Prise en compte de l'incertitude et impacts économiques des points de bascule du système climatique

La science des points de bascule

Loïc Berger (CNRS and iRisk Research Center on Risk and Uncertainty)

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The challenge

Perspective

The missing risks of climate change

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James Rising[1]✉, Marco Tedesco[2], Franziska Piontek[3] & David A. Stainforth[4,5]

The risks of climate change are enormous, threatening the lives and livelihoods of millions to billions of people. The economic consequences of many of the complex risks associated with climate change cannot, however, currently be quantified. Here we argue that these unquantified, poorly understood and often deeply uncertain risks can and should be included in economic evaluations and decision-making processes.

Climate policymaking

- Global and long-lasting consequences
- Long-time lags involved
- Fundamental irreversibilities in physical systems
- Imprecise nature of existing climate-science knowledge
- Unpredictability of technological adaptation

What is the challenge?

- limits to our understanding of the potential economic impact of climate change, and in particular of climate tipping points (TPs)

What is the challenge?

- limits to our understanding of the potential economic impact of climate change, and in particular of climate tipping points (TPs)
- different sources of uncertainty associated with TPs:
  - scientific: size, probability, interactions
  - socio-economic: impacts of TPs on economic opportunities and social well-being

Uncertainty tradeoffs

- How much weight do we assign to:
  - best guesses
  - potentially bad outcomes

  when designing policy?

- Do we act now, or do we wait until we learn more?

Talk outline

...

- TPs in the climate system
- Economic analysis of climate TPs
- Decision-making under uncertainty

TPs in the climate system

What are tipping points in the climate system?

Definitions from IPCC AR6

- Abrupt climate change is "change in the climate system that takes place over a few decades or less, persists...for at least a few decades and causes substantial impacts in human and/or natural systems"
- A TP is "a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly"
- TPs "may involve global or regional climate changes from one stable state to another ... or to changes that occur faster than the rate of change of forcing ... and include shifts from one equilibrium state to another and other responses of the climate system to external forcing"

Understanding tipping points in the climate system

- Heterogeneous class of phenomena that includes non-linear feedbacks and both reversible and irreversible phase changes
- This heterogeneity makes it challenging to incorporate climate TPs in macro models
- In popular discourse, TPs are identified with abrupt change on economic timescales, and some work in economics reflects this
- Crossing climate TPs may lead to abrupt changes on economic timescales, or not – it largely depends on the TP

Economic analysis of climate TPs

Climate tipping points in economics

Review of the climate economics literature in relation to TPs (Dietz et al, PNAS 2021)

- Most studies either ignored climate TPs or had very indirect/partial coverage
- 52 papers explicitly model the economic consequences of at least one climate TP
- Most of these studies represented climate TPs in a highly stylized way, many by associating crossing a climate TP with an economic catastrophe/disaster
- Each study takes an individual TP (or a few TPs) and employs a particular IAM

