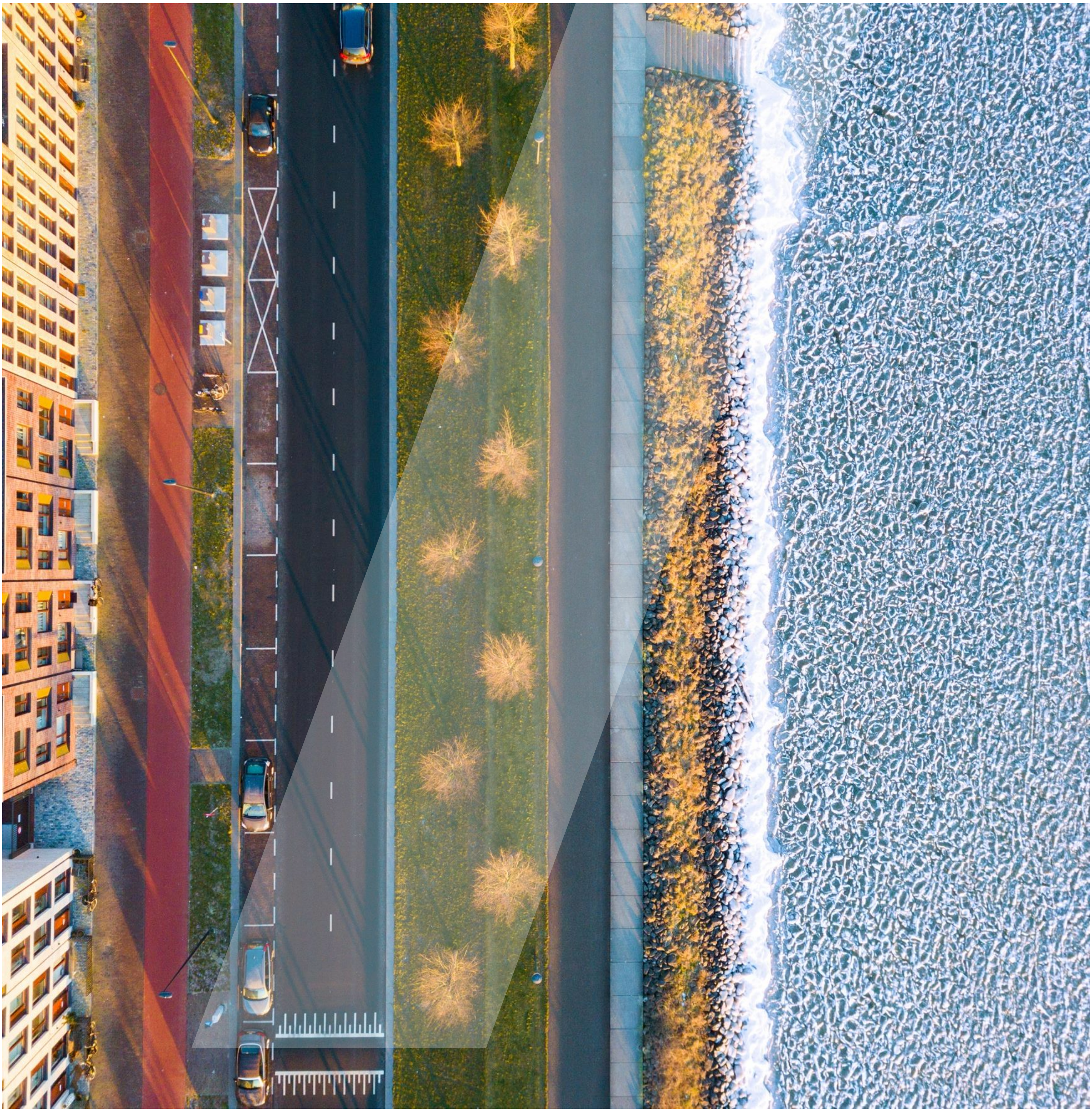

Extended analysis: Assessing climate risk for the insurance industry

How reliable are climate scenarios?

forvis mazars

As climate risks intensify, regulators and the insurance industry face growing pressure to refine risk assessment frameworks. This article provides a critical technical review of the role of climate scenarios, the limitations of current models, and the implications of new regulatory developments, including the ECB and EIOPA's latest proposals, for shaping a resilient and innovative future.

