Center on Regulation and Markets at BROOKINGS

POLICY BRIEF | SEPTEMBER 2022

WHY CLIMATE POLICY SCENARIOS ARE IMPORTANT, HOW TO USE THEM, AND WHAT HAS BEEN LEARNED

ROSHEN FERNANDO, WEIFENG LIU, AND WARWICK MCKIBBIN

Summary

In an ideal world without uncertainty, policymakers should use a range of policies to reduce greenhouse gas emissions, but the core policy should be to price carbon emissions at the level of the marginal cost of carbon emissions, or equal to the social cost of carbon emissions. However, the real world is highly uncertain. Uncertainty regarding climate science, the economic impact of climate change, and appropriate discount rates across generations all complicate estimates of the social cost of carbon emissions. There are a wide range of estimates ranging from negative numbers to thousands of U.S. dollars per ton of CO2 (Wang et al. 2019), and it is unlikely for policymakers to reach even a vague agreement on the social cost of carbon. There is also a strong argument to go beyond carbon pricing and adopt a mix of policies that lower economic costs and raise the political acceptance of alternative climate policies.

In response to climate uncertainty, researchers, businesses, and policymakers are turning to scenario analysis. The use of scenarios is critical for policy design because of the extent of uncertainty and the highly dynamic nature of the system. Policies must adapt to new information on the changing climate, emergent technologies, and the reactions of the economy. However, to effectively use scenarios, policymakers need to understand how scenarios are developed and the strengths and weaknesses of the different modelling approaches.

This policy brief has two goals. The first is to inform policymakers about existing scenario approaches and how scenarios that are applied to large-scale models should be used first to understand the nature and scale of possible climate shocks and then develop and evaluate alternative policy approaches to respond to climate change. A key message for policymakers who are increasingly using scenarios for stress testing financial systems is to not force convergence of results across different types of models. The differences in model projections help policymakers to understand the nature of uncertainty and what policies might help minimize those uncertainties. For example, integrated assessment models (IAMs) focus on technologies required to reduce emissions, whereas economic models focus more on changing the behaviour of house-

holds and firms and endogenous structural change in economies in order to reduce emissions.

The second goal of the paper is to draw some policy conclusions for climate policy design that have emerged from recent scenario exercises. There are significant climate risks with potential large economic costs, such as physical risk from chronic climate change and extreme climate events as well as shocks to economies from changes in climate policies (transition risk).

We also summarize the various types of scenarios that have been considered and outline the types of models generally used for long-term and short-term scenario development. Carbon pricing is important for changing the behaviour of households and firms to reduce greenhouse gas emissions. However, carbon prices might not be sufficient as, due to market failures, there is an important role for infrastructure investment by governments and other policies to reduce adjustment costs involved in transitioning to a low-carbon world.

In addition to the insights already gained using model-based scenarios, another key policy lesson from this brief is that policymakers should be careful in using scenarios to design robust policies across a wide range of economic viewpoints rather than seeking optimal policies in a particular model.

I. The Challenge – Climate Risk

There is widespread consensus that climate change is a major global challenge. Climate mitigation requires global collective action since greenhouse gas emissions impose negative externalities across countries. With increasing awareness of climate damages and risks, the world has been accelerating efforts and commitments to mitigate climate change in the last decade. Almost 200 countries joined the Paris Climate Agreement in December 2015, and 89 countries accounting for 74% of global greenhouse gas (GHG) emissions have so far communicated plans for net-zero carbon emissions around mid-century, including some of the largest emitters (Europe, Japan, Korea, China, India, and the U.S.).[1] However, the Paris Agreement is far from sufficient to reduce global emissions to be consistent with the 2-degree goal,[2] and the net-zero commitments do not set out clear roadmaps. Even with net-zero commitments, the history has demonstrated that achieving international cooperation is difficult due to significant heterogeneities across countries, especially between developed and developing countries. The United Nations COP26 meeting has again witnessed the conflict between developed and developing countries, particularly regarding the phase-out of coal and climate finance. The Intergovernmental Panel on Climate Change report (IPCC 2021) reinforces the urgency of concerted climate policy action.