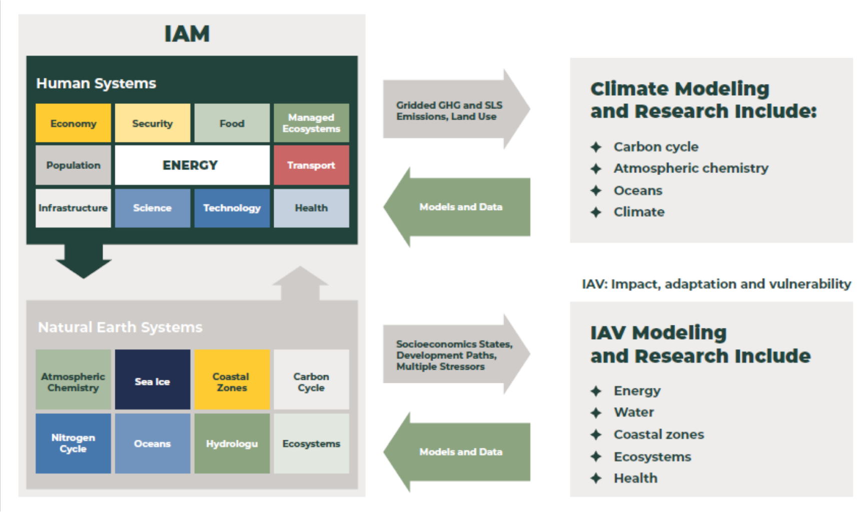
Paper	Integrated assessment model	Tipping point (TP)	TP module
Anthoff, Estrada, Tol (*AER P&P*, 2016)(6)	FUND version 4.0	AMOC	Geophysical
Azar, Lindgren (*Climatic Change*, 2003)(7)	DICE	Inspired by AMOC and WAIS collapse	Stylized
Bahn et al. (*Energy Policy*, 2011)(8)	MERGE5	AMOC	Geophysical
Baranzini, Chesney, Morriset (*Energy Policy*, 2003)(9)	Cline (1992)	WAIS collapse and AMOC	Stylized
Belaia (Dissertation, 2017)(10)	RICE-ISM-AD	ISM	Geophysical
Belaia, Funke, Glanemann (*ERE*, 2017)(11)	DICE-CJL	AMOC	Geophysical
Berger, Emmerling, Tavoni (*Mgt Sci*, 2016)(12)	DICE adapted	AMOC	Stylized
Bickel (*Env. Systems & Decisions*, 2013)(13)	DICE 2007	Not specified	Stylized
Cai et al. (*PNAS*, 2015)(14)	DSICE (based on DICE07)	Not specified	Stylized
Cai, Lenton, Lontzek (*NCC*, 2016)(15)	DSICE (based on DICE-2013R)	5 TPs: AMOC, GIS, WAIS, AMAZ, ENSO	Stylized/geophysical
Cai, Lontzek (*JPE*, 2019)(16)	DSICE (based on DICE07)	AMOC, GIS, WAIS, AMAZ, ENSO	Stylized
Cai, Brock, Xepepadeas (Working paper, 2016)(17)	extends DSICE model of Cai et al. 2015	AMOC	Stylized/geophysical
Ceronsky, Anthoff, Hepburn, Tol (Working paper, 2011)(18)	FUND version 3.6	AMOC, OMH	Geophysical
Chao (*Risk Analysis*, 1995)(19)	unique to this paper	Inspired by WAIS collapse inter alia	Stylized
Diaz and Keller (*AER P&P*, 2016)(20)	DICE - WAIS	Potential WAIS collapse	Geophysical
Dumas and Ha-Duong (Book chapter, 2005)(21)	DIAM 2.3	Inspired by AMOC	Stylized
Engstrom, Gars (*ERE*, 2016)(22)	Golosov et al. (2014)	3 TPs: damages, CO_2 removal; PCF	Stylized
Gjerde, Grepperud and Kverndokk (*REE*, 1999)(23)	from Kverndokk (1994)	Inspired by WAIS collapse, AMOC, PCF	Stylized
González-Eguino et al. (*Earth's Future*, 2017)(24)	DICE 2013R	SAF-inspired	Geophysical
Guillerminet, Tol (*Climatic Change*, 2008)(25)	n/a	WAIS collapse	Stylized
Heutel, Moreno-Cruz, Shayegh (*JEBO*, 2016)(26)	DICE 2007	3 TPs: climate feedback, carbon sink, economic loss (pre- and post-climate policy)	Stylized
Hope, Schaefer (*NCC*, 2016)(27)	PAGE09	PCF	Geophysical
Keller et al. (*Climatic Change*, 2000)(28)	DICE 1994	AMOC	Geophysical
Keller, Bolker, Bradford (*JEEM*, 2004)(29)	DICE94	AMOC	Geophysical
Kessler (*Climate Change Economics*, 2017)(30)	DICE-2013R	PCF	Geophysical
Lamperti et al. (*Ecological Economics*, 2018)(31)	Dystopian Schumpeter meeting Keynes (DSK)	Not applicable	Stylized