Setting the scene: Insurance regulatory developments for climate resilience

The increasing frequency and severity of climate-related risks pose significant challenges for the financial sector, particularly insurers and reinsurers tasked with managing these impacts. Recent years have seen heightened regulatory efforts to integrate climate risk into financial frameworks. Initiatives such as France's ACPR climate pilot exercises and the use of NGFS scenarios have provided methodologies for assessing physical and transition risks, while also exposing the limitations of existing tools and models in capturing the full scope of potential impacts.

Building on this momentum, the European Central Bank (ECB) and the European Insurance and Occupational Pensions Authority (EIOPA) have added to the regulatory discourse with their December 2024 report, *"Towards a European System for Natural Catastrophe Risk Management."* This report highlights the economic risks associated with the growing insurance protection gap for natural catastrophes and proposes EU-level measures to improve risk-sharing, modelling, and coordination between public and private entities. These developments reflect the increasing demand for sophisticated tools to assess and mitigate climate risks effectively.

As these regulatory efforts evolve, the role of climate scenarios becomes ever more crucial. It has become clear that the impacts of climate risks are often shaped not by average patterns but by extreme scenarios. Integrated Assessment Models (IAMs), which commonly assume average deterministic responses to global warming, may underestimate these risks. Nevertheless, actuaries and risk managers rely on climate scenarios to anticipate the impacts of global warming and the transition to a low-carbon economy. The critical literature on IAMs offers insights into addressing these challenges, helping to develop more consistent modelling approaches for climate risks and effective strategies for their management.

1. Climate scenarios: tools for measuring climate risk

In response to the growing climate risks, EIOPA issued recommendations to integrate climate risk into the ORSA (Own Risk and Solvency Assessment) framework. European insurance and reinsurance companies are asked to:

- Integrate short-term and long-term climate risks into their Own Risk and Solvency Assessment (ORSA[1]);
- Identify and study material exposures to these risks, initially using qualitative analyses;
- If significant exposure is identified, complement the qualitative analyses with quantitative analyses based on at least two scenarios: one where global temperature rises by more than 2°C, and another where it remains below this threshold.

Some European national supervisors, such as the ACPR for France (prudential supervision authority), launched a voluntary climate pilot exercise within the banking and insurance markets. In France, between July 2020 and April 2021, the exercise aimed to measure the impact of climate risk on insurers' activities through three transition risk scenarios and one physical risk scenario[2]. This pilot exercise resulted in highlighting methodological limitations. To address the latter and incorporate the latest climate and macroeconomic data, a second climate stress test was launched in 2023 by ACPR.

[1] As part of Solvency II, the European insurance prudential directive.
[2] Physical risks can be defined as risks arising from direct losses caused by extreme and chronic climatic phenomena.
Transition risks can be defined as risks arising from the economic and financial impacts of the transition to a low greenhouse gas emission economy.

One of the pillars of climate risk assessment is the use of climate scenarios. A climate scenario outlines a plausible trajectory for the economy and climate, considering social, economic, political, and technological trends over a relevant horizon, such as 2050 or 2100. At a minimum, it includes projections of:

- Annual CO2 emissions;
- Global average temperature;
- CO2 emission costs;
- Global GDP growth.

Forecasts may also include various macroeconomic variables (e.g., unemployment rates, debt levels), demographic data (e.g., population growth, migration flows), and energy mixes. Depending on the model, these forecasts may be detailed by country or economic sector and can either be natively generated by the model or result from applying an additional modelling layer (e.g., sectoral disaggregation).

Each climate scenario represents a narrative about the evolution of climate policies, generally expressed in the form of a carbon price. It could also be the evolution of technologies expressed, for example, by the rate of development of CO2 capture and storage techniques or the speed of vehicle electrification. These scenarios also account for disparities between countries regarding climate policies, as seen in ACPR's stress test scenarios, illustrated in the diagram below.

The use of diverse narratives helps cover multiple combinations of physical and transition risks, as illustrated by the NGFS (Network for Greening the Financial System)[3] scenarios.

