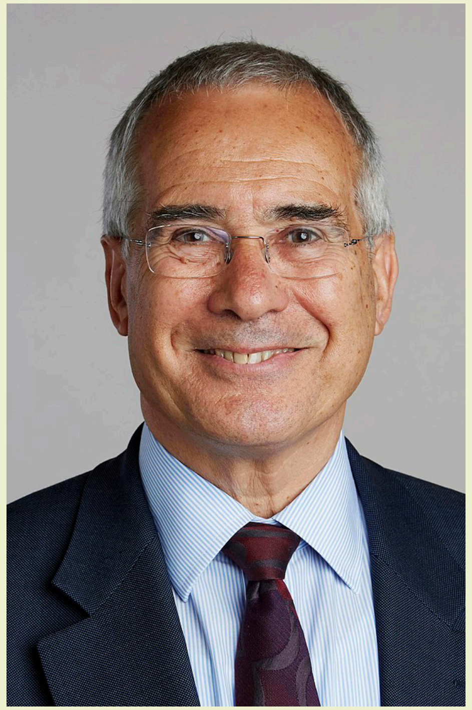
New Approaches to the Economics of Climate Change:

Urgency, Scale, Opportunity

Tuesday, October 11, 2022



Professor Lord
Nicholas
STERN

IG Patel Chair of Economics and Government, London School of Economics; Chair, Grantham Research Institute on Climate Change and the Environment

OPEN TO THE PUBLIC

andlinger center
for energy+the environment

High Meadows
Environmental
Institute

C-PREE | Center for Policy Research on Energy and the Environment

The Griswold Center for Economic Policy Studies

New Approaches to the Economics of Climate Change: Urgency, Scale, and Opportunity

Nicholas Stern
IG Patel Professor of Economics & Government, London School of Economics and Political Science
Chair of the ESRC Centre for Climate Change Economics and Policy
Chair of the Grantham Research Institute on Climate Change and the Environment
Co-Chair of the Global Commission on the Economy and Climate (New Climate Economy)
(Prepared with Rob Macquarie)

Griswold Center for Economic Policy Studies, Princeton University
October 2022

These slides are intended to have sufficiently detailed argument to be read independently of the lecture.

THE NEW CLIMATE ECONOMY
The Global Commission on the Economy and Climate
Grantham Research Institute on Climate Change and the Environment
Centre for Climate Change Economics and Policy
E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL
The Grantham Foundation for the Protection of the Environment
UNIVERSITY OF LEEDS
LSE The London School of Economics and Political Science

Structure

- **Section I: Economics missing and/or misdirected**
- Section II: Analytical approaches appropriate (or inappropriate) to scale and nature of challenge
- Section III: Imperfections, policies, values
- Section IV: Further research

Climate has been largely missing from mainstream economics journals

Economics Research

Journal name	*Number of articles ever published on climate change*
Quarterly Journal of Economics	0
Economic Journal	9
Review of Economic Studies	3
Econometrica	2
American Economic Review	19
Journal of the European Economic Association	8
Economica	4
Journal of Political Economy	9
American Economic Journal – Applied	3

Source: Oswald and Stern, September 2019

The leading economics journals have largely ignored an urgent and fundamental economic issue, arguably the most important of our time.

Economics must get more serious in five key areas for understanding and policy on climate change

i. ***Urgency and scale***. ***Time*** is critical; delay is dangerous. Need a "public economics as if time matters" (see Stern, 2018).

ii. ***Fundamental uncertainty*** and ***extreme risk***, including possible large-scale, indeed, for many, existential consequences.

iii. ***Systemic and structural change and dynamics***, often exhibiting increasing returns to scale in production, discovery and networks (potentially also in endogenously determined, beliefs and preferences, see e.g. Besley & Persson, 2020).

iv. ***Scale and number of market failures*** (beyond that of the GHG externality); and crucial markets are ***absent***. Tackling these market failures essential to public policy, although abilities to do so have limitations.

v. ***Values*** and ***discounting*** that shape policy decisions require explicit analysis and discussion. Crucial issues within and across generations.

Arguments and analytics are set out in Stern & Stiglitz, 2022, and Stern, 2022.

Rapid change requires some shared understanding and coordination of action, driven by analytics, principles, evidence and leadership.

