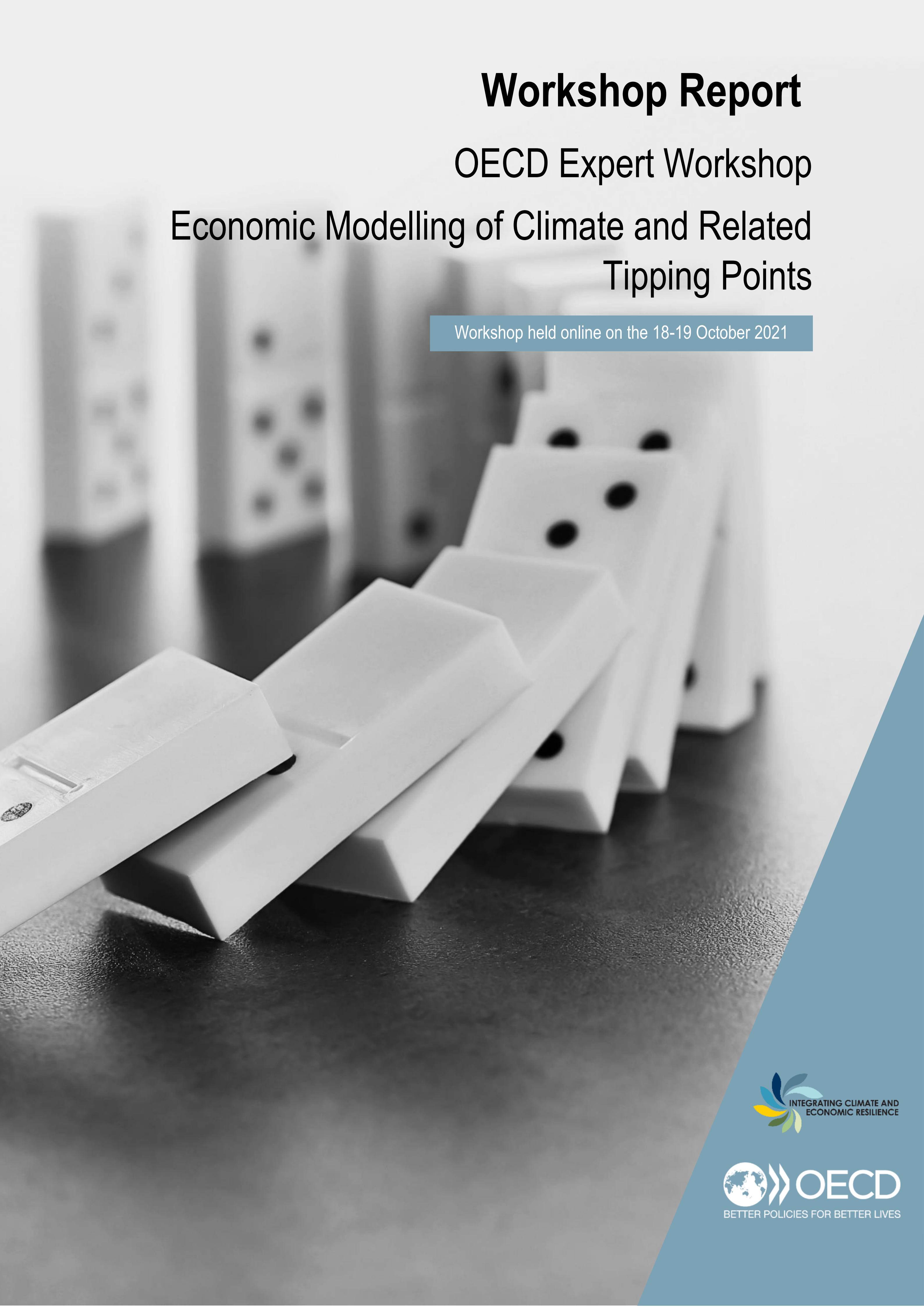
Workshop Report

OECD Expert Workshop

Economic Modelling of Climate and Related Tipping Points

Workshop held online on the 18-19 October 2021



INTEGRATING CLIMATE AND ECONOMIC RESILIENCE

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BETTER POLICIES FOR BETTER LIVES

Foreword

This document presents a factual summary of the discussions held at the workshop on 18-19 October 2021. It was prepared by Hélia Costa, Shardul Agrawala and Elisa Lanzi of the OECD Secretariat. The report benefitted from valuable comments and suggestions from OECD colleagues including Andrew Praeg, Killian Raeser, Stephanie Venuti, and Soim Lee, as well as speakers and panellists who participated to the event.