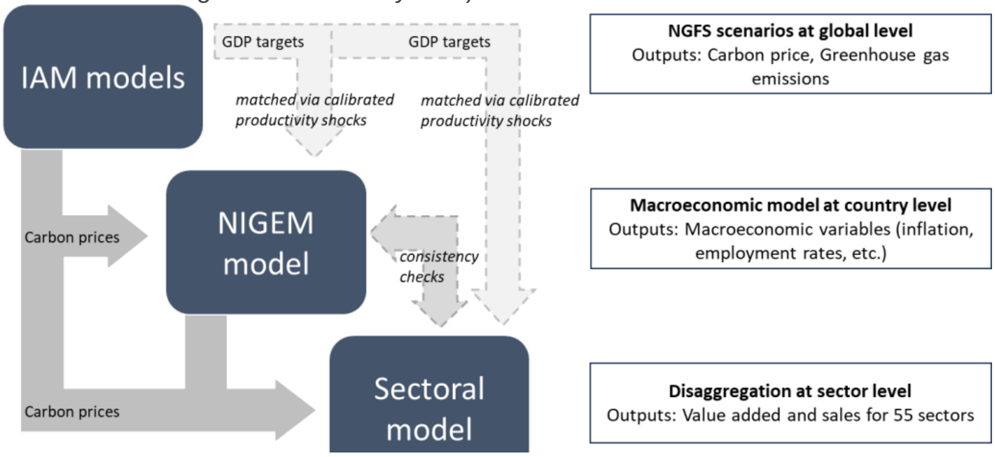

Chart 1: Climate scenario modeling architecture - Source: Allen et al. (2020)

[3] The Network for Greening the Financial System (NGFS) is a group of central banks and supervisors that voluntarily share best practices and contribute to the development of environmental and climate risk management in the financial sector. NGFS

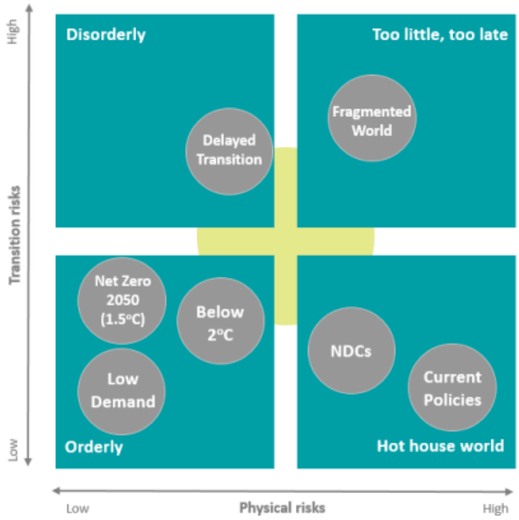

Chart 2: Overview of NGFS scenarios - Source: NGFS (2024)

The information from these scenarios is then used by insurers and reinsurers to assess the impact of climate risks on claims and asset values.

2. Generating climate scenarios: a neglected challenge to master

The generation of climate scenarios relies heavily on Integrated Assessment Models (IAMs), which link economic activity to climate outcomes. However, the process of creating these scenarios is fraught with challenges, including model limitations and uncertainties. This section delves into how climate scenarios are generated, the assumptions underpinning IAMs, and the improvements needed to enhance their reliability.

a. Definition of an IAM

Most insurance business institutions assessing their climate risk exposure quantitatively use climate scenarios provided by supervisors or organizations like the NGFS as inputs to their models. Therefore, these scenarios are typically generated without being questioned.

The origin of these scenarios are IAMs (Integrated Assessment Models). IAMs are designed to model the interaction between the economy and climate.