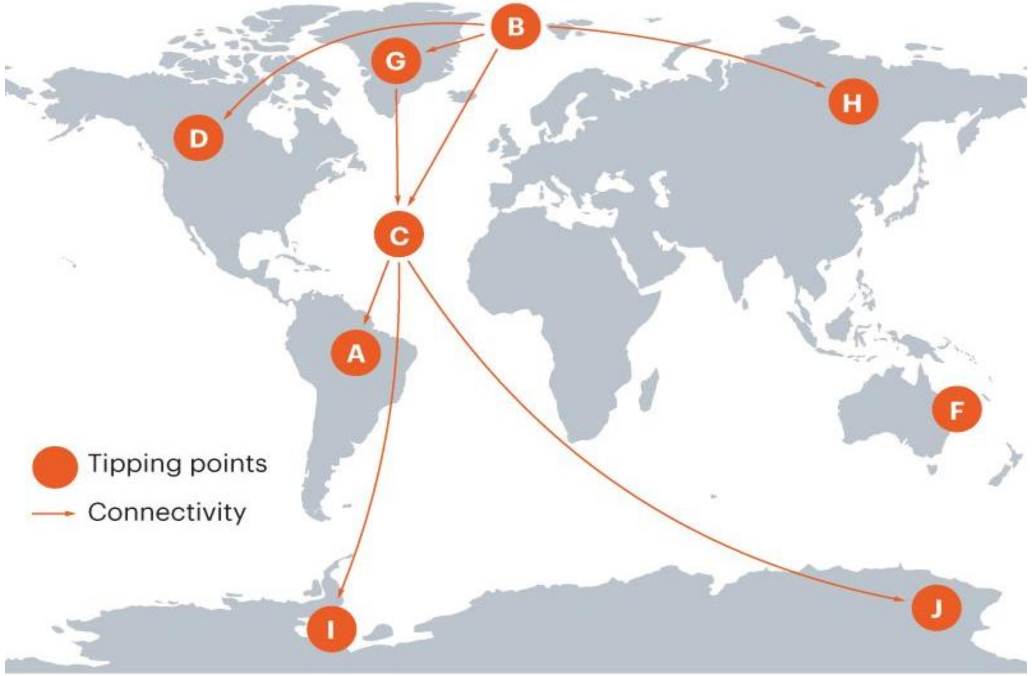
Economics has not only been slow to respond, it has also, in large measure, failed to grapple effectively with many of the core issues.

Structure

- Section I: Economics missing and/or misdirected
- **Section II: Analytical approaches appropriate (or inappropriate) to scale and nature of challenge**
- Section III: Imperfections, policies, values
- Section IV: Further research

Most economic modelling fails to capture nature and scale of risks

- Current economic analyses of climate change fail to incorporate many of the largest risks, including the effects from ***crossing climate thresholds*** or ***'tipping points'.***
- The impacts would significantly affect and disrupt the ***lives and livelihoods*** of hundreds of millions, probably billions, of people worldwide. How many people could a world of 4°C or 5°C support and how many would be killed along the way?
- These impacts would also undermine economic growth and development, ***exacerbate poverty, destabilise communities, and lead to mass migration and conflicts***.
- These risks - existential for many - are different from the kind that we use ***expected utility theory*** to deal with.