Confronted with significant uncertainty in climate damages, policymakers have taken a more pragmatic approach: First reach an agreement on goals and constraints and then find the best way to achieve the goals within the constraints. This guardrail approach has been applied in many arenas of policy where there are potential extreme risks and the benefits are hard to evaluate (Stern et al. 2022). In the context of climate change, policymakers have reached an agreement on a long-run global target to reduce the probability of tipping points and catastrophic disasters, i.e., limiting the rise in the global mean temperature to 2 degrees Celsius above the pre-industrial level by the end of this century. With that goal set, climate models can then be used to derive the level of atmospheric concentrations of emissions that are consistent with the global temperature target. The level of emissions concentrations puts an upper bound on incremental emissions from now to the end of this century on top of the current emissions stock. Economic models can then be used to derive paths for carbon prices that are consistent with the emissions upper bound. This approach shifts the focus of climate policy from the social cost of carbon based on cost-benefit analysis to the abatement cost of carbon based on cost-effectiveness analysis.

Still, there is much uncertainty, especially about technological innovation in energy sectors and the economy more broadly. Thus, there are various emissions pathways from now to the end of this century. Fortunately, it has been further agreed that the world should target net zero emissions by mid-century, and as noted above many countries have already committed to doing so.

II. Developing climate scenarios

Modeling climate risks can be seen as envisioning alternative futures for the world. The Intergovernmental Panel on Climate Change (IPCC) has developed different scenarios to explore how global emissions might evolve during the twenty-first century. The IPCC 5th Assessment Report (AR5) (IPCC 2014) developed the Representative Concentration Pathways (RCPs): RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 (van Vuuren et al. 2011). The pathways represent different radiative forcing levels achieved by the end of the century from GHG concentration in the atmosphere compared to the pre-industrial times. Although there are socio-economic scenarios underlying the outcomes described in the RCPs, they aren't the primary focus. The RCPs are primarily concerned with the implications of the alternative pathways for emissions.

Extending the RCPs, the IPCC 6th Assessment Report (AR6) uses the Shared Socioeconomic Pathways (SSPs).[3] SSPs provide greater attention to how socio-economic factors might change over this century, including population, economic growth, education, urbanization, and technological development. There are five pathways: SSP1 (Sustainability - Taking the Green Road), SSP2 (Middle of the Road), SSP3 (Regional Rivalry - A Rocky Road), SSP4 (Inequality - A Road Divided), SSP5 (Fossil-fueled Development – Taking the Highway). SSPs indicate future energy use and GHG emissions within IAMs. The SSPs describe alternative future pathways in the absence of climate policy and look at how different GHG concentration pathways defined by RCPs could be achieved. Since the AR5 report, three RCPs have been added: RCP 1.9 represents a pathway that limits warming to below 1.50C; RCP 3.4, a pathway consistent with the 20C goal; and RCP 7.0, which describes a pathway where warming could be between 3.8 – 4.20C. SSPs enable researchers and policymakers to examine economic consequences arising from structural changes (particularly in the energy, transportation, and land-use sectors), achieving the same emission outcome and designing efficient and effective mitigation policies.

The emphasis on transition risks is not explicit in either the RCPs or SSPs. With the considerable increase in interest from central banks and financial markets, the Network for Greening the Financial System (NGFS), which is a collection of central banks and regulators from many countries, has organized climate scenarios with emphasis on both the physical and transition risks. Physical risks tend to be inversely related to transition risks. Depending on the ambition of climate policy, the NGFS divides scenarios into three broad groups: (1) orderly scenarios: Climate policies are introduced early and become gradually more stringent, with both physical and transition risks relatively subdued; (2) disorderly scenarios: Policies are delayed or divergent across countries and sectors, resulting in higher transition risk; (3) hothouse world scenarios: Global efforts are insufficient to halt significant global warming, resulting in severe physical risk including irreversible impacts. In the NGFS studies, the IAMs choose SSP2 as the baseline.

III. Physical risks in IAMs and economic models

A key source of uncertainty in modeling consequences of climate change lies in the different model representations of how the physical and economic systems function and interact. IAMs and general equilibrium models (both Computable General Equilibrium (CGE) models and Dynamic Stochastic General Equilibrium (DSGE) models) have been widely used in assessing the economic consequences of climate damages.[4] Additionally, there are also small-scale impact models which focus on assessing the implications of climate change on specific environmental bodies, such as biomes (e.g., forests), freshwater ecosystems, and marine ecosystems, as well as economic sectors, such as agriculture, energy, and households (health). We provide an overview of how IAMs and general equilibrium models assess physical risks of climate change—chronic climate risks (gradual global warming) and extreme climate risks (climate-related extreme events)—and highlight the important differences in those approaches and their implications for policymaking.