Lempert, Sanstad, Schlesinger (*Energy Economics*, 2006)(32)	DICE94	AMOC	Stylized
Lemoine, Traeger (*AEJ:Pol*, 2014)(33)	4-stated DICE (based on DICE07)	Jump in ECS, drop in CO_2 removal	Stylized
Lemoine, Traeger (*NCC*, 2016)(34)	4-stated DICE (based on DICE07)	Jump in equilibrium climate sensitivity; fall in CO_2 removal; damages	Stylized
Lemoine, Traeger (*JEBO*, 2016)(35)	4-stated DICE (based on DICE07)	Jump in ECS, drop in CO_2 removal	Stylized
Link and Tol (*Port Econ J*, 2004)(36)	FUND version 2.8	AMOC	Geophysical
Link and Tol (*Climatic Change*, 2011)(37)	FUND version 2.8n	AMOC	Geophysical
Lontzek, Narita, Wilms (*ERE*, 2016)(38)	n/a	Tropical and boreal forest dieback	Geophysical
Lontzek et al. (*NCC*, 2015)(39)	"DSICE" (based on DICE07)	AMOC, GIS, WAIS, AMAZ, ENSO	Stylized/geophysical
McInerney, Lempert, Keller (*Climatic Change*, 2012)(40)	DICE-07	AMOC	Stylized
Naevdal (*JEDC*, 2006)(41)	n/a	WAIS	Stylized
Naevdal, Oppenheimer (*REE*, 2007)(42)	n/a	AMOC	Stylized
Nicholls, Tol, Vafeidis (*Climatic Change*, 2008)(43)	FUND version 2.8n	WAIS	Geophysical
Nordhaus (Book chapter, 1994)(44)	DICE-94	Inspired by WAIS, AMOC; PCF, etc.	Stylized
Nordhaus (*PNAS*, 2019)(3)	DICE16R2-GIS	GIS	Geophysical
Nordin (Dissertation, 2014)(45)	DICE2013	GIS, WAIS, AMAZ, PCF, OMH	Stylizedl
Peck, Teisberg (*Climatic Change*, 1995)(46)	CETA-R	None specified	Stylized
Pycroft, Vergano, Hope (*Global Environmental Change*, 2014)(47)	PAGE09	Extreme sea-level rise from GIS and WAIS	Stylized/geophysical
Schlesinger et al. (Book chapter, 2006)(48)	DICE99	AMOC	Geophysical
Shayegh, Thomas (*Climatic Change*, 2015)(49)	DICE 2007	Climate sensitivity	Stylized
Sims, Finoff (*JAERE*, 2017)(50)	n/a	Ice sheet collapse, special case	Stylized
van der Ploeg (*EER*, 2014)(51)	n/a	OMH	Stylized
van der Ploeg, de Zeeuw (*JEEA*, 2017)(52)	n/a	None specified	Stylized
Whiteman, Hope and Wadhams (*Nature*, 2013)(53)	PAGE09	OMH (Arctic)	Geophysical
Wirths, Rathmann, Michaelis (*EEPS*, 2018)(54)	DICE 2013R with PCF	PCF	Geophysical
Yohe (*Global Environmental Change*, 1996)(55)	CONN	Change in equilibrium climate sensitivity	Stylized
Yohe, Schlesinger, Andronova (*Integrated Assessment Journal*, 2006)(56)	DICE99 adding a simple ATHC model	AMOC	Geophysical
Yumashev, et al. (*Nature Comms*, 2019)(57)	PAGE-ICE	PCF, SAF	Geophysical