A. Amazon rainforest
Frequent droughts

B. Arctic sea ice
Reduction in area

C. Atlantic circulation
In slowdown since 1950s

D. Boreal forest
Fires and pests changing

F. Coral reefs
Large-scale die-offs

G. Greenland ice sheet
Ice loss accelerating

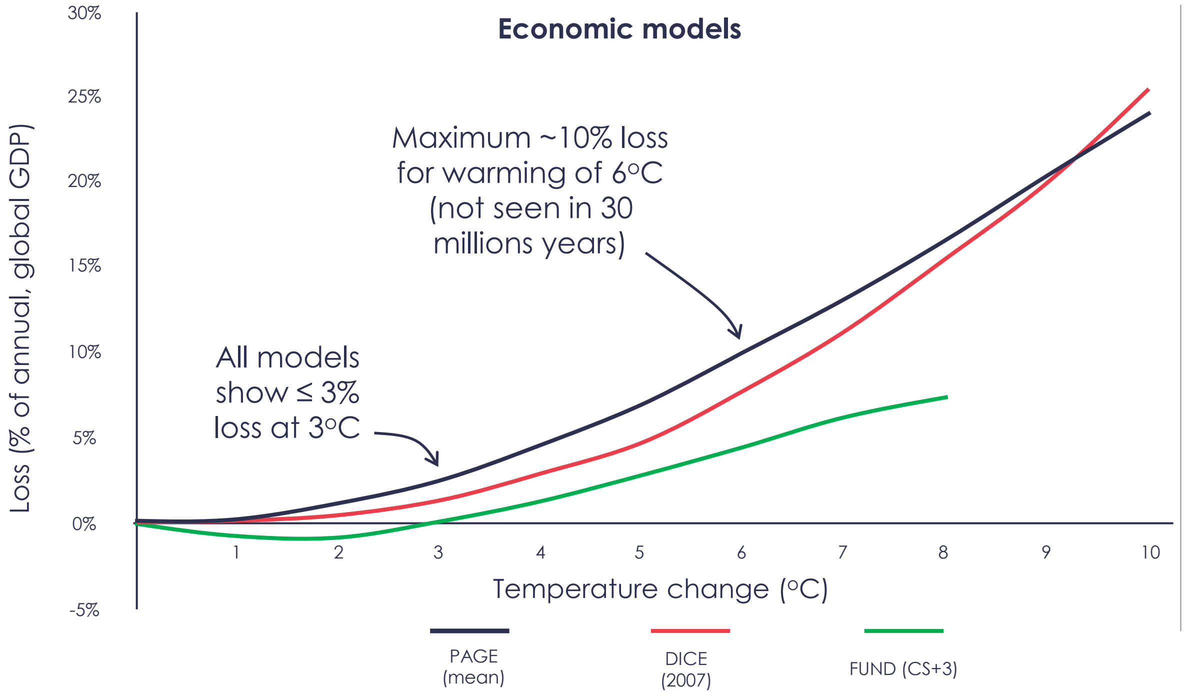
H. Permafrost
Thawing

I. West Antarctic ice sheet
Ice loss accelerating

J. Wilkes Basin,
East Antarctica
Ice loss accelerating

©nature Source: Lenton et al., 2019

Economic approach to risks is way behind the science



Source: Recreated from the Interagency Working Group on Social Cost of Carbon, United States Government (2010)

Potential impacts and risks (e.g. submergence of large areas, desertification of others, migration, conflict…) are at a scale not seen before and not consistent with long-run, continuous growth or current economic structures. They are rarely included in current impact assessment models.

The impacts of failure could be devastating; difference between 1.5°C and 2°C potentially very strong

	1.5°C	2°C	2°C vs 1.5°C
Extreme Heat[1] (Proportion of global pop. exposed to severe heat at least once every 5 years)	14%	37%	2.6x worse
Number of sea-ice-free Arctic summers[2]	At least 1 after ~100 years of stabilised warming	At least 1 after ~10 years of stabilised warming	10x worse
Bioclimatic range loss of >50%[3]	Vertebrate species: 4% Plant species: 8% Insect species: 6%	Vertebrate species: 8% Plant species: 16% Insect species: 18%	Vertebrate species: 2x worse Plant species: 2x worse Insect species: 3x worse

Differences between 1.5°C and 2°C are major. Differences from 2°C to 2.5°C, and then to 3°C likely still bigger. Current paths likely to lead to 3°C or more, with real risks of still higher temperatures.

Immense risks to lives and livelihoods across the world. Hundreds of millions, or billions, likely to have to move, with possibility of widespread, severe and extended conflict.

Grantham Research Institute on Climate Change and the Environment

Centre for Climate Change Economics and Policy

1 Dosio et al. (2018)
2 IPCC (2018)
3 Warren et al. (2018)

Scale of change must be fundamental, rapid and systemic

- Net zero by 2050 for 1.5°C, plus strong path en route (note that net zero can stabilise concentrations of GHGs and thus temperatures; the earlier net zero is achieved, the lower the stabilised temperature).

- Transformation of systems of cities, land, energy, transport.

- Way beyond tweaks, parameter shifts or minor adjustments.

- Dislocation and disequilibria associated with change must be managed.

Analysis of investment needs show the scale of change required

- Global investment needs to be ***increased and sustained*** above pre-pandemic levels by around ***2 - 3% of GDP p.a.*** over this decade and beyond for the augmentation and transformation of physical and natural capital. More in some countries, less in others. And change in composition of investment. See Stern, 2021.
- EMDEs will account for the **vast preponderance of new physical capital** in the coming three decades, and drive a global doubling of infrastructure in the next 15-20 years. Human and natural capital also central.
- The majority of investment will be in the **private sector**, but **public investment** will have to play a key role in the early period, particularly for sustainable infrastructure and natural capital.

Investment requirements for EMDEs (excluding China) in four key areas:	Gross spending 2019		Spending target 2025		Spending target 2030	
	US$ bn	% GDP	US$ bn	% GDP	US$ bn	% GDP
Human capital	1,470	7.0	2,000	8.2	3065	9.5
Sustainable infrastructure	730	3.5	1,160	4.8	1,840	5.7
AFOLU (agriculture, food, land use, nature)	150	0.7	355	1.4	650	2.0
Adaptation and resilience	35	0.2	180	0.7	325	1.0
Total	**2,385**	**11.3**	**3,695**	**15.1**	**5,880**	**18.2**

Source: Bhattacharya et al. (2022)

Sustainable, resilient growth: six mutually reinforcing drivers

1. ***Resource efficiency*.** Huge potential cost savings and quality improvements.
2. ***Increasing returns*.** In both discovery and production. Also in networks and systems.
3. ***Systemic change*,** as a source of increased productivity. Cities, land use, transport, energy, digital; e.g., cities where you can move and breathe.
4. ***Pace of change*** can be very rapid when social priorities shift. Pandemic response demonstrated the potential. Mobilisation in emergencies or war.
5. ***Improvements to health*** from reduced pollution. Air pollution, mostly from fossil fuels, kills up to 8 million per year and maim many further millions.
6. ***International coordination*** and its reinforcing effect: generates confidence in direction of markets and investment and in potential of scale.