The diagram below provides a schematic representation of the structure of this type of model:

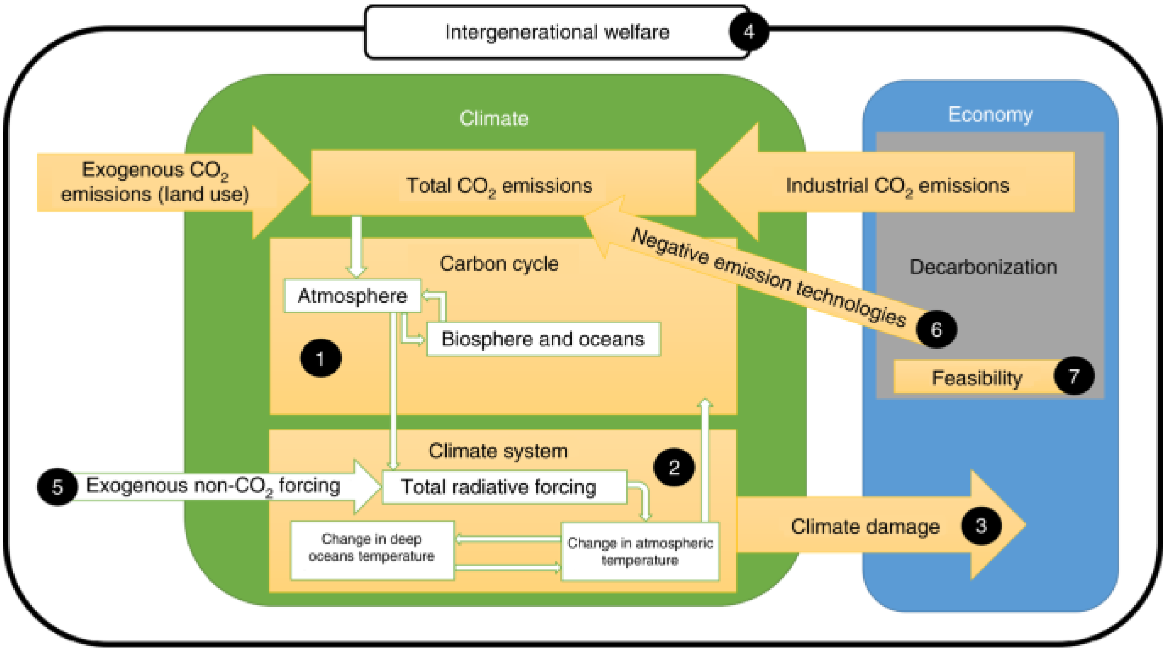

Chart 3: Structure of sequential updates to the DICE model - Source: Hänsel et al. (2020)

The "Economic Growth and Climate: The Carbon Dioxide Problem" article by William Nordhaus, published in 1977, led to the development of IAMs along with the DICE (Dynamic Integrated Climate-Economy) model published in 1992. The DICE model, like many of its successors, is based on several assumptions:

- Economic activity generates CO2 emissions;
- These emissions increase global temperatures;
- This temperature rise damages part of the production output;
- CO2 emission externalities can be managed through taxation.

The model seeks to maximise intertemporal economic utility for a given taxation trajectory.

This model can optimise CO2 emission reduction policies by determining a "social cost of carbon" (SCC): the marginal damage and losses caused by emitting additional CO2. Such a tool can therefore be helpful for political decision-making via cost-benefit analyses.

Since the DICE model, other notable models such as GCAM (Edmonds and al., 2014), REMIND-MAgPIE (Baumstark and al., 2021; Dietriech and al., 2019) and MESSAGEix-GLOBIOM (Krey and al. 2020; Fricko and al., 2017) have emerged. These models were used to produce the NGFS scenarios used by ACPR for its stress tests. Most of these new models are in line with the general framework of the DICE model but add complexity and refinement: increasing the complexity of the economy-energy model, the CO2 circulation model and radiative forcing, endogenising the technical progress, etc.

b. IAMs: models with significant limitations

Interpreting IAM results requires a good understanding of the uncertainties involved. Van Asselt & Rotmans (2002) suggest a taxonomy of uncertainties that can be represented by the diagram below:

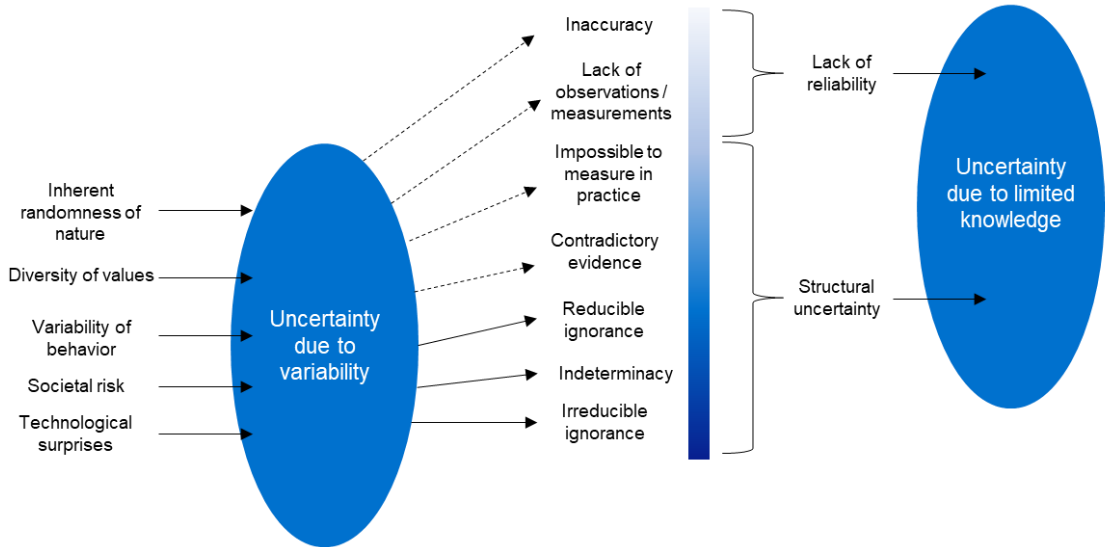

Chart 4: Taxonomy of uncertainties - Source: Van Asselt & Rotmans (2002)

They identify multiple sources of uncertainty:

- **Uncertainty about model structure**: this refers to the potential flaws in the structure of the model itself, including the assumptions made about how different variables interact.
- **Uncertainty about model completeness**: this involves questioning whether the model captures all relevant processes. A model may exclude important climate or economic mechanisms, leading to incomplete or inaccurate predictions.
- **Uncertainty about parameters, inputs, and initial states:** this refers to the inherent uncertainty in all models, arising from the challenge of accurately estimating parameters based on observational data.
- **Uncertainty about model operations**: this relates to errors that might occur during the operation of the model, such as numerical inaccuracies, software bugs, or the accumulation of propagated uncertainties.

One of the first papers to tackle the problem of interpreting IAM results is Weitzman (2009). The aim of this article is to suggest a mathematically rigorous, though abstract, economic and statistical framework for high-impact and low-probability disasters. It focuses on uncertainties related to:

- The parameter indicating the climate system temperature response to a doubling of the concentration of CO2 in the atmosphere;
- The parameter defined more roughly as “a scaling parameter of the generalised climate response.”

Drawing on geophysical arguments such as the existence of tipping points and positive feedback loops, as well as the results of climatological studies, Weitzman argues that these parameters have a heavy-tailed distribution. He then demonstrates explosive asymptotic behaviour, including when he tries to close the model by introducing a “statistical value of life as we know it on Earth” below which utility would be zero. The key point of this article is that the impacts of global warming could be dominated by extreme scenarios. IAM, which generally assume an average deterministic response to global warming and its consequences, could therefore significantly underestimate the risk.

Yet, some research articles criticise IAM and address the various types of uncertainty mentioned above. The criticisms below are primarily drawn from two articles: Ackerman et al. (2009) and Stern et al. (2021).

It should be noted that some of the major limitations expressed in 2021 overlap with those mentioned in 2009, indicating a certain inertia in the most widely used models. These criticisms relate to several modelling aspects:

- Discounted utility expectation framework with a unique representative agent;
- Choice of discount rate;
- Unpredictability of key economic drivers;
- Substitutability of environmental goods;

- Social cost of carbon;
- Damage function;
- Mitigation costs.

Criticism of the discounted utility expectation framework with a unique representative agent:

The criticism of the general framework relates to several assumptions underlying the modelling.

First, it is plausible that the objective maximised by individuals differs from the one that society or the legislator seeks to maximise. The same applies to the constraints of the maximisation problem.