This report has been prepared under the auspices of the on-going OECD Horizontal Project on Building Climate and Economic Resilience in the Transition to a Low-Carbon Economy.

The views expressed herein do not necessarily reflect the official views of the OECD or of the governments of its member countries.

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Introduction

Emerging evidence highlights the increasing risks of non-linearities and systemic changes caused by climate change. These include large-scale tipping points in the Earth's climate, such as a collapse of the West Antarctic ice sheet, as well as climate change-induced impacts that could cause abrupt changes to the economic system, such as a collapse of global supply chains due to extreme events or the sharp fall in asset prices when actors do not sufficiently anticipate increasingly stringent climate mitigation policies. Models that underpin most economic analyses of climate change rarely include the possibility of abrupt changes to climate or economic systems. Nevertheless, such changes – climate and related tipping points – are a major determinant of the optimal levels of policy effort.

Against this background, the OECD organised an Expert Workshop in October 2021 to discuss the current state of scientific understanding surrounding abrupt changes to climate and economic systems due to climate change and climate-related policies.

This event was part of the on-going OECD Horizontal Project on *Building Climate and Economic Resilience in the Transition to a Low-Carbon Economy*. This project is delivering a whole-of-OECD perspective in supporting policymakers to drive the transformational change needed to tackle climate change, as part of their efforts to improve economic and social resilience in the face of ongoing disruption such as COVID-19. The workshop convened leading experts in the field of environmental-economic modelling and climate science to contribute ideas on what the path for policy and academic research could look like.

The workshop was articulated in four sessions distributed over two days. The first session set the scene by providing an overview of our understanding of tipping points in the earth's biophysical systems and their implications for economic discussions. The following two sessions focused on state-of-the-art economic modelling of climate and related tipping points. Specifically, in the second session recent advances in modelling economic costs of geophysical tipping points were discussed. The third session meanwhile addressed climate-related socio-economic tipping points. Both incremental impacts from climate change and the transition to a low-carbon economy could substantially affect the real economy and the financial system, potentially triggering non-linear socio-economic impacts – a human economic catastrophe – even before climate tipping points are triggered. Finally, a panel discussion provided a reflection on the broader implications for research advancement.

This report provides a summary of the workshop. Information is also available on the OECD website.[1]

Session 1: Climate tipping points and early attempts to incorporate them into policy analysis

Following a welcome by **Rodolfo Lacy**, Director OECD Environment Directorate, **Laurence Boone**, Chief Economist of the OECD opened the first session by stressing the importance of integrating climate tipping points into economic analyses of climate change, in addition to incremental impacts of climate change. Of great importance from her perspective was how to best reflect tipping points in short-, medium-, and long-term economic projections.

In his presentation, **Tim Lenton**, Director of the Global Systems Institute and Chair in Climate Change and Earth System Science at the University of Exeter, explained the physical science basis of tipping points, and argued that they might arrive earlier than previously thought (Lenton et al., 2019[1]). He specified that the earth system comprises a number of tipping elements that can undergo irreversible changes once a certain critical threshold in climate forcing – a tipping point – is exceeded (Lenton et al., 2008[2]), and presented a stylized representation of these tipping elements (Figure 1). The physical impacts of passing tipping points can be felt on the temperature, sea level, precipitation, atmospheric and ocean circulation, and biogeochemical cycles. Causal interactions, or coupling, between tipping

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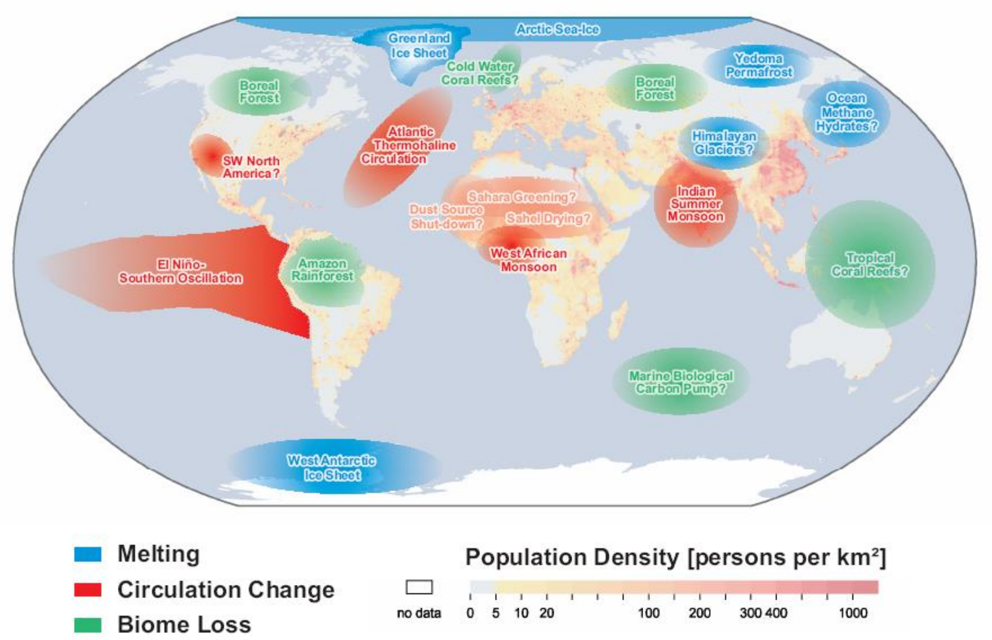
[1] http://oe.cd/ClimateTipping