5 - 10 years	Investment in sustainable infrastructure and other assets can boost shorter-run demand and growth, sharpen supply and efficiency, reduce waste and pollution, promote sustainable development and reduce poverty.
~ 10 years	Spur innovation, creativity and growth in the medium term, unleash new waves of innovation and discovery.
~ 20 years	Low-carbon is the only feasible longer-run growth on offer; high carbon growth self destructs.

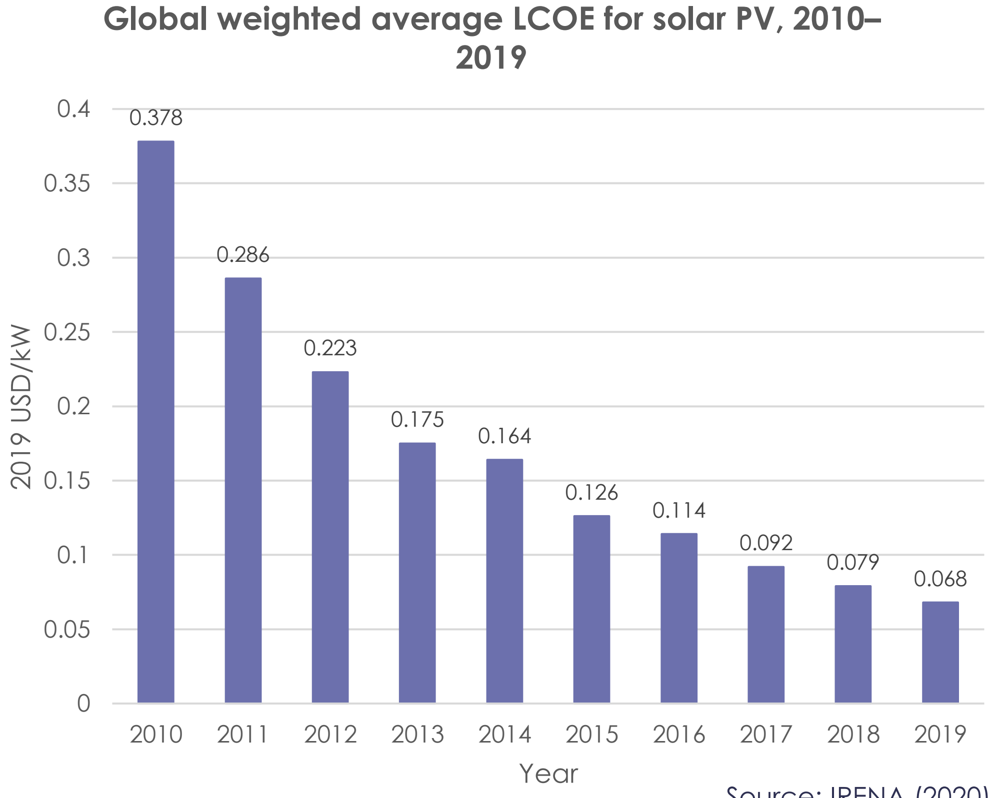
The economy is not at an efficiency frontier. Many simultaneous, and dynamic, net improvements are available to us.

Economics must capture dynamics, complexity, and collaboration: early modelling missed most of this

- Early attempts to examine climate and growth based on the use of **Integrated Assessment Models** (IAMs) (e.g. Nordhaus 1991). Assumed only minor perturbations from climate change and a (largely given) underlying growth rate.
- Reasonable first effort turns out to fail to capture the scale of the phenomenon and nature and pace of necessary action.
- Was an attempt to ***shoehorn*** a "new" problem into a framework and toolkit of the standard workhorses of exogenous growth models and marginal change. The reality of climate change is of a magnitude beyond that framework.
- Have seen some modification of functions and parameters within the framework but it still dominates. The IAM framework ***leaves out the big issues*** that worry us and form the real policy challenges. ***Time to move beyond it***.
- An alternative approach (to potential catastrophic outcomes) is to put in place considered and appropriate ***targets or guardrails.*** Then ask what the best way is to keep within them. Understanding of and potential agreement on such targets can be reached by: 1) describing the likely consequences from climate change, under current arrangements; 2) understanding how the economy and emissions could be managed for a good chance of stabilisation at acceptable temperatures; 3) combining these two elements into a judgement on an appropriate temperature target.
- This was the approach taken within the Paris Agreement. COP21 created a new paradigm of ***collaboration and mutual support, including finance***, ***for a shared goal*** – to be achieved through the ***aggregation*** of independently determined efforts – in place of self-interest and sanctions. Glasgow COP26 continued, now with greater clarity on targets and strong private sector involvement.