INTEGRATED ASSESSMENT MODELS (IAMS)

IAMs illustrate the interactions among the biophysical and socio-economic systems within a single model. They often have separate climate and economic modules which are integrated with or without feedback. IAMs could follow either a vertical or horizontal approach to integrating biophysical systems with socioeconomic systems. Horizontal integration has often been used to evaluate climate change along with other environmental concerns, such as ozone depletion, acidification, and air pollution. Vertical integration, which is widely used in evaluating the economic consequences of climate change, starts with assumptions about demographic change, economic growth, technological change, and any existing climate policies. The atmospheric accumulation of the emissions from such assumptions is modeled, and the radiation and global climate are then derived. Then the regional climate and weather are modeled to observe the impacts of climate change on biological ecosystems. The economic impacts are derived from the climate impacts on biological ecosystems. Deviating from the simple causal chain, contemporary models also enable complex linkages across biophysical systems (such as terrestrial systems, atmosphere, and ocean), socio-economic systems, and policy responses (Parson & Fisher-Vanden 1997).

Depending on the model focus, IAMs often also have detailed energy, transportation, and land-use sectors. IAMs could either be solved to obtain the emission trajectories of a given set of socio-economic, technological, and climate policy assumptions or to illustrate the structural and policy changes necessary to achieve the desired emission outcome. The economic implications of different scenarios defined in terms of their socio-economic and policy assumptions are then compared against a model baseline. IAMs could be developed to incorporate both chronic and extreme risks of climate change and illustrate their impacts on different sectors or the macroeconomy. The chronic risks covered in IAMs include global mean temperature change and sea-level rise, and extreme risks include extreme temperature, precipitation, heatwaves, and coldwaves.

Goodess et al. (2003) identify three classes of IAMs: cost-benefit analysis models, biophysical models, and policy guidance models. The cost-benefit analysis models focus on assessing the costs and benefits of climate change against the cost of adaptation and mitigation policies. The Dynamic Integrated Model of the Climate and the Economy (DICE) by William Nordhaus is a popular example of a cost-benefit analysis model. Other popular examples include the Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) model and the Policy Analysis of the Greenhouse Effect (PAGE) model. The cost-benefit analysis models tend to follow vertical integration with the simple causal chain and are widely used to optimize policies. Biophysical impact models emphasize climate change impacts on ecosystems and illustrate feedback across systems in vertical integration. However, due to the absence of explicit focus on policies, their economic modules are less developed. Therefore, they are better suited for policy evaluation rather than optimization. Policy guidance IAMs combine the policy optimization and evaluation approaches within tolerable windows defined by the policymakers.

The earlier estimates of the global economic impacts of climate risks are mostly relatively smaller in IAMs. Tol (2012) reviews about a dozen studies that show that the effects of a doubling of the atmospheric concentration of greenhouse gas emissions (leading to global warming of 2.5 to 30C) are a few percentage points of GDP even after a century or so. Weitzman (2012) argues that climate impacts might be considerably underestimated by using conventional quadratic damage functions and thin-tailed temperature distribution. Stern (2016) also warns of the underestimation because of two critical weaknesses of IAMs: limited spatial coverage, including averaged impacts across countries and regions, and unreasonable assumptions on the discount rate, which translate into a relative lack of forward-looking behavior in economic forecasts and resulting negative effects on the future generations.

There also are different damage outcomes from comparable models for the same temperature outcomes. Diaz and Moore (2017) review the DICE, FUND, and PAGE IAMs from the cost-benefit analysis classification and illustrate that the GDP losses at 2 and 40C are vastly different due to the changes in damage functions and key characteristics, especially regarding sector details, in those IAMs. Batten (2018) discusses the subjectivity involved in the choice of parameters and functional forms for damage functions. As Ackerman and Stanton (2012) argue, the damage function estimates have not been consistent with observations, pointing out the importance of updating and calibrating damage functions constantly, which arises from the absence of any economic (or other) theory or empirical foundation underlying the damage functions. Both the oversimplification of climate and economic models or the compromise of mostly economic details at the expense of extensive climate modules have the effect of masking the dynamic approaches via which climate change could affect economic growth and welfare.

GENERAL EQUILIBRIUM MODELS

General Equilibrium models are richer in details about the economic interactions among the economic agents—households, firms, the government, central banks, and the external sector (via trade and investments) —and often disaggregate economies into multiple sectors, but they have little detail on climate and energy systems and do not usually directly incorporate environmental damages. Deriving the economic impacts of climate change using general equilibrium models, which do not explicitly define the interactions among physical and socio-economic systems, allows the formulation of economic shocks that translate exogenous climate impacts on physical systems to impacts on economic variables.