elements are also possible, with the crossing of a tipping point by an element accelerating the probability of crossing another element's tipping point.

Figure 1. Overview of tipping points in the climate system



Note: The colour code indicates the system in which they could occur. Question marks indicate systems whose status as tipping elements is particularly uncertain.
Source: (Lenton et al., 2008[2]) and (Lenton, 2012[3]) as presented at the workshop.

Drawing on ongoing research, Tim Lenton stressed that there are several tipping points that could be crossed with significant probability in the near-term (the 2030's) should global economic growth continue on its current trajectory. On the other hand, limiting warming to within the temperature targets under the Paris Agreement, while still entailing some risk of crossing the near-term tipping points, would avoid several other tipping points that would be crossed under the current policy trajectory in the medium-term (the 2040s and 2050s). This adds to the urgency to consider tipping points in economic analyses.

Elizabeth Kopits, Senior Economist at the National Center for Economic Analysis at the US Environmental Protection Agency, provided an overview of earlier attempts of incorporating tipping points into economic policy discussions. In their 2013 review, she and her co-authors found that this literature was not yet able to inform policy in a substantive way (Kopits, Marten and Wolverton, 2013[4]). This is largely because past modelling efforts that included large-scale singular events in Integrated Assessment Models (IAMs) used ad-hoc parameters without empirical bases and typically without considering the multi-decade time horizons at which such large-scale events may unfold.

Her presentation stressed the importance of better defining *tipping points* and *catastrophic events*, and of accurately incorporating the work of physical science into economic models. In this sense, it is necessary to better capture the dynamics of earth systems and their associated uncertainties as well as to improve the mapping of dynamic changes into welfare effects. This includes covering all potential earth system changes – instead of a single one in isolation – as the probabilities of tipping points in system dynamics are positively correlated with each other.

The discussion that followed focused on the importance of climate tipping points for policy making, not only in the long-term, but also in the medium- and short-term. Tim Lenton again stressed that the processes leading to the crossing of tipping points are expected to be triggered much earlier than previously expected. While definite studies are lacking, both speakers agreed that, because of the difficulty of connecting the physical science modelling of climate tipping points with economic models, most existing estimates of the costs of reaching tipping points are conservative estimations.

Session 2: Recent attempts to model the economic impacts of climate tipping points

Shardul Agrawala, Head of the Environment and Economy Integration Division at the OECD Environment Directorate, opened the session with the observation that in order to effectively provide cost-benefit analysis and determine optimal mitigation and adaptation policies, it is key to understand how, when, and where economic damages will occur in response to biophysical climatic changes, particularly tipping points. Historically, studies that have accounted for tipping points have failed to accurately capture the timescales, dynamics, and uncertainties associated with the biophysical aspects of tipping points, to consider coupling between tipping points, and to model welfare losses in a non ad-hoc way. The ensuing session discussed recent contributions that have managed to overcome some of these issues.

Modelling geophysical foundations and meta-analyses

Simon Dietz, Professor in the Department of Geography and Environment at the London School of Economics and Political Science, presented recent work that provides estimations for the impacts of different tipping points on the social cost of carbon (Dietz et al., 2021[5]). This was motivated by the observation that the majority of work modelling the economic consequences of a specific tipping point model these in a highly stylized way, with ad-hoc assumptions on impacts, and thus cannot derive inference on the relative importance of these impacts. In contrast, a subsection of these studies builds on geophysical foundations to model climate tipping points by including at least a reduced-form representation of the key underlying geophysical relationships. These studies each focus on a specific tipping point using a particular IAM (such as DICE, FUND, or PAGE).