The perceived costs of climate action are overstated in many models: failure to capture increasing returns to scale and dynamics of learning

- ***Innovation and discovery*** - drives down costs, spurs further innovation and spillovers.
- Solar power and LED ***costs have plummeted*** as the world has scaled investment and innovation, with co-benefits of reduced emissions and pollution. Same can happen with batteries, hydrogen, etc...
- ***Co-benefits*** extend beyond climate: biodiversity, less congestion, better health, new jobs, fuel cost savings, etc.
- ***Existing and new technologies*** will be necessary. By 2030, low-carbon technologies and business models could be competitive in sectors representing over 70% of global emissions (today 25%) (see Systemiq, 2020).



Source: IRENA (2020)

Increasing returns to scale, both dynamic and static, are vitally important.

Some progress in recent IAMs

- Some attempts to:
  1) Capture ***extreme risks***. E.g. incorporating climate and social tipping points into IAMs (Keller, et al., 2004 Lemoine & Traeger 2014; Lontzek et al. 2015; Cai et al., 2016; Diaz & Keller, 2016; Lemoine & Traeger, 2016; Grubler et al., 2018; Yumashev et al., 2019; Dietz et al., 2021).
  2) Incorporate ***distributional*** considerations. E.g. equity weighting (Schumacher, 2018); accounting for the distribution of consumption and damage within regions (Dennig et al., 2015); comparative importance of discounting, inequalities and catastrophes (Budolfson et al., 2017).
  3) Improve ***calibration of damage functions***. E.g. Carleton & Hsiang, 2016; Hsiang et al., 2017; Ciscar et al., 2019.
  4) Incorporate ***dynamic characteristics*** of mitigation costs. E.g. Grubb et al., 2018 & 2021.
- Many of the improved IAMs produce results on targets and "social cost of carbon" (SCC) more in accord with the international consensus on keeping temperature rise "well below" 2°C and reaching net zero emissions by 2050. (Moyer et al., 2014; Dietz & Stern, 2015; Moore & Diaz, 2015; Hänsel et al., 2020).
- This work demonstrates the great sensitivity of results from IAMs to model specification (e.g. on SCC and temperature targets). This is a serious problem for their use in policy making.

Fundamental flaws remain. The IAM framework is not well suited to analysing problems of deep uncertainty, extreme risk, endogenous technologies and preferences, systemic and structural change, and equity.

Structure

- Section I: Economics missing and/or misdirected
- Section II: Analytical approaches appropriate (or inappropriate) to scale and nature of challenge
- **Section III: Imperfections, policies, values**
- Section IV: Further research

Policy design must take important market imperfections into account

Market Failure	Description	Policy Options
Greenhouse gases (GHGs)	Negative externality because of the damage that emissions inflict on others.	Carbon tax / cap-and-trade / regulation of GHG emissions (standards)
Research, development and deployment (R,D&D)	Supporting innovation and dissemination.	Tax breaks, support for demonstration / deployment, publicly funded research.
Imperfection in risk/capital markets	Imperfect information assessment of risks; understanding of new projects/technologies.	Risk sharing / reduction through guarantees, long-term contracts; convening power for co-financing.
Networks	Coordination of multiple supporting networks and systems.	Investment in infrastructure to support integration of new technologies in electricity grids, public transport, broadband, recycling. Planning of cities.
Information	Lack of awareness of technologies, actions or support.	Labelling and information requirements on cars, domestic appliances, products more generally; awareness of options
Co-benefits	Consideration of benefits beyond market rewards.	Recognising impacts on health. Valuing ecosystems and biodiversity.

Different market failures point to the use of different instruments, but the collection should be mutually reinforcing. We have the tools to drive action, but cannot fully resolve all the failures.

Absent markets and government limitations

- Key futures markets are ***absent***. For example, private investors cannot trade fully, over project lifetimes, on future carbon. Some of the relevant insurance markets covering key risks are absent (including some of those around future policy). Markets for unknown, but possibly vital future technologies are not there. As a matter of basic theory, a competitive equilibrium with some absent markets cannot be assumed to be (Pareto) efficient. Similarly, just "correcting" for the greenhouse gas externality does not bring us efficiency.
- Such absences mean that ***expectations***, and how they are formed, are crucial for investment. They can and should be shaped by public action, including by the key public policy and financial institutions which set direction.
- Public policy is set in a way that does not have the full horizon that is relevant in this context, given that governments are made up of complex compromises and coalitions, and not necessarily long lasting. And it is not clear that these structures, as they exist and work in practice, can fully represent the ***interests of future generations***.
- Governments have limitations on policy instruments and face ***major administrative and political constraints***.
- ***Governments cannot fully commit*** to future actions in a credible way. Lack of confidence in the future of government policies can be a major deterrent to investment ("government-induced policy risk").