Notes: PCF - permafrost carbon feedback; OMH - dissociation of ocean methane hydrates / clathrates; SAF - surface albedo feedback / arctic sea ice; AMAZ - Amazon rainforest dieback; GIS - Greenland ice sheet disintegration; WAIS - West Antarctic ice sheet disintegration; AMOC - Atlantic meridional overturning circulation slowdown; ISM - Indian summer monsoon variability; ECS - equilibrium climate sensitivity.

Integrated assessment models (IAMs)

- are simplified representations of complex physical and social systems, focusing on the interaction between economy, society and the environment.
- aim to provide policy-relevant insights into global environmental change by providing a quantitative description of key processes in the human and earth systems and their interactions.

IAMs



Source: http://www.iamconsortium.org/

IAMs

Policy questions

- To project emissions and temperature (understand climate change)
- To assess climate change and its economic and physical impacts
- To define the optimal mitigation level (CBA, cost benefit analysis) and to define the Social Cost of Carbon
- To assess the implication and costs of national climate change policy
- To assess the implications and investments associated to various carbon budgets (CEA, cost effective analysis).

Social Cost of Carbon (SCC)

Key policy input

- SCC is the key welfare measure of climate change in policy discussions
- SCC represents the economic cost of emitting one additional ton of CO_2 (i.e., the marginal damage cost)
- SCC can be used to internalize the climate change externality, and to set carbon prices

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⇒ SCC can be used to inform mitigation efforts tell us how strong climate policy should be

IAMs and TPs

- TPs are represented in a highly stylized way in IAMs
  - instantaneous jump in the model's equilibrium climate sensitivity
  - an arbitrary reduction in global gross domestic product (GDP)
  - and a one-off permanent reduction in global utility

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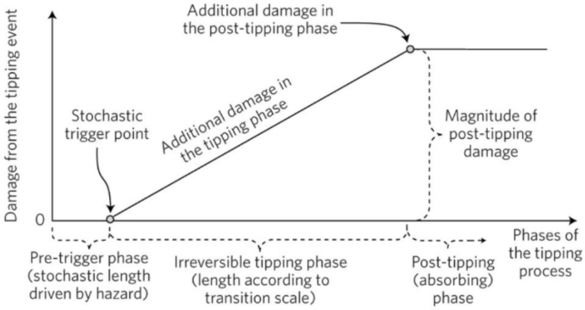

Source: Lontzek et al. (2015)

IAMs and TPs

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- Poor treatment of uncertainty

IAMs and TPs

+ Existing studies have helped put climate TPs on the economic research agenda and contributed to understanding qualitative aspects of climate policy in the face of TPs
- Stylized representations are unrealistic from a geophysical point of view and difficult to calibrate quantitatively
- Poor treatment of uncertainty

$\Rightarrow$ As a result, TPs are only weakly reflected in the policy advice economists give on climate change

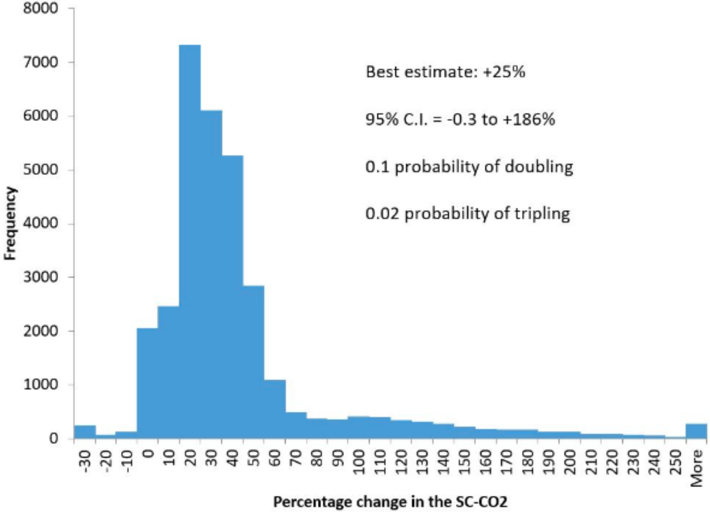
Dietz et al. (PNAS, 2021)

- Focus on studies with geophysical foundations, i.e., with at least a reduced-form representation of the key underlying geophysical relationship(s) that govern the TP
- Tried to produce unified estimates of the economic impacts of climate TPs, synthesising studies that are geophysically realistic, using a 'meta-analytic' IAM

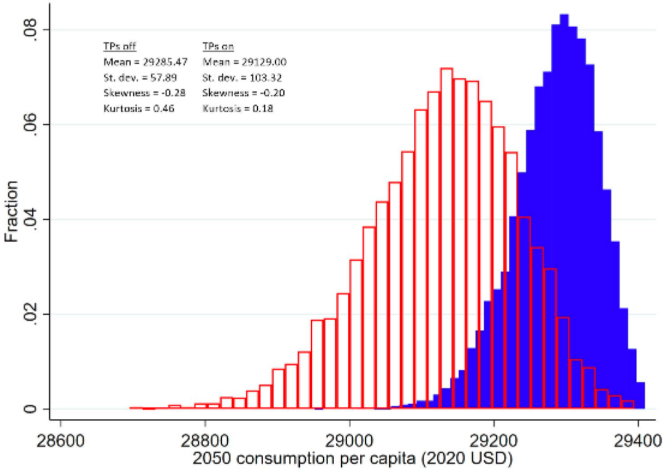
Tipping models replicated and synthesised