One example is the approach of Nordhaus (2019[6]). This study considers additional biophysical information on tipping points, by combining a long-run economic growth model (DICE) with a climate model and a Greenland ice sheet (GIS) model, to estimate the economic impact of the potential disintegration of the Greenland ice sheet, under a range of assumptions. Within the framework of this augmented DICE model, the different simulations show that the risk of GIS disintegration makes a small contribution to the optimal stringency of climate policy, increasing the Social Cost of Carbon (SCC) by less than 5%.

Against this background, Simon Dietz and co-authors propose a framework to produce unified estimations for the impact of different tipping points. They developed a meta-analytic IAM that includes eight climate tipping points under a unified framework. They find that, taken collectively, tipping points increase the SCC by around 25% and, importantly, that they increase global economic risk. While their analysis is incomplete – it excludes some tipping points and tipping point interactions – according to the authors their estimations can be used as a lowerbound.

Uncertainty and interacting tipping points

Yongyang Cai, Associate Professor at the Department of Agricultural, Environmental and Development Economics of the Ohio State University, focused in his presentation on the implications of uncertainty in studying the economic consequences of multiple interacting tipping points. Uncertainty is particularly important to the study of tipping points, as there is uncertainty as to what the threshold for tipping points is in terms of global and regional temperatures, the timeframe in which it can be reached, the damage levels, and the duration of processes where damages are gradual. He presented work aiming to answer what the policy response to rising emissions should be, given prevailing uncertainty.

Yongyang Cai introduced the Dynamic Stochastic Integration of Climate and Economy (DSICE) framework, a stochastic extension of the Nordhaus DICE model. The DSICE model includes uncertainty, and tipping points are modelled in the damage function. The tipping event is assumed to follow a Markov process with hazard rates inferred from expert opinion. In their first application of this framework, Yongyang Cai and co-authors study the impact of including tipping points when modelling an optimal carbon tax (Lontzek et al., 2015[7]). With conservative assumptions about the rate and impacts of a stochastic tipping event, the optimal carbon tax is increased by around 50%. Mitigation thus has two effects, decreasing both the probability of damages and their volatility. In further work Yongyang Cai and co-authors introduce environmental tipping points in the same stochastic dynamic integrated assessment model to study the cost−benefit of carbon taxes (Cai et al., 2015[8]). Here they also find that the risk of tipping points substantially increases the optimal carbon tax. The results indicate the importance of considering tipping point risk in cost-benefit analyses for the design of environmental policy.

In additional work presented, Yongyang Cai and co-authors study the impact of interacting tipping points – where the occurrence of a tipping point increases the probability of the occurrence of another tipping point. Consideration of such a domino effect was shown to significantly increase the SCC (Cai, Lenton and Lontzek, 2016[9]). Finally, in a further study that builds on their previous work, Cai and co-authors develop a complex model that includes uncertainty on economic and climate risks (Cai and Lontzek, 2019[10]). They find that including such uncertainties has a large effect on the social cost of carbon. Importantly, their results imply that, contrary to what is used in deterministic IAMs, there is no uniform discount rate, and that the discount rate for future damages from tipping events should be lower than that from temperature increases.

Christian Traeger, Professor at the Department of Economics of the University of Oslo, presented work on the importance of explicitly modelling tipping points in order to translate natural phenomena into damages, look at interactions, and capture irreversibility. In early work, Lemoine and Traeger (2014[11]) use a recursive stochastic implementation of DICE, based on Kelly and Kolstad (1999[12]), but including tipping points in the actual climate system with unknown thresholds and Bayesian learning. Here, tipping points are assumed to increase climate sensitivity and decrease carbon sinks, thereby increasing the discount rate, so they lead to only a moderate increase in the SCC.

In further work, they introduce three interacting tipping points in their DICE-based stochastic model: one affecting CO_2 accumulation in the atmosphere, one affecting the warming feedback, and another affecting directly the sensitivity of economic damages, which is included directly in the damage function (Lemoine and Traeger, 2016[13]). They find that introducing multiple tipping points and a domino effect significantly increases the costs of delayed action. The interaction has particularly large effects when interacted with the tipping point in the damage function. For example, when used as a proxy for sea level rise, this interaction causes the damage function to report cubic, as opposed to quadratic, damages. Christian Traeger argued that the damage tipping model used could be improved to be more consistent with scientific consensus, with damages happening more slowly.

He concluded that while tipping points are relevant, their damages are similar to smooth damages when the threshold is unknown. The main differences relative to smooth damages have to do with irreversibility, interactions between tipping points, and the possibility of very abrupt economic consequences or behavioural market responses. However, how much each of these differences matters remains unknown. Thus, further work is required in order to better understand the extent to which tipping points differ from smooth damages.