Implications for policy analysis and action: a whole set of instruments; centrality of expectations; focus on risk and dynamics; public economics as if time matters (see Stern, 2018).

Discounting (I)

- Decisions now affect lives and livelihoods, and the risks faced, in the future.
- Key concept is the ***social discount factor***: the relative social evaluation of any extra unit of account (e.g. consumption) in the future, relative to an extra unit now. The proportional rate of fall of the social discount factor is the ***social discount rate*** (can be state, person, and commodity contingent).
- The valuation of an extra unit at time *t* will depend, for most ethical observers, on: (i) the levels of living at time *t* relative to now; (ii) the valuations of a future life (or utility) relative to now.
    - The first will, for most ethical observers, point to a high valuation if future generations are likely to be poor and low if they are likely to be rich.
    - The second is "pure-time discounting" and concerns "discrimination by date of birth" (remember that levels of living are in i) not ii)). Other than the possibility of extinction, there is no serious ethical argument in favour of pure-time discounting.
- For discussion of extinction and discounting, see e.g. Stern, 2015; Chichilnisky, Hammond & Stern, 2020. Insight goes back, at least, to Arrow & Mirrlees in 1960s; also examined by Dasgupta, Heal, Solow, Stiglitz….

Discounting (II)

- ***Levels of living in the future are endogenous*** – they depend on choices now. Unmanaged climate change could make future generations poor, thus leading potentially to negative discounting. In any case, we cannot read off from external sources, or exogenously impose, a rate of discount for capturing effect (i).
- ***Risk*** in these analytical frameworks would often be reflected in expectations of utility rather than through discount rates. That approach (treating utility functions and risk separately and then combining) is much more analytically transparent and less rigid.
- The ***capital or financial markets do not give us information*** of relevance to social discounting because: (a) they do not reflect ethical social decisions; (b) they embody expectations and views about risk that are hard to identify; (c) they involve many imperfections.
- Social discounting should be examined largely through effect (i) and that depends fundamentally on how we manage climate change.
- Weitzman (e.g. 2011) pointed to the possibility that extreme risks could lead to infinite willingness to pay to avoid climate change. In this context the guardrail approach, rather than trying to optimise simple expected utility, makes sense from a consequentialist perspective (see Stern & Stiglitz, 2022).

Beyond narrow consequentialism

- The 'rationality' associated with solutions emerging from optimisation of social welfare functions and expected utility theory is useful but based on a ***limited approach to values.***
- Other ethical views and political theories can guide us on tackling the great 21st century challenge:
  - ***Virtue ethics*** – from Aristotle – how do we promote human flourishing and leading a good life?
  - ***Social contract*** – from Rousseau and Locke to the Paris Agreement – social consensus to be governed in return for protection from those who govern. Action to mitigate and build resilience to climate change can flow, and has flowed in the past, from this idea of contracts.
  - Duties and the ***Categorical Imperative*** – from Kant – do we have universal, rational duties to act in certain ways, such as those that sufficiently avoid immense risk?
- Thinking through these alternative approaches supports strong action (see Stern, 2015).

Centrality of distribution and collaboration

- Climate change is fundamentally ***inequitable***: the poorest are hit hardest despite being least responsible for emissions. Women and girls are often affected most severely.
  - Must reflect on ***duties and obligations***, including historical, of rich countries to support poor countries.
  - The necessary fundamental structural transformations will involve ***dislocations and disruption*** and there are similar responsibilities *within* societies. Create a ***just transition***.
- Recognising and supporting values beyond simplistic self-interest increases prospects for ***international and inter-community collaboration*** that can create new solutions and bold action.
  - International climate agreements and institutions built on pooled capital can be seen as a ***global social contract***. Collaboration on one front (e.g. climate) can foster willingness to cooperate on others (e.g. trade and IP). Four wins: Keynesian recovery; expectations and growth; cost/technology; environment.
  - New forms of societal solidarity in response to crisis, including at sub-national levels, can form ***social capital*** and enable measures for ***resilience***, such as disaster response or shared responsibility for environmental commons.

Foundations of relevant notions of justice

- Injustice can be seen as a right or entitlement denied (see Sen, 2009 – "The Idea of Justice").
- Which rights are relevant? Suggest right to development or, in older language, the related idea of the 'pursuit of happiness'.
- Emissions violate rights across generations, across nations and within communities.