All macroeconomic models, irrespective of their complexity and details, would constitute a production function illustrating the aggregate supply side of the economy. Hence, it is often the starting point to think about climate impact transmission channels to the economy. Batten (2018) conceptualizes both the chronic and extreme climate impacts on various forms of capital within the production function (such as natural capital, physical capital (infrastructure), human capital, and social and organizational capital) and productivity (efficiency, technology, and learning) to be the main transmission channels in a real economy. The policy responses to adaptation and mitigation could also be featured as shocks to the above forms of capital and other economic policy variables (e.g., tax rates) depending on the details of the economic models. The shocks could also be formulated either at the aggregate or sector level, depending on the sectoral disaggregation of the models. Similar to IAMs, general equilibrium models also have a model baseline, and the implications of economic shocks from different scenarios could be evaluated against the baseline.

Kompas et al. (2018) outline how the macroeconomic consequences of chronic climate risks could be evaluated within a CGE model. Using the damage functions developed by Roson and Sartori (2016), they consider four main channels via which chronic climate change affects the economy: (1) the loss of land due to sea-level rise and the resulting implications for the productivity of different economic sectors depending on their reliance on land as a production factor; (2) changes in agriculture productivity and spillover effects to the productivity of other economic sectors depending on their reliance on agriculture intermediate inputs; (3) changes in the incidence of vector-borne diseases and its implications on economy-wide labor productivity mapped onto production sectors depending on their reliance on labor as a production factor; and (4) changes in heat stress for agriculture, manufacturing and service sectors and its implications on labor productivity of the sectors.

Most economic studies estimating climate change impacts have paid little attention to extreme climate shocks (Narita et al. 2009). The biggest shocks have been predicted to be in agriculture by far. Extreme climate shocks are becoming a pressing public health issue with significant welfare and distributional implications due to their adverse health effects (Schmitt et al. 2016). Fernando et al. (2021) is the first economic evaluation of both chronic and extreme climate risks, to the best of our knowledge. They use the same approach as Kompas et al. (2018) for chronic risks and develop and use damage functions to assess the implications of five extreme climate risks (droughts, floods, heatwaves and coldwaves, storms, wildfires). Within the hybrid DSGE-CGE model, i.e., the G-Cubed model,[5] implications of extreme risks on labor productivity (via morbidity and mortality due to extreme events) and sector productivity (via extreme climate impacts on agriculture, energy production, and electricity generation) are assessed.

There are several general conclusions on the economic effects of extreme climate shocks (Handmer et al. 2012). First, global economic losses from climate-related disasters have increased over time with large spatial and temporal variability. Second, increasing exposure of people and economic assets has been the primary cause of long-term increases in economic losses. Climate change projections are expected to increase the frequency and intensity of future extreme weather events, with more extreme events as the temperature scenario increases. Third, total economic costs associated with climate shocks are higher in developed countries, while fatality rates and economic costs in GDP are higher in developing countries. Fourth, extreme shocks will significantly impact sectors with closer links to climate, such as water, agriculture and food security, forestry, health, and tourism.

The impacts of climate change can differ significantly across countries, which justifies Stern's (2016) criticism of IAMs regarding spatial coverage. Kompas et al. (2018) show that the effects on individual countries can be enormous across various RCPs, and averaging across countries into regions can severely mask the heterogeneous effects. The impacts on GDP in Sub-Saharan Africa, India, and Southeast Asia are on the order of 10 percent by the end of this century, while most European countries slightly gain by the mid-century and slightly suffer by the end of this century with less than 0.5 percent of GDP losses. Fernando et al. (2021) find a wide range of outcomes for the loss of GDP from chronic climate change across countries, time, and RCP scenarios by 2100. Under RCP 2.6, the impact on GDP ranges between -0.4 percent to -3.3 percent per year, and for RCP 8.5, the GDP outcome per year ranges from -1.1 percent to -17.4 percent by 2100. Also, sectoral output losses vary significantly within and across countries.

While some policymakers prefer a single worldview to reinforce philosophical positions, models are valuable precisely because they can explore different assumptions about future economic and population growth, technological change, climate policies, and how physical systems and economies are likely to respond. All models are a simplification of a complex system. The variety of models available reflects the uncertainty of how complex systems function. Alternative models with different approaches to modeling climate scenarios also highlight essential issues that a single model framework is unlikely to clarify and provide a range of estimates to account for uncertainties involved in data and modeling approaches.