Moreover, aggregation assumes that agents have homogeneous and constant beliefs and knowledge. However, it is clear that society comprises agents with heterogeneous beliefs, which are changing and probably endogenous—as evidenced by the growing proportion of individuals convinced of the anthropogenic nature of global warming.

The use of a unique representative agent assumes that each generation cares about the next and passes on an inheritance, but the literature shows that this is not a satisfactory representation of the economy, even when considering that the governments drive inter-generational redistribution.

Finally, the literature shows that in the presence of extreme risks, individuals do not maximise utility expectation but prefer flexibility, which would justify prudent behaviour.

Criticism of the choice of discount rate:

The level of the discount rate is a key factor in the cost-benefit balance of public policies. This is because most of the costs of reducing emissions occur immediately, while the harmful effects of global warming are more distant. With a discount rate of 2%, damage occurring 70 years from now will be weighted with a factor of 25% compared with costs paid immediately, whereas with a discount rate of 5%, they will be weighted with a factor of only 3%.

One of the criticisms raised on the use of a positive discount rate relates to ethics and moral philosophy. Discounted amounts are not monetary amounts but utilities. The question raised is: Is it ethically acceptable for the present generation to make decisions that significantly impact future generations who are unable to express themselves, while underweighting their utility?

The procedures used to calibrate the discount rate are also criticised. With r as the discount rate, p as the rate of pure preference for the present, n as risk aversion, and g as the economy's long-term growth rate, calibration is most often based on Ramsey's rule:

$$r \approx \rho + \eta g$$

The positive nature of r is not guaranteed, since g could turn out to be negative as a result of environmental damage. Similarly, in the presence of uncertainty, there is not necessarily a single rate, but several rates depending on the degree of risk. Under certain assumptions about the distribution of this risk, we can have the following approximation, under which the positive character of the rate is not guaranteed independently of the sign of g:

$$r^f \approx \rho + \eta g - \frac{1}{2}\eta^2 g^2$$

We also note the difficulty of inferring these parameters based on observed household behaviour. Additionally, even if capital markets were perfect, in the absence of intertemporal redistribution, the rates observed on the market only reflect the intertemporal trade-off of the current generation, and not a societal trade-off between two generations.

Criticism of the unpredictability of key economic drivers:

Demographic trends, changes in consumer preferences, and technological progress are key factors in the evolution of the economy. However, these factors are notoriously complex to predict, and it is difficult to intervene directly in their evolution.

Criticism of the substitutability of environmental goods:

Environmental goods are not directly a parameter in the utility function which depends solely on the wealth of society. Environmental benefits and damages are only considered through their impact on this wealth. They are therefore considered perfectly substitutable for ordinary consumer goods, which is a strong assumption.

Criticism of the social cost of carbon:

The social cost of carbon is envisaged as a Pigouvian tax, i.e., a tax designed to internalise the social cost of an externality linked to economic activity. Stern, Stiglitz, and Taylor (2021) argue that a Pigouvian tax is sufficient only if the only externality not managed by the market is greenhouse gas emissions.

They cite several crucial market failures ignored by IAMs, which could thereby underestimate the social cost of carbon. They also indicate that a Pigouvian tax might be insufficient and require additional measures, such as obligations to publish information related to corporate social and environmental responsibility.

Criticism of the damage function:

The damage function is an essential dimension of the model. Its form and parameterisation have major consequences for the optimal social cost of carbon, as well as the estimated economic and financial impacts.

Le Guenedal (2019) illustrates the different consequences on production of an average increase in temperature, depending on the specification chosen for the damage function. It should be noted that we have only limited data with which to calibrate this function, as we observe only one warming trajectory, currently below 2°C.