Structure

- Section I: Economics missing and/or misdirected
- Section II: Analytical approaches appropriate (or inappropriate) to scale and nature of challenge
- Section III: Imperfections, policies, values
- **Section IV: Further research**

Important areas for economic research

- **Behaviour**
  - Behaviour change in the face of adjustment costs and missing information; incentives, public discussion and nudges.
- **Values**
  - Change through discussion, example, interactions, evidence, leadership.
- **Innovation**
  - Learning by doing, network effects and path dependency; investing in R&D; clarity of regulation, standards and design.
- **Efficiency**
  - Resource efficiency, circular economy, understanding inefficiencies.
- **Systems**
  - Energy, cities, transport, land use; will require a whole set of policies and public action to foster change.
- **Biodiversity**, climate, pollution
  - Intimately related and all require urgent action; examine mix of policies and role of institutions (see Dasgupta, 2021).

Ways forward in economics

- The strategic challenge is to move to a net-zero carbon economy within a few decades and reduce emissions rapidly in this decade. The economics of action must be focused on the achievement of ***fundamental economic change at real pace***.

- This involves assembling microeconomic, structural, technological, and macroeconomic ***analyses of change***, for countries and communities across the world, accounting for the circumstances, difficulties and opportunities they face.

- The work will involve bringing the best of economic analysis to the table, including around ***innovation, behaviour*** and ***political economy***, which will all be central to change.

- It will involve learning from many ***branches of economics***, including international, industrial, labour, health, education, environmental, energy economics and much more, and ***working together*** with science, technology and the social sciences and humanities.

A fascinating, important and urgent research and policy agenda, given the decisive nature of the next decade for climate, biodiversity and the environment. Must move quickly to centre stage in economic research.

References (I)

- Besley, T. & Persson, T. (2020). Escaping the Climate Trap? Values, Technologies, and Politics.
- Bhattacharya A, Dooley M, Kharas H and Taylor C (2022) Financing a big investment push in emerging markets and developing economies for sustainable, resilient and inclusive recovery and growth. London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science, and Washington, DC: Brookings Institution.
- Budolfson, M., Dennig, F., Fleurbaey, M., Siebert, A., & R.H., Socolow (2017). The comparative importance for optimal climate policy of discounting, inequalities and catastrophes. Climatic Change. 145, 481–494.
- Cai, Y., Lenton, T.M., & Lontzek, T.S. (2016). Risk of multiple interacting tipping points should encourage rapid CO 2 emission reduction. Nature Climate Change, 6(5), 520.
- Carleton, T.A., & Hsiang, S.M. (2016). Social and economic impacts of climate. Science, 353, aad9837.
- Chichilnisky, G., Hammond, P., & Stern, N. (2020). Fundamental utilitarianism and intergenerational equity with extinction discounting. Social Choice and Welfare, 54, 397–427.
- Ciscar, J.C., Rising, J., Kopp, R.E., & Feyen, L. (2019). Assessing future climate change impacts in the EU and the USA: insights and lessons from two continental-scale projects. Environmental Research Letters, 14, 084010.
- Dasgupta, P. (2021), The Economics of Biodiversity: The Dasgupta Review. London: HM Treasury.
- Dennig, F., Budolfson, M.B., Fleurbaey, M., Siebert, A. & R.H., Socolow (2015). Inequality, climate impacts on the future poor, and carbon prices. PNAS. 112(52), 15827-15832.
- Diaz, D., & Keller, K. (2016). A potential disintegration of the west antarctic ice sheet: Implications for economic analyses of climate policy. The American Economic Review, 106(5), 607-611.
- Dietz, S., & Stern, N. (2015). Endogenous Growth, Convexity of Damage and Climate Risk, How Nordhaus' Framework Supports Deep Cuts in Carbon Emissions. Econ J, 125, 574-620.
- Dietz, S., Rising, J., Stoerk, T., Wagner, G. (2021). Economic impacts of tipping points in the climate system. Proceedings of the National Academy of Sciences, 118(34), e2103081118.
- Dosio A, Mentaschi L, Fischer EM, and Wyser K, (2018). Extreme heat waves under 1.5°C and 2°C global warming. Environmental Research Letters, 13(5), 054006.
- Grubb, M., Mercure, J.-F., Salas, P., Lange, R.-J., & Sognnaes, I. (2018). Systems innovation, inertia and pliability: A mathematical exploration with implications for climate change abatement.
- Grubb, M., Wieners, C., & Yang, P. (2021). Modeling myths: On DICE and dynamic realism in integrated assessment models of climate change mitigation. WIREs Clim Change. 12:e698.
- Grubler, A., Wilson, C., Bento, N., et al. (2018). A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. Nat Energy, 3, 515–527.
- Hänsel, M.C., Drupp, M.A., Johansson, D.J., et al. (2020). Climate economics support for the UN climate targets. Nature Climate Change, 10(8), 781-789.
- High-level Panel on Climate Change Finance (2010). Final report. United Nations.
- Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., Rasmussen, D.J., Muir-Wood, R., Wilson, P., Oppenheimer, M., Larsen, K., & T., Houser (2017). Estimating economic damage from climate change in the United States. Science. 356(6345), 1362-1369.
- IPCC (2018). Global Warming of 1.5 °C: An IPCC Special Report. [Masson-Delmotte, V., Zhai, P., Pörtner H.-O., Roberts D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T. (eds.)]. In Press.
- Interagency Working Group on Social Cost of Carbon (2010). Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis. United States Government
- IRENA (2020). Renewable Power Generation Costs in 2019. Abu Dhabi, International Renewable Energy Agency.