Tipping point	Papers	IAM	Model of TP
1) Permafrost carbon feedback (PCF)	Kessler (2017, *Clim. Chge. Econ.*)	DICE	Process-based
	Hope & Schaefer (2016, *Nat. Clim. Chge.*)	PAGE09	Process-based
	Yumashev et al. (2019, *Nat. Comms.*)	PAGE-ICE	Process-based
2) Ocean methane hydrates (OMH)	Ceronsky et al. (2011, unpublished)	FUND	Tipping event
	Whiteman et al. (2013, *Nature*)	PAGE09	Tipping event
3) Arctic Sea Ice/Surface Albedo Feedback (SAF)	Yumashev et al. (2019, *Nat. Comms.*)	PAGE-ICE	Process-based
4) Amazon dieback	Cai et al. (2016, *Nat. Clim. Chge.*)	DSICE	Tipping event
5) GIS disintegration	Nordhaus (2019, *PNAS*)	DICE	Process-based
6) WAIS disintegration	Diaz and Keller (2016, *AER P&P*)	DICE	Tipping event
7) AMOC slowdown	Anthoff et al. (2016, *AER P&P*)	FUND	Tipping event
8) India summer monsoon (ISM) variability	Belaia (2017, unpublished), based on Schewe and Levermann (2012, *ERL*)	RICE	Process-based

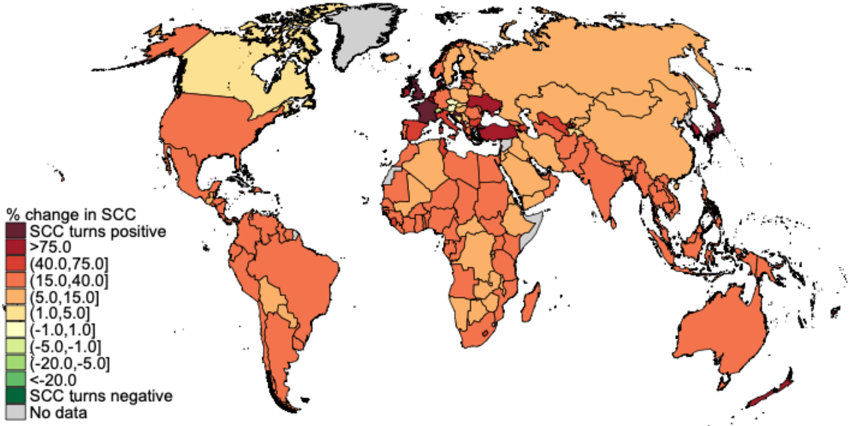
Tipping points increase the social cost of carbon



Tipping points add to global consumption risk



Tipping points increase climate damages almost everywhere



Decision-making under uncertainty

Risk vs. Uncertainty

Following Knight (1921), Keynes (1921):

- Uncertainty: situations in which the probabilities of uncertain events are unknown (= deep uncertainty/ambiguity/Knightian/radical/extreme/... uncertainty)

$\neq$ Risk: situations in which probabilities are perfectly known

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- Probabilities in majority of events cannot be perfectly known
  - too little information available
  - different predictions exist (relying on different datasets, different techniques, etc.)
  - different experts provide different probability assessments

Practical framework

Uncertainty through the lens of models.

Decompose uncertainty into 3 distinct layers:

(Arrow 1951, Hansen 2014, Marinacci 2015, Hansen & Marinacci 2016, Aydogan et al. 2023)

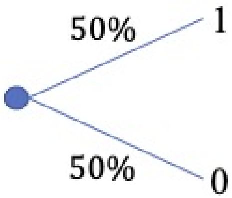
1. Risk (aleatory uncertainty)
2. Model ambiguity
3. Model misspecification

(epistemic uncertainty)

Risk

(= aleatory uncertainty, physical uncertainty)

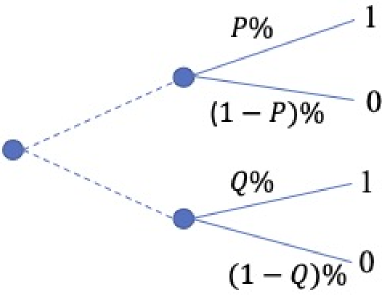
- Situations with an *objectively* known probability distribution



- uncertainty about states: variability *within* a particular probability model
- examples: chance mechanisms (roulette, coin, dice)
- deals with variability in data (because of inherent randomness, measurement errors, omitted minor explanatory variables)
- characterizes data generating processes (i.e. probability models)
- *probability* is an objective measure of randomness/variability

Model ambiguity

- Arises when the DM is not able to identify a single probability model corresponding to the phenomenon of interest