Open issues for economic impacts of geophysical and economic catastrophes caused by climate change

The last speaker in the session, **William Nordhaus**, Sterling Professor of Economics, School of the Environment, Yale University, discussed key open issues in the research on catastrophes related to climate change. Focusing on geophysical tipping elements, an important gap relates to the need to improve tipping metrics. The commonly used method is to have a temperature threshold that, once crossed, triggers catastrophic costs. Nordhaus stressed that geophysical changes are much more complex than this, with considerable changes occurring at lower temperatures even before the tipping element is triggered. Considering ice sheets, for example, metrics like degree-years (integrating the exceedance of a temperature target over time) have been shown to be better in determining tipping behaviour. Echoing previous discussions, William Nordhaus also stressed the need to improve coupling of economic and geophysical models, particularly by introducing better and more complex geophysical modelling. This coupling may be more easily achieved using simulation-based models, but understanding how to achieve it in an optimization model is necessary.

Discussing economic catastrophes caused by climate change, William Nordhaus stressed the need to consider the relationship between temperature and economic growth, in particular whether a change in temperature causes a one-off decrease in output (in which case level-level specification should be used) or whether it leads to a decrease in the growth rate (calling for a level-growth specification). These two scenarios have immensely different implications for the link between temperature and economic costs, and particularly on how to use this link to project costs of future climate change.

Nordhaus questioned the level-growth specification used in some recent empirical studies examining the impact of climate change on economic growth. Using a simple simulation exercise based on the results of Dell, Jones and Olken (2012[14]), Nordhaus showed that the level-growth effect implies a human economic catastrophe, even in the absence of climate tipping points or jumps in temperature, which was not plausible. Nordhaus identifies an import limitation in these studies in that they do not provide a plausible and empirically estimated mechanism through which a change in temperature would affect total factor productivity.

Another significant issue raised by Nordhaus is that most existing studies are global and use countries of different sizes and characteristics as data points, thereby masking potentially large heterogeneity within countries. A corollary from this discussion is the need for higher resolution economic data, which can be better integrated with disaggregated geophysical data.

The discussion that followed stressed the importance of the choice between level-level or level-growth specifications. This underscores the need to better understand the micro-economic foundations of the relationship between temperature and economic growth. Also discussed was the need to improve the coupling of geophysical and economic models, in particular in the presence of spatial and temporal differences between the models.

Finally, the discussion highlighted the importance of considering adaptation – both autonomous and reactive – and innovation. While some empirical studies already include adaptation at the current technological level, it is considerably more difficult to estimate adaptation at different levels of technological progress. Here, it is important to distinguish between private adaptation, with less potential for spillovers, such as buying an air conditioning unit, and network-based adaptation or adaptation that involves political processes or conflict. An example of this is coastal protection in the form of dikes, which affects different agents and requires redistributive public decision-making.

Session 3: Modelling non-linearities in the economic impacts of climate change

David Turner, Head of the Macroeconomic Analysis Division at the OECD Economics Department, introduced the third session by stressing the need to connect the session's presentations with the previous discussions, in particular with respect to points of agreement and complementarities, as well as contradictions and points of conflict.

Economic impacts of incremental climate change: estimating risk

Michael Kiley, Deputy Director at the Federal Reserve Board in Washington DC, presented recent work on climate change and financial stability (Kiley, 2021[15]). Climate change causes increases in temperature, shifts in precipitation, increases in sea-level rise, and increases the intensity and frequency of extreme weather events, which can depress economic activity. Most of the empirical literature studying these impacts has focused on average expected effects (Dell, Jones and Olken, 2014[16]; Newell, Prest and Sexton, 2021[17]; Burke, Hsiang and Miguel, 2015[18]; Kalkuhl and Wenz, 2020[19]). Yet these changes are also likely to alter risks to economic activity, particularly increasing downside risk – where climate change makes severe contractions in economic activity more likely.

In his paper, Michael Kiley examines the risk associated with climate change in a large panel of countries. He uses quantile regressions linking growth and weather to study the entire distribution of costs, instead of the average. The results indicate that the effects of temperature on downside risks to economic growth can be much larger than on the central tendency of economic growth, particularly in low income countries and countries with hot climates, stressing the need for additional research on the impacts of climate change on economic and financial stability.

During the discussion, Michael Kiley pointed out that an issue with using econometric estimations of impacts of temperature on GDP to extrapolate impacts of climate change into the future is that the permanent component of GDP is very difficult to identify econometrically. Another issue raised by Michael Kiley is whether year-to-year weather fluctuations (temperature or precipitation) should be used as a proxy for climate change. While persistent changes may allow for adaptation, year-to-year fluctuations are much more difficult to adapt to, possibly leading to very different estimated impacts.