IV. Transition risks in IAMs and economic models

National or global climate policy can cause economic costs and risks during the transition from fossil-intensive to low-carbon economies.

In many studies it is convenient for policies to be evaluated in terms of the price of carbon or shadow price of carbon required to achieve a particular target. Many modeling studies of alternative emission targets focus on pricing carbon emissions either through carbon taxes, cap and trade carbon markets, or hybrids of the two approaches. Carbon pricing is widely believed among economists to be the most effective policy to mitigate climate change. Carbon pricing shifts energy structures from high-carbon to low-carbon energy, especially renewables, and changes economic structure across non-energy sectors depending on their energy intensity and mix. It is crucial to provide qualitative insights and quantitative estimates of the economic impacts of carbon pricing scenarios to guide climate policy design and negotiations through general equilibrium models. As shown in Liu et al. (2020), carbon prices generally cause negative impacts on output and employment. The magnitudes of the effects depend on the ambitions of emissions reductions. In the NGFS (2021) scenarios under an orderly net-zero transition scenario, the GDP losses by 2050 are around 2.5 percent of GDP globally. In the G-Cubed model (Fernando et al. 2021), the GDP losses by 2050 are similar, although the GDP loss across countries ranges from 2 percent for the U.S. and Europe to 10 percent for Russia. A more significant difference occurs in the early years of the transition because of the forward-looking nature of the G-Cubed model, where investment in fossil fuel-intensive sectors contracts and reduces GDP by more than in the NGFS scenarios.

How carbon tax revenues are recycled can offset some adverse effects of carbon pricing, especially distributional effects. For example, lump-sum transfers to low-income households can reduce income inequality and boost aggregate consumption. Subsidies to renewable energy can create further incentives for producing and consuming renewable energy and thus accelerate the energy transition. Corporate tax reduction can increase private investment. Reducing government debt can mitigate fiscal stress for many countries in the current world of high public debt. McKibbin et al. (2015) show that using carbon tax revenue to reduce the corporate tax rate results in better macroeconomic outcomes than using the carbon tax revenue for lump-sum transfers. With rebates, consumption tends to rise in the short run, but investment tends to fall in the short and long run. In contrast, a corporate tax reduction has little effect on consumption in the short run and causes investment to rise in the long run.

As models differ in assumptions, structure, parameters, and granularity of geographic, energy and economic systems, they present a wide range of carbon prices to achieve net-zero emissions. Clarke et al. (2014) provide a comprehensive analysis of the economic impacts of achieving various goals through a uniform carbon price based on 31 models (primarily IAMs) with almost 1,200 scenarios and show that carbon prices vary significantly across studies. Carbon prices in 2050 (in terms of 2010 USD per ton of CO2) required to reach 480-530 ppm (consistent with 1.7-2.1 °C) range from about $40 to $800 across 60 studies (with the median slightly below $200). For achieving 430-480 ppm (consistent with 1.5-1.7 C), carbon prices vary from about $75 to $950 among 34 studies (with the median slightly above $200). NGFS (2022) also presents large heterogeneity in carbon prices of achieving net-zero emissions by mid-century.

The same level of carbon prices (and other synchronized carbon policies) can have different impacts across regions because of significant economic and energy structure heterogeneity (Bang et al. 2020). Fossil fuel exporters tend to experience more substantial investment contractions and output losses than non-fossil-exporters with similar carbon pricing. Even if fossil fuel exporters do not implement domestic climate policies, they still experience significant investment and output contraction due to reduced demand for their fossil fuel exports. In contrast, regions with abundant renewable resources, like Europe, tend to experience smaller investment and output impacts given similar carbon pricing. In the Paris Agreement, the differential targets across regions correspond to very different levels of impact, whether measured by the CO2 price required or the effects on GDP and welfare. In the net-zero scenario, the effects of the policies differ significantly across countries, with fossil fuel-intensive economies tending to have the highest economic costs due to the loss of revenues from exporting fossil fuels. These economies also need to undertake more substantial structural change domestically to reduce domestic emissions from energy use. If there is some capacity to substitute fossil fuels with other energy sources such as renewables, this negative impact can be substantially reduced.