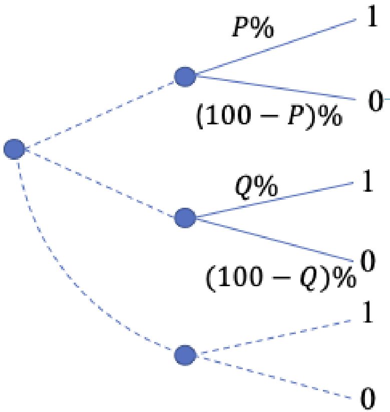


- uncertainty *across* models
- ex: deals with the truth of propositions
  - "the composition of the urn is $P\%$ red and $1 - P\%$ black balls"
- Notation: $M = \{P\%, Q\%\}$
- epistemic uncertainty may be quantified by means of *subjective* probabilities

$\rightarrow$ *probability*=measure of degree of belief

Model misspecification

- Arises when the set of models under consideration might not include the correct model



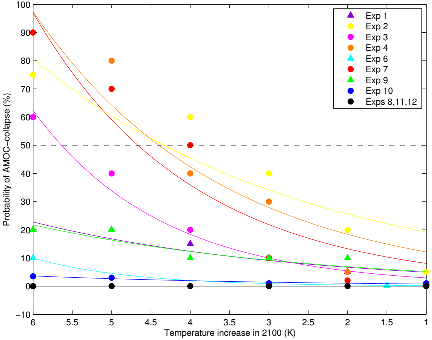
- uncertainty *about* models
  → The set M is *misspecified*
- emerges as the result of the approximate nature of the models under consideration
- in real-life problems, models are, by design, approximations (= simplification of complex phenomena)

Useful framework to analyze decision problems under deep uncertainty

These different layers (uncertainty *within*, *across*, and *about* models):

- are inherent in any decision problem under uncertainty where the DM has probabilistic theories about the outcomes of a phenomenon and forms beliefs over their relevance
- underlie many aspects of the economy-climate system
- pose significant challenges in the design of climate policy

Example: Scientific uncertainty about AMOC



Source: Berger et al. (2017)

- Risk of collapse of the Atlantic Meridional Overturning Circulation (AMOC) due to global climate change
- large scale impacts: strong cooling by several degrees, increase in sea level up to 1m (direct) + shift of the Intertropical Convergence Zone, warming of the Southern ocean (indirect)
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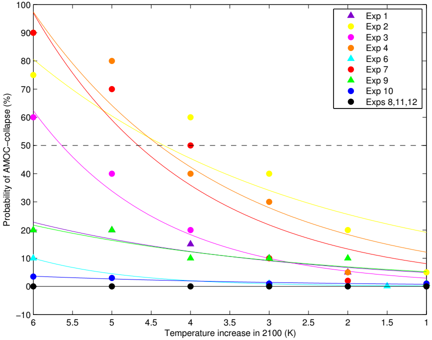

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→ More generally, when different experts provide opinions about the probability of an event

Navigating uncertainty

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- Goals:
  - assess the impact of uncertainty on climate policy outcomes
  - isolate the forms of uncertainty that are most consequential for these outcomes
  - use models in sensible ways rather than discard them

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- Goals:
  - assess the impact of uncertainty on climate policy outcomes
  - isolate the forms of uncertainty that are most consequential for these outcomes
  - use models in sensible ways rather than discard them
- How?
  - aversion – dislike of uncertainty about probabilities over future events
  - implementation – target the uncertainty components with the most adverse consequences for the decision maker
  - outcome – an uncertainty adjusted probability measure pertinent for valuation along with robust decision rules

Decision theory

Modern developments:

- extend notions of uncertainty beyond risk in ways that make contact with applied challenges
- allows for a broad perspective on uncertainty
- distinguish concerns about potential misspecifications of likelihoods from concerns about robustness of alternative priors
- include formulations that are dynamic and recursive

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$\Rightarrow$ Opens the door to better ways for conducting uncertainty quantification for dynamic economic models used for private sector planning and governmental policy assessment.

Concluding remarks

- Uncertainty matters for policy tools
- Climate TPs are a serious reason for concern and increase the case for limiting global warming to a low level, particularly if we conceptualise the uncertainties as deep/Knightian
- Most numbers are probable underestimates because, e.g., some TPs are missing and some climate impacts are missing from TPs that are included.
- But if we can progress from thinking about TPs as generic catastrophes in our models, we might open out a set of decision-useful insights for adaptation and economic policy

Thank you

email: loic.berger@cnrs.fr