References (II)

- Keller, K., Bolker, B., & D., Bradford (2004). Uncertain climate thresholds and optimal economic growth. Journal of Environmental Economics and Management. 48(1), 723-741.
- Lemoine, D., & C.P., Traeger (2016). Economics of tipping the climate dominoes. Nature Climate Change. 6(5), 514.
- Lemoine, D. & C., Traeger (2014). Watch Your Step: Optimal Policy In A Tipping Climate. American Economic Journal: Economic Policy. 6(1), 137–66.
- Lenton, T.M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., and Schellnhuber, H.J. (2019). Climate tipping points — too risky to bet against. Nature.
- Lontzek, T.S., Cai, Y., Judd, K.L. & T.M., Lenton (2015). Stochastic Integrated Assessment of Climate Tipping Points Indicates the Need for Strict Climate Policy. Nature Climate Change. 5, 3–6.
- Met Office Hadley Centre (2021). HadCRUT4 Data. Accessed 10/10/2021, at: https://www.metoffice.gov.uk/hadobs/hadcrut4/data/current/download.html
- Moore, F.C., & Diaz, D.B. (2015). Temperature impacts on economic growth warrant stringent mitigation policy. Nature Climate Change, 5(2), 127.
- Moyer, E., Woolley, M., Matteson, N., Glotter, M., & Weisbach, D. (2014). Climate Impacts on Economic Growth as Drivers of Uncertainty in the Social Cost of Carbon. The Journal of Legal Studies, 43(2), 401-425.
- Nordhaus, W.D. (1991). To Slow or Not To Slow: The Economics of the Greenhouse Effect, The Economic Journal 101(407), 920–937.
- Olivier, J.G.J. and Peters, J.A.H.W. (2020). Trends in global CO2 and total greenhouse gas emissions: 2020 report. Report no. 4331. PBL Netherlands Environmental Assessment Agency, The Hague.
- Oswald, A.J. and Stern, N., 2019. Why are economists letting down the world on climate change? www.voxeu.org in collaboration with the WEF.
- Schumacher, I. (2018). The Aggregation Dilemma in Climate Change Policy Evaluation. Climate Change Economics, 09, 03.
- Sen, A.K. (2009). The Idea of Justice. Cambridge: Harvard University Press.
- Stern, N. (2007). The Economics of Climate Change: The Stern Review. Cambridge: Cambridge University Press.
- Stern, N. (2015). Why Are We Waiting? The Logic, Urgency and Promise of Tackling Climate Change. Cambridge: MIT Press.
- Stern, N. (2018) Public economics as if time matters: Climate change and the dynamics of policy. Journal of Public Economics, 162, 4-17.
- Stern, N. (2021). G7 leadership for sustainable resilient and inclusive economic recovery and growth: an independent report requested by the UK Prime Minister for the G7, London School of Economics. London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science.
- Stern, N. (2022). A time for action on climate change and a time for change in economics. The Economic Journal, 132(644), 1259-1289.
- 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(3), 181-216.
- Systemiq (2020). The Paris Effect: How the climate agreement is reshaping the global economy. London: Systemiq Ltd.
- Warren R, Price J, Graham E, Forstenhaeusler N, and Van Der Wal J, (2018). The projected effect on insects, vertebrates, and plants of limiting global warming to 1.5°C rather than 2°C. Science, 360(6390), 791–795.
- Weitzman, M. (2011). Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change. Review of Environmental Economics and Policy. 5(2) 275–292.
- Yumashev, D., Hope, C., Schaefer, K., Riemann-Campe, K., Iglesias-Suarez, F., Jafarov, E., Burke, E.J., Young, P.J., Elshorbany, Y., & Whiteman, G. (2019). Climate policy implications of nonlinear decline of arctic land permafrost and other cryosphere elements. Nature Communications, 10, 1900.