Economic impacts of the environmental transition

Jean Pisani-Ferry, Tommaso Padoa Schioppa chair at the European University Institute and non-resident Senior Fellow at the Peterson Institute for International Economics, discussed the interdependence between macroeconomic and climate policy, based on a recent policy note (Pisani-Ferry, 2021[20]). The overall macroeconomic effect of the green transition will vary with the speed and timing of the transition. If policy action is delayed or insufficient, the necessary change would be too abrupt, with implications for systemic risk. For example, a sudden reduction of energy supply and increased energy costs could impair macroeconomic activity. Moreover, a rapid repricing of asset prices poses financial stability concerns.

Given the current path of emissions, avoiding catastrophic events of the type discussed in the workshop requires a very sharp change in the pace of decarbonisation. This transition will necessarily have macroeconomic implications that go beyond the impacts on GDP and standards of living addressed in most the IAM literature, such as those on growth, investment, inflation, and fiscal deficits.

Particularly relevant aspects of the impacts of a sharp transition are a possible adverse supply shock, due to carbon being taxed at a high rate, distributional effects, due to the uneven exposure of households to adverse effects of policies, a reduction of consumption resulting from the necessary increase in investment (to replace obsolete capital), and the implications of the transition for public finances. The latter might occur because climate policy is likely to use regulatory means other than pricing and require subsidies and public investment, making the double dividend of carbon pricing less likely. The negative supply shocks and decrease in consumption associated with ambitious climate policies are likely to have significant macroeconomic consequences. Broadly, there is likely to be significant instability along the transition, with particular implications for monetary policy.

Impacts of climate change and climate policy: lessons for research relevant for monetary policy

In her talk, **Sandra Batten**, Senior Research Economist at the Bank of England, offered a framework to think about climate-related economic tipping points, both arising from climate risks and transition risks, with a focus on the UK from the perspective of monetary policy. Monetary policy requires an assessment of current macroeconomic conditions and any climate-related impacts on the economy in the short and medium term. Resulting imbalances could lead to macro-financial tipping points, with particular relevance for monetary policy.

Referring back to the discussion of the previous session, Sandra Batten stressed that global studies using country-level data can mask important heterogeneity, and that within country studies were still lacking. In this direction, Colacito, Hoffmann and Phan (2018[21]) study the impact of quarterly temperature changes for a panel of US states on value added for different industries, as well as the mechanisms behind this. In her new work, Batten (forthcoming[22]) studies the impact of temperature and precipitation on Gross Value Added (GVA) growth across 179 UK regions. In both studies, the use of quarterly temperature and precipitation data, rather than aggregate annual variations, results in higher economic impacts, pointing to the importance of using disaggregated weather data. The results also vary widely across industries, with aggregate effects masking these differences.

A key conclusion from this analysis is that heterogeneity is crucial to understanding economic tipping points, as these may be found on smaller scales and affect some sectors particularly (an example of this would be the collapse of some agriculture systems driven by radical changes in weather patterns). This points to the importance of collecting higher resolution economic data, which would allow to better integrate disaggregated geophysical data.

Considering policy-makers' evaluation of the impacts of the green transition, Sandra Batten highlighted that central banks can use both top-down and bottom up approaches to assess the impacts of climate policy on the economy. For a top-down assessment, a tool that is often used by central banks for climate stress testing of the financial system is scenario analysis. A bottom-up approach could focus on those sectors whose reductions are necessary to achieve carbon neutrality. One issue with this approach is that these sectors include both household and business activities, thus affecting both components of demand and supply. For issues like supply bottlenecks generated by ambitious policy targets, an analysis disaggregated by sector can be useful.

Impacts of climate change on the risks of financial crises

Finally, **Francesco Lamperti**, Assistant Professor at the Institute of Economics of the Scuola Superiore Sant'Anna, presented recent work that adopts an Agent Based Model (ABM) with climate feedback loops to estimate the impacts of climate change on the probability of financial crises (Lamperti et al., 2019[23]) (Lamperti et al., 2020[24]). ABMs are simulation models that study the evolution of complex systems, featuring a large number of heterogeneous agents that interact not only through markets but also through their behavioural choices.