Due to the lack of concerted international climate policy in practice, border carbon adjustments (BCAs) have been discussed recently, such as in Europe. McKibbin et al. (2018) explore BCAs on top of carbon prices on fossil fuels and find no evidence of significant implications on global emissions. However, BCAs can have strikingly different effects depending on the use of the revenue within a country. A rebate of the revenue from a BCA causes a slightly more significant output loss in most sectors than would occur under the same carbon tax without BCAs. BCAs thus do more harm than good to the production side of the economy. In contrast, when the revenue is used to reduce a distortionary tax such as the tax on capital, BCAs tend to result in higher output than the carbon tax alone. Given insignificant emissions leakage and high administrative costs of implementation, BCAs are not a cost-effective policy.

Despite a wide range of carbon prices, policymakers should continue to take pragmatic action by setting price floors. McKibbin et al. (2014) proposed using price floors and price ceilings as a way to get countries to participate in international agreements. Stiglitz et al. (2017) propose that the carbon-price level consistent with the Paris temperature target is at least $50–100 per ton of CO2 by 2030. Parry et al. (2021) argues that international carbon price floors should focus on a small number of key large-emitting countries and allow differentiation in price floors according to level of development, with price floors of $75, $50, and $25 per ton of CO2 by 2030 for advanced, high-income emerging market economies EME (for example, China), and low-income EME (for example, India) countries, respectively.

IV. Policy Implications

The shape and scale of the world economy between now and the end of the century are highly uncertain.

Large-scale models for analyzing climate change and the associated risks provide essential and evolving insights for policymakers. Scenario planning based on various models and future scenarios reveals a compelling picture of the urgency of responding to the climate challenge. Governments, corporations, and central banks increasingly use climate scenarios to plan policies and investment strategies. In addition, these scenarios are increasingly being used to stress-test financial systems in the face of physical climate risk and transition risk scenarios.

Greater use of models will help policymakers understand the range of uncertainties and the sensitivity of policy outcomes based on different model assumptions.

Different modeling approaches and different assumptions about policies to achieve a particular emission outcome give different results. However, there are some shared insights from the various scenarios in alternative models.

> 1) The design of the policy that is implemented to reduce emissions is critical. Well-designed policies that cover the entire economy result in emissions reduction at lower costs. Carbon prices are the most efficient mechanism for reducing greenhouse gas emissions. However, utilizing a suite of policies can lower economic losses as compared to relying solely on carbon pricing. Using a carbon tax rather than a cap-and-trade approach with the same carbon prices can result in different outcomes depending on how the carbon tax revenue is allocated or how the emission permits are distributed.
>
> 2) Coordinated early action across countries leads to lower economic costs to reach the same level of global emissions reduction by 2050 because of the existence of adjustment costs. It is better to smooth the energy transition as much as possible over time rather than rushing policies in the future.
>
> 3) Outcomes are very sensitive to assumptions regarding technological innovation and the changing costs of alternative technologies over time. The availability and costs of different technologies in the future are highly uncertain. They require various scenarios in order to test which outcomes are robust under alternative assumptions about the future. For example, locking a particular technology into the design of climate policy may prove costly if better or cheaper technologies become available in the future.

While carbon pricing is widely regarded as the most effective policy to mitigate carbon emissions, there are different approaches of implementing carbon pricing, either through carbon taxes, carbon trading, or hybrids of the two approaches. If there is no uncertainty, carbon taxes and carbon trading are equivalent. But in an uncertain world, they have different implications. If one sets the price through a carbon tax, the marginal cost of abatement is clear, but the level of emissions can deviate from the expectation. In contrast, if one sets the emissions cap through a cap-and-trade system, the price of achieving the emissions target can vary. Weitzman (1974) suggests that the quantity instrument (the cap-and-trade system) should be used if the marginal benefit curve is steeper than the marginal cost curve, and otherwise the price instrument (the carbon tax) should be used, because the price instrument leads to lower expected costs while the quantity instrument leads to higher expected benefits. Building on Weitzman (1974), McKibbin and Wilcoxen (1997) and Pizer (1997, 1999) argue that setting prices is better than setting quantities, because overshooting one year’s emissions target does not have much effect on the emissions stock in the atmosphere, while forcing businesses to meet a quantity target at a specific time could push up resource costs sharply if policymakers have misjudged the scope for abatement. This argument is convincing at least in the short run with the evidence of the price volatility of European carbon permits. Due to the price surge in the last several years, some EU member states and some members of the European Parliament have urged legislation to curb volatility (European Roundtable on Climate Change and Sustainable Transition (2022)).

However, in the long run, given the possibility of tipping points in the climate system and rising risks of catastrophe at higher temperatures, it is still necessary to consider revising the carbon price path if the emissions path deviates persistently from the expected one. To draw on the pros of the price and quantity approaches, a hybrid approach has been proposed (McKibbin and Wilcoxen 1997).

