (9)], and should clarify how to incorporate accumulating evidence into IAMs. Third, work is required on how aggregate economic output is affected by changes in climate (10). How climate change or the rate of change affect the level of output, the growth rate of output, the stock of capital, or some other metric, can have a major impact on the SCC, because it is a measure of accumulated damage over time. Current evidence is mixed, and resolving the debate will be crucial. The fourth area for research is adaptation, which has the potential to drastically change the gross damages from climate change. It is one of the least explored areas of climate economics, and little guidance is available on how to build adaptation into damage functions. For example, how farmers may adapt agricultural practices dampens agronomic estimates of damage from a change in climate. A frontier for research is how to con-

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nect impact estimates derived from historical short-run fluctuations in weather to potential future impacts from longer-run changes (incorporating adaptation) in climate. Rigorous methods for doing this are in their infancy and urgently need improvement (11).

Finally, SCC-focused IAMs, the main tools for aggregating economic costs of mitigation and adaptation, as well as economic damage from changed climate to produce SCC estimates, need a more structured way of incorporating new information. Damage functions in IAMs can rely in part on studies completed more than 20 years ago (12). The treatment of uncertainty in IAMs needs improvement, with research needed on the computational challenges of explicitly including decision-making under uncertainty (13). Last, the choice in most existing IAMs to examine the well-being (utility) of a representative agent may be inappropriate if impacts differ greatly by region or by type of agent. Understanding nuances of how these models aggregate costs and benefits across disparate regions and populations is of particular importance.

IMPROVING POLICY DESIGN. Political resistance to carbon pricing in many jurisdictions, as well as the emergence of a piecemeal approach to domestic and international climate policy-making, means that it is insufficient to study merely how to price the climate externality in a “first-best” world with no other economic distortions. Although many existing “second-best” policies, such as efficiency standards and support for renewables, are cost-ineffective relative to carbon pricing (14), they continue to be implemented for political, distributional, or other reasons.

Research must consider practical dimensions of optimally designing and implementing such policies. First, more rigorous ex post empirical analysis of energy and environmental policies will be critical (15). Policies such as carbon pricing schemes, tradable obligations, fuel taxes, renewable portfolio standards, and energy efficiency standards are already in use in different countries and will become more common as countries try to operationalize their pledges in the United Nations Framework Convention on Climate Change process. But there is often little empirical evidence on individual- or market-level responses to these policies. Existing evidence suggests that behavioral responses to a given policy can drive a wedge between ex ante engineering estimates of program costs and benefits and ex post estimates of true costs and benefits (16). More evidence with rigorous analysis is sorely needed on a range of mitigation and adaptation policies.

In the long term, the costs of addressing climate change using current technologies could be very large, which makes technologi-

cal progress critical. A large body of work on the rate and direction of innovation exists, but research is needed on what combinations of R&D and climate policies shape innovation and diffusion of low-carbon technologies (17).

BEYOND ADVANCED ECONOMIES. Much of the existing research on climate damages or policies has focused on the developed world. This is problematic, both because developing countries currently represent the majority of the world’s population and greenhouse gas emissions and because the nature of impacts and context for policy choice could differ greatly relative to developed regions.

A first key research need is to rigorously quantify how vulnerability to climate change shifts as countries develop and the structure of their economies changes, a question on which evidence is mixed (10, 11). Attention to the burden borne by low-income households will be important, as little is known about how changes in climate and climate policy affect these households’ productivity and livelihoods. Growing availability of expenditure surveys in these countries, potentially combined with remotely sensed measures of livelihoods (18), could allow rapid progress.

“...what combinations of R&D and climate policies shape innovation and diffusion of low-carbon technologies [?]...”

Emerging economies will play an essential role in the success of mitigation efforts, given their projected demographic and economic growth. Thus, a second key research agenda will be to better understand climate mitigation options in the developing world. Carbon mitigation proposals have faced opposition in many developing countries because of concern that they could hamper growth by constraining energy supply and increasing costs (although a few middle-income countries are experimenting with carbon pricing). Yet, because tax evasion rates are lower for energy taxes compared with income taxes (19), implementing a carbon tax may allow developing-country governments to simultaneously achieve climate-policy goals and raise revenue. Research is needed on the feasibility of different policy tools in different political and institutional contexts, because the appropriateness of policies may differ in countries with heavily subsidized fossil fuels, high rates of tax evasion, and large informal and state-owned sectors. An understanding of how innovation policy can be effective and, more broadly, of how to make low-car-

bon technologies adoptable in the developing world, is also essential.

Our list of research priorities is not comprehensive and likely debatable. Others, including some of the authors, might emphasize other priorities (e.g., research on temporal discounting, international policy cooperation and coordination, and political economy). But what is crystal clear is that society is hampered in using natural science knowledge of climate change because of gaps in the knowledge of economic and social dimensions of climate change. A much more substantive research program on the economics of climate change is essential; otherwise, effective policy solutions with broad societal support will remain elusive. Future research must continue to include data-intensive empirical work to strengthen the foundations upon which policy-relevant “end products” (such as the SCC) are based, along with research aimed at defining and reframing key questions. ■

REFERENCES AND NOTES

1. O. R. Edenhofer et al., Eds., *Climate Change 2014: Mitigation of Climate Change: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge Univ. Press, New York, 2014).
2. National Research Council, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (National Academies Press, Washington, DC, 2010).
3. M. Greenstone, E. Kopits, A. Wolverton, *Rev. Environ. Econ. Policy* **7**, 23 (2013).
4. Committee on Assessing Approaches to Updating the Social Cost of Carbon, *Assessment of Approaches to Updating the Social Cost of Carbon: Phase I Report on a Near-Term Update* (National Academies Press, Washington, DC, 2016).
5. R. S. Pindyck, *J. Econ. Lit.* **51**, 860 (2013).
6. W. Pizer et al., *Science* **346**, 1189 (2014).
7. Committee on Extreme Weather Events and Climate Change Attribution, *Attribution of Extreme Weather Events in the Context of Climate Change* (National Academies Press, Washington, DC, 2016).
8. S. Hsiang, M. Burke, E. Miguel, *Science* **341**, 1235367 (2013).
9. D. J. Benjamin et al., *Am. Econ. Rev.* **102**, 2083 (2012).
10. M. Burke, S. M. Hsiang, E. Miguel, *Nature* **527**, 235 (2015).
11. M. Dell, B. F. Jones, B. A. Olken, *J. Econ. Lit.* **52**, 740 (2014).
12. S. K. Rose et al., *Understanding the Social Cost of Carbon: A Technical Assessment* (Report 3002004657, Electric Power Research Institute, Palo Alto, CA, 2014).
13. D. L. Kelly, C. D. Kolstad, *J. Econ. Dyn. Control* **23**, 491 (1999).
14. S. Borenstein, *J. Econ. Perspect.* **26**, 67 (2012).
15. M. Greenstone, in *New Perspectives on Regulation*, D. Moss, and J. Cisternino, Eds. (The Tobin Project, Cambridge, MA, 2009).
16. K. Gillingham, K. K. Palmer, *Rev. Environ. Econ. Policy* **8**, 18 (2014).
17. D. Popp, R. G. Newell, A. B. Jaffe, in *Handbook of the Economics of Innovation*, vol. 2, B. H. Hall, N. Rosenberg, Eds. (Elsevier–North Holland, Amsterdam, 2010).
18. J. V. Henderson, A. Storeygard, D. N. Weil, *Am. Econ. Rev.* **102**, 994 (2012).
19. A. A. Liu, *J. Environ. Econ. Manage.* **66**, 656 (2013).

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