Francesco Lamperti and co-authors develop a macro-financial ABM of endogenous growth and fluctuations endowed with a climate module and micro-level damage functions. They emphasise the link between the physical risks of climate change (such as extreme weather events and gradual changes in climate) and non-preforming loans due to lower growth and productivity affecting financial conditions. Additionally, they focus on the negative economic feedback from tighter financial conditions. The model is used to study the properties of the financial system under alternative scenarios. The behaviour of agents is modelled in a direct way, where agents do not optimize but instead learn which strategy leads to the largest payoff through trial and error.

The authors find that climate change increases the frequency and size of banking crises. They estimate an abrupt change to the economy and financial markets in the second half of the century (2050-2100) with low growth and high financial instability. This puts pressure on public debt if bank insolvencies are solved through publicly financed bailouts. Their results call for macroprudential regulation targeting climate risks to alleviate these impacts.

The discussion that followed touched upon the importance of estimating the financial risks of climate change and the disorderly transition and their impact on the real economy. Going beyond the emphasis on financial stability, it is relevant to focus on the challenges of the economy and to better understand the interactions between fluctuations in the economy and impacts on the financial sector.

Session 4: Taking stock and the road ahead

The last session was chaired by **Elisa Lanzi**, Senior Economist at the Environment and Economy Integration Division at the OECD Environment Directorate, who led a discussion about the priorities ahead for the modelling community. The discussion convened five experts: **Karen Fisher-Vanden**, Professor of Environmental and Resource Economics and Public Policy at the Pennsylvania State University, **Simon Dietz**, Professor at the Department of Geography and Environment of the London School of Economics and Political Science, **Francesco Lamperti**, Assistant Professor at the Scuola Superiore Sant'Anna, **Rob Dellink**, Senior Economist, Environment and Economy Integration Division of the OECD Environment Directorate, and **Valerio Nispi Landi**, Economist at the International

Relations and Economics Directorate of the Bank of Italy. Some conclusions arising from this discussion as well as directions for future work emerging from the rest of the workshop are distilled in the section below.

Directions for future work

The Workshop's discussions stressed the progress made in past decades in incorporating the impacts of climate tipping points in economic analyses. The work discussed highlighted the importance of considering economic and geophysical uncertainties, of including the possibility of interacting tipping points, and of providing a unified framework in which to include tipping points of varying sources.

In thinking about the economic implications of climate tipping points and priorities for research, a key concern is the need to improve the link between economic and geophysical modelling. Main recommendations emerging from the discussions include:

- Economic models of climate tipping points should account not only for changes in global mean temperature but also for other physical climate or weather elements (e.g. water cycle, radical changes in the seasonality of extreme events, etc.);
- There is a need for improved tipping metrics, for example considering degree-years or some interval of temperatures;
- In order to improve coupling of economic and geophysical models, researchers should start with a recursive/simulation model, and only then move to optimization models. There seems to be merit in performing simulation-based, not optimization models, to try and get a better sense of expected damages.

Spurred by the recent attention paid to environmental protection, research into non-linear macroeconomic or financial impacts of climate change and the related low-carbon transition has developed quickly. A number of the papers presented use new methods, such as the growth at risk approach, geographically disaggregated analyses, or ABMs, to provide not only estimates of climate and policy change damages, but also a full description of the associated macroeconomic and financial risks.

When considering the evaluation of the economic and financial impacts of climate change and the low-carbon transition, a few priorities for the future emerged:

- In the same way we look at interacting geophysical tipping points, we should look at interactions in economic tipping points, such as interactions between sectors. Here, it is necessary to capture explicit interactions across overlapping and interacting networks. For example, an increase in temperature that causes a jump in electricity demand due to more air conditioning use will have impacts on the manufacturing industry and implications for the supply of low-carbon electricity. It is vital to consider these interactions when understanding non-linear economic impacts.
- On the policy side, a number of participants suggested the importance of the impacts of climate change on financial stability, and the need to continue to design policies and buffers to mitigate the impacts of climate change (both physical risks and disorderly transition risks) on the financial sector. As next steps, it will be important to bring macroeconomic and financial risks together. In this sense, the discussion focused on the need for models that are able to capture short-term dynamics, such as ABMs or DSGE models.
- Given the complementarity between modelling tools, there is need for multi-model comparison exercises to understand which of the insights gained are model-driven and which are robust across approaches.
- In terms of adaptation efforts, it is important to understand how to best include them in econometric analyses and modelling. In particular, it would be relevant to think about the linkages between adaptation and mitigation and to understand the possibility of reaching adaptation tipping points, namely the point at which change is such that adaptative action is

no longer able to meet its objective.

- Finally, there is a need to understand the micro-foundation of the relationship between climate elements and macroeconomic and financial impact. In this sense, it is important to develop microeconometric analyses, for example at the industry or firm level, that could be incorporated into macroeconomic models. Analyses at the subnational level and disaggregated by industry would be a step in the right direction.