In summary, policymakers need to make greater use of model-based scenario analysis to evaluate alternative policies, but the focus should be to widen the range of different models used for a given scenario rather than focusing on seeking consensus across a narrow range of models. The evaluation of climate risk must acknowledge the uncertainty surrounding climate change and the impacts of policies to address climate change. Until policymakers better understand the range of uncertainties about climate risk, they will keep searching for optimal policies in a particular world view rather than robust policies across a range of different world views. The idea of robust policy has both practical implications for national policy design but also important implications for how to fashion international climate agreements across a wide range of countries with different economic structures and different ideologies of how the world works.

ENDNOTES

1. Climate watch, “Net-Zero Tracker,” Accessed September 22, 2022, https://www.climatewatchdata.org/net-zero-tracker.
2. See IPCC (2021) and Liu et al. (2020).
3. See Riahi et al. 2017 for an overview of SSPs.
4. Ciarli and Savona (2019) identify five types of models used to assess economy-wide climate damages: Integrated Assessment Models (IAMs), Computable General Equilibrium (CGE) Models, Structural Change Models (SCMs), Ecological Macroeconomic Models (EMKs), and Evolutionary Agent-based Models (EABMs).
5. See McKibbin & Wilcoxen (1999 and 2013) for more details.

REFERENCES

Ackerman, F. & Stanton, E. A. 2012. Climate risks and carbon prices: Revising the social cost of carbon. Economics, 6.

Bang, E., Barrett, P., Banerjee, S., Bogmans, C., Brand, T., Carton, B., Eugstger, J., Fernandez, D. R., Jaumotte, F., Kim, J., Liu, W., McKibbin, W. J., Mohammad, A., Pugacheva, E., Tavares, M. M. & Voights, S. 2020. Mitigating Climate Change. World Economic Outlook. Washington D.C.: International Monetary Fund.

Batten, S. 2018. Climate change and the macro-economy: a critical review. Staff Working Paper. London, UK: Bank of England.

Ciarli, T. & Savona, M. 2019. Modelling the evolution of economic structure and climate change: A review. Ecological Economics, 158, 51-64.

Clarke, L., et al. Assessing Transformation Pathways (2014). O. Edenhofer, et al. (Ed.) Climate Change 2014: Mitigation of Climate Change (Vol. 3). Intergovernmental Panel on Climate Change (IPCC).

Diaz, D. & Moore, F. 2017. Quantifying the economic risks of climate change. Nature Climate Change, 7, 774-82.

European Roundtable on Climate Change and Sustainable Transition 2022. European Roundtable on Climate Change and Sustainable Transition: 2022 Prospectus. European Roundtable on Climate Change and Sustainable Transition.

Fernando, R., Liu, W. & J., M. W. 2021. Global economic impacts of climate shocks, cimate policy and changes in climate risk assessment. Climate and Energy Economics Discussion Paper. Washington D.C.: Brookings Institution.

Goodess, C. M., Hanson, C., Hulme, M. & Osborn, T. J. 2003. Representing climate and extreme weather events in integrated assessment models: a review of existing methods and options for development. Integrated Assessment, 4, 145-71.

Handmer, J., Honda, Y., Kundzewicz, Z. W., Arnell, N., Benito, G., Hatfield, J., Mohamed, I. F., Peduzzi, P., Wu, S., Sherstyukov, B. & Takahashi, K. 2012. Changes in impacts of climate extremes: human systems and ecosystems. Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC) 2021. Climate Change 2021: The Physical Science Basis. Cambridge, United Kingdom and New York, NY, USA: Intergovernmental Panel on Climate Change.

Kompas, T., Pham, V. H. & Che, T. N. 2018. The Effects of Climate Change on GDP by Country and the Global Economic Gains From Complying With the Paris Climate Accord. Earths Future, 6, 1153-1173.

Liu, W., McKibbin, W. J., Morris, A. C. & Wilcoxen, P. J. 2020. Global economic and environmental outcomes of the Paris Agreement. Energy Economics, 90, 1-17.

McKibbin W. & P., W. 1997. A Better Way to Slow Global Climate Change. Brookings Policy Brief.

McKibbin W.J., Morris, A., Wilcoxen P.J. & Liu, W. 2018. The Role of Border Adjustments in a U.S. Carbon Tax. Climate Change Economics, 9, 1-42.