Furthermore, these damages are generally expressed as a percentage of consumption or production, with no

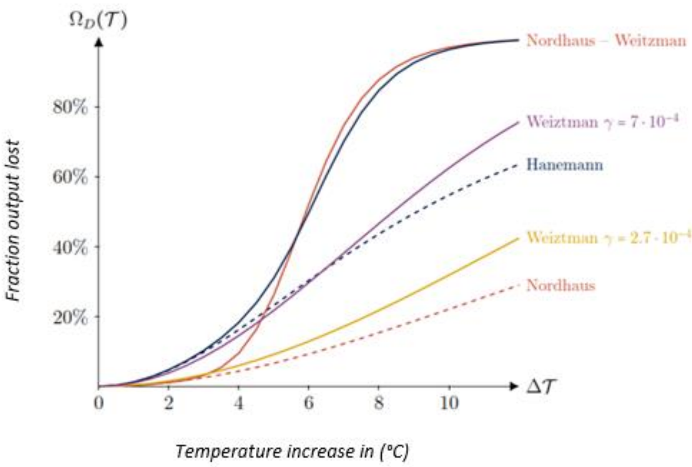

Chart 5: Possible forms for the damage function - Source: Le Guenedal (2019)

reduction in capital stocks or the underlying growth rate. This does not seem consistent with the imaginable consequences of significant warming: some parts of the world could become unliveable due to severe exposure to climatic hazards, and their resources could become unexploitable.

The existence of tipping points also suggests that damage is likely to become particularly severe for temperature variations in the tail of the distribution. The social cost of carbon is also highly sensitive to social and spatial inequalities. Indeed, the poorest sections of the population are less insured, have fewer resources to adapt, and generally live in the least protected areas. A damage function representing "average" damage cannot account for such disparities.

Criticism of mitigation costs:

The fact that climate policies can have other beneficial effects (e.g., on water, air, and soil pollution, biodiversity, etc.) tends to overestimate the costs of mitigation compared with the benefits obtained. An article by McCollum et al. (2013) demonstrated synergies in the costs of policies to combat global warming when benefits from reduced air pollution or improved energy security were considered.

Furthermore, these models ignore the fact that preferences can be at least partially endogenous. For example, individuals might, by adapting their diets, start to prefer a diet with less or no meat consumption. In this case, substantial reductions in CO_2 emissions could be achieved without changes that are usually considered as loss of well-being.

c. Impact of these limitations on IAM results

Beyond the theoretical criticisms, some articles, such as Cooke (2012), focus on highlighting abnormal results from conventional models. The study uses the DICE model, freezes technical progress and population at their initial values, assumes no global warming or abatement policy, and observes two trajectories:

- One with an initial capital value equal to $1800 trillion;
- One with an initial capital value equal to $1.

The study then shows that in 60 years, the level of capital converges, which seems far too short a timeframe given the differences in initial wealth.

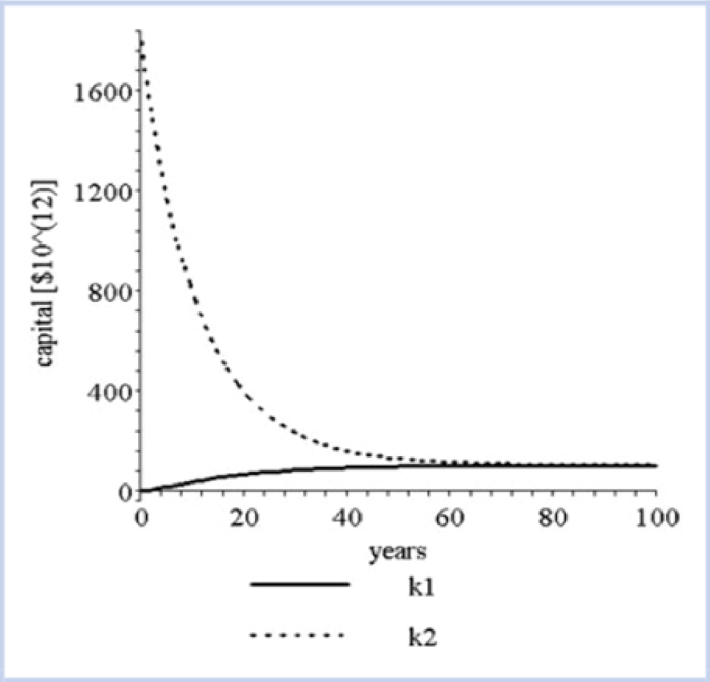

Chart 6: Two capital trajectories obtained with the DICE model with default values, no temperature increases and no abatement (k1(0) = $1; k2(0) = $1800 trillion) - Source: Cooke (2012)

He also shows that for a global warming of 20°C, which leads to the impossibility of life on earth, the model predicts a destruction of around 50% of initial wealth. This therefore questions the validity of the capital dynamics used.