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Annex I: Workshop agenda

DAY 1

14:00 – 14:05 *Opening remarks*, **Rodolfo Lacy,** Director of the Environment Directorate, OECD

14:05 – 15:00 **1. CLIMATE TIPPING POINTS: THE STATE OF KNOWLEDGE**

This session aims to provide an overview of the physical science that underpins climate tipping points and of their possible consequences on the economic system.

Chair: Laurence Boone, Chief Economist, OECD

Presentations:

- *The state of scientific knowledge on climate tipping points*, **Timothy M. Lenton**, Director of the Global Systems Institute and Chair in Climate Change and Earth System Science, University of Exeter
- *Incorporating tipping points into policy analysis*, **Elizabeth Kopits,** Senior Economist, National Center for Economic Analysis, US Environmental Protection Agency

15:00 – 16:45 **2. MODELLING THE ECONOMIC CONSEQUENCES OF TIPPING POINTS IN THE CLIMATE SYSTEM**

There is a long history of research at the interface of climate and economic systems. However, models so far have only had limited integration of the effects of climate tipping points on the economy. This session aims to look at the current state-of-the-art modelling of the economic consequences of climate tipping points to gain a better understanding of future risks, their scale and magnitude.

Chair: Shardul Agrawala, Head of Environment and Economy Integration Division, Environment Directorate, OECD

Presentations:

- *Economic impacts of tipping points in the climate system using a meta analytic integrated assessment model*, **Simon Dietz**, Professor, Department of Geography and Environment, London School of Economics and Political Science
- *Economic implications of multiple interacting tipping points*, **Yongyang Cai**, Associate Professor, Department of Agricultural, Environmental and Development Economics, Ohio State University
- *Implications of tipping points for optimal climate policy,* **Christian Traeger,** Professor, Department of Economics, University of Oslo
- *Approaches to modelling the economic consequences of climate change tipping points,* **William Nordhaus,** Sterling Professor of Economics, School of the Environment, Yale University

Q&A

DAY 2

14:00 – 15:45

3. MODELLING THE IMPACTS OF CLIMATE-RELATED TIPPING POINTS ON THE MACRO-ECONOMY

Looking beyond the physical science basis and global economic impacts of climate-related tipping points, this session has as its objective to investigate the ways in which both large-scale shifts and incremental changes in the climate system can affect macroeconomic and financial stability. In addition, the effect of unanticipated changes in climate policies on the economy will also be further investigated.

Chair: Dave Turner, Head, Macroeconomic Analysis Division, Economics Department, OECD

Presentations:

- *Climate impacts, economic growth and financial instability*, **Michael Kiley,** Deputy Director, Federal Reserve Board, Washington DC
- *Impacts of climate policies on the macro-economy*, **Jean Pisani-Ferry,** Tommaso Padoa Schioppa chair at the European University Institute, Senior Fellow at Bruegel and Non-Resident Senior Fellow at the Peterson Institute for International Economics
- *Monetary policy implications of climate change*, **Sandra Batten,** Senior Research Economist, Bank of England
- *Climate change, public debt and financial crises: an agent-based modelling analysis*, **Francesco Lamperti**, Assistant Professor, Institute of Economics, Scuola Superiore Sant'Anna and Scientist at the RFF-CMCC European Institute on Economics and the Environment

Q&A

15:45 – 16:40

4. IRREVERSIBLE CHANGE: TAKING STOCK AND THE WAY AHEAD

An expert panel discussion provides an opportunity for leading researchers to reflect on the broader implications of climate change and climate-related tipping points on the economy, as well as the state-of-the-art integration of such incremental and abrupt changes in economic models.

Chair: Elisa Lanzi, Senior Economist, Environment and Economy Integration Division, Environment Directorate, OECD

Panel discussion:

- **Karen Fisher-Vanden**, Professor of Environmental and Resource Economics and Public Policy, and Director of the Institute for Sustainable Agricultural, Food, and Environmental Science (SAFES), Pennsylvania State University
- **Simon Dietz**, Professor, Department of Geography and Environment, London School of Economics and Political Science
- **Francesco Lamperti**, Assistant Professor, Institute of Economics, Scuola Superiore Sant'Anna and Scientist, the RFF-CMCC European Inst. on Economics and Environment
- **Rob Dellink,** Senior Economist, Environment and Economy Integration Division, Environment Directorate, OECD
- **Valerio Nispi Landi,** Economist, International Relations and Economics Directorate, Bank of Italy

16:40 – 16:45

Closing remarks