McKibbin, W. J., Morris, A. & Wilcoxen, P. J. 2014. A Proposal for Integrating price Mechanisms into International Climate Change Negotiations. Asia and the Pacific Policy Studies, 1, 600-608.

McKibbin, W. J., Morris, A., Wilcoxen, P. J. & Cai, Y. 2015. Carbon taxes and US Fiscal Reform. The National Tax Journal, 68, 139-156.

McKibbin, W. J. & Wilcoxen, P. J. 1999. The Theoretical and Empirical Structure of the G-Cubed Model. Economic Modeling, 16, 123-148.

McKibbin, W. J. & Wilcoxen, P. J. 2013. A Global Approach to Energy and the Environment: The G-cubed Model. Handbook of CGE Modeling. North Holland.

Narita, D., Tol, R. S. & Anthoff, D. 2009. Damage costs of climate change through intensification of tropical cyclone activities: an application of FUND. Climate Research, 39, 87-97.

Parry, I., Black, S. & Roaf, J. 2021. Proposal for an International Carbon Price Floor among Large Emitters. IMF Staff Climate Notes. Washington, D.C.: International Monetary Fund.

REFERENCES CONT.

Parson, E. A. & Fisher-Vanden, A. K. 1997. Integrated assessment models of global climate change. Annual Review of Energy and the Environment, 22, 589-628.

Pizer, W. A. 1997. Prices vs. quantities revisited: the case of climate change. Discussion Paper. Washington, D.C.: Resources for the Future.

Pizer, W. A. 1999. The optimal choice of climate change policy in the presence of uncertainty. Resource and Energy Economics, 21, 255-87.

Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O. & Lutz, W. 2017. The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Global Environmental Change, 42, 153-68.

Roson, R. & Sartori, M. 2016. Estimation of climate change damage functions for 140 regions in the GTAP9 database. Policy Research Working Paper. Washington D. C.: World Bank Group.

Schmitt, L. H., Graham, H. M. & White, P. C. 2016. Economic Evaluations of the Health Impacts of Weather-Related Extreme Events: A Scoping Review. Int J Environ Res Public Health, 13.

Stern, N. 2016. Economics: Current climate models are grossly misleading. Nature, 530, 407-09.

Stern, N., Stiglitz, J. & Taylor, C. 2022. The economics of immense risk, urgent action and radical change: towards new approaches to the economics of climate change. Journal of Economic Methodology, 29, 181-216.

Stiglitz, J. E., Stern, N., Duan, M., Edenhofer, O., Giraud, G., Heal, G. M., La Rovere, E. L., Morris, A., Moyer, E., Pangestu, M. & Shukla, P. R. 2017. Report of the high-level commission on carbon prices. Washington D.C.: Carbon Pricing Leadership Coalition.

The Network for Greening the Financial System (NGFS). 2021. NGFS Climate Scenarios for Central Banks and Supervisors [Online]. The Network for Greening the Financial System (NGFS). Available: https://www.ngfs.net/sites/default/files/media/2021/08/27/ngfs_climate_scenarios_phase2_june2021.pdf [Accessed 22 September 2022].

The Network for Greening the Financial System (NGFS) 2022. Running the NGFS scenarios in G-Cubed: A tale of two modelling frameworks. NGFS Occasional Paper Series. Paris, France: The Network for Greening the Financial System.

Tol, R. S. 2012. On the uncertainty about the total economic impact of climate change. Environmental and Resource Economics, 53, 97-116.

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J. F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J. & Rose, S. K. 2011. The representative concentration pathways: an overview. Climatic Change, 109, 5-31.

Wang, P., Deng, X., Zhou, H., and Yu, S. (2019). Estimates of the social cost of carbon: A review based on meta-analysis. Journal of Cleaner Production, 209, 1494-1507.

Weitzman, M. L. 1974. Prices vs. Quantities. Review of Economic Studies, 41.

Weitzman, M. L. 2012. GHG targets as insurance against catastrophic climate damages. Journal of Public Economic Theory, 14, 221-44.

The authors gratefully acknowledge the financial support from the Australian Research Council Centre of Excellence in Population Ageing Research (CEPAR) (CE170100005).

The Brookings Institution is financed through the support of a diverse array of foundations, corporations, governments, individuals, as well as an endowment. A list of donors can be found in our annual reports published online. The findings, interpretations, and conclusions in this report are solely those of its author(s) and are not influenced by any donation.

BROOKINGS

1775 Massachusetts Ave NW,
Washington, DC 20036
(202) 797-6000
www.brookings.edu