As a proof of concept, the study proposes a simple alternative dynamic in which global warming no longer impacts production but rather GDP growth:

$$PIB(t+1) = PIB(t) \times [1 + \beta + \alpha T(t)]$$

This dynamic allows for the appearance of recessionary phases and leads to results where no equilibrium is reached on relevant time scales.

Meta-analyses, such as the one by Wang (2019), show a very wide distribution of the estimated social cost of carbon, ranging from -$13/tCO2 to $2387/tCO2.

Finally, Stern et al. (2021) highlight the contradiction between the international consensus around target temperatures of 2°C (or even 1.5°C) and the conclusions of literature using IAMs, which find a "social optimum" between 3.5°C and 4°C, even though decision-makers were fully aware of these results.

3. What role for actuaries?

The criticisms of IAM models can seem daunting. Robert Pindyck, in his 2013 article "Climate Change Policy: What Do the Models Tell Us?" goes so far as to warn that IAMs "have crucial flaws that make them close to useless as tools for policy analysis".

Despite the challenges, actuaries and risk managers need climate scenarios to anticipate the impacts of global warming and the low-carbon transition. The critical literature on IAMs provides guidance, suggesting that a range of models and scenarios should be used to address uncertainties.

a. Proposals from leading experts

Van Asselt & Rotmans (2002) advocate the use of a multitude of different models to reduce uncertainties.

Ackerman and al. (2009) and Stern and al. (2021) suggest a more "insurance-like" use of these models. The idea would be to draw on the literature in the field of climatology to define a warming target not to be exceeded, and then to ask the IAMs to provide the "socially least costly" carbon tax trajectory to meet these targets.

Kaufman and al. (2020) suggest a similar approach, which they call "Near-Term Net Zero". This approach can be broken down into four steps: set a date by which net CO2 emissions must be zero, choose an emissions reduction trajectory, use an IAM to estimate a CO2 price consistent with the chosen trajectory and periodically repeat the above steps to update the estimates.

a. The need to expand actuarial skills and access to scenarios

It is unreasonable to expect insurance companies to develop, calibrate and pilot models capable of producing climate scenarios. Nevertheless, given the state of the art of IAMs, it seems necessary in the context of climate risk management not to rely solely on the scenarios produced by the NGFS. The results obtained when using the latter must be nuanced and interpreted as a lower bound of the impact of transition scenarios on economic and financial systems. Actuaries therefore need to be trained in the limits of these models.

Finally, supervisors at national or European level could also share scenarios produced by models other than the NGFS to get a wider range in the risk estimations rather than a lower bound. Centralising the production of these scenarios via supervisors also offers a major advantage: it enables players to work on a common basis, enabling supervisors and investors alike to better compare the risks to which different companies are exposed.

Next steps: preparing for the next wave of regulations

The regulatory landscape is poised to demand more precise, data-driven approaches to climate risk assessment and management. Insights from France's ACPR climate exercises and NGFS scenarios, along with the ECB and EIOPA's recent report, highlight the need for enhanced modelling, improved data sharing, and stronger public-private coordination. These initiatives aim to close the insurance protection gap and prepare the sector for the challenges posed by extreme climate scenarios.

For the EU insurance and actuarial industry, this presents both opportunities and challenges. Regulators are likely to mandate advanced scenario analyses, robust risk modelling, and actionable adaptation measures. Actuaries, in particular, must refine their skills in interpreting complex scenarios and their implications for financial stability. Insurers will also need to invest in resilience-building strategies to align with increasing regulatory expectations.

As the EU seeks to harmonise climate risk frameworks across Member States, it positions itself to lead globally in addressing the financial and societal challenges of climate change. By embracing these changes, the EU insurance sector can set a benchmark for innovation, collaboration, and resilience, strengthening its role as a global leader in the transition to a low-carbon, climate-resilient future.