What is wrong with the climate change damage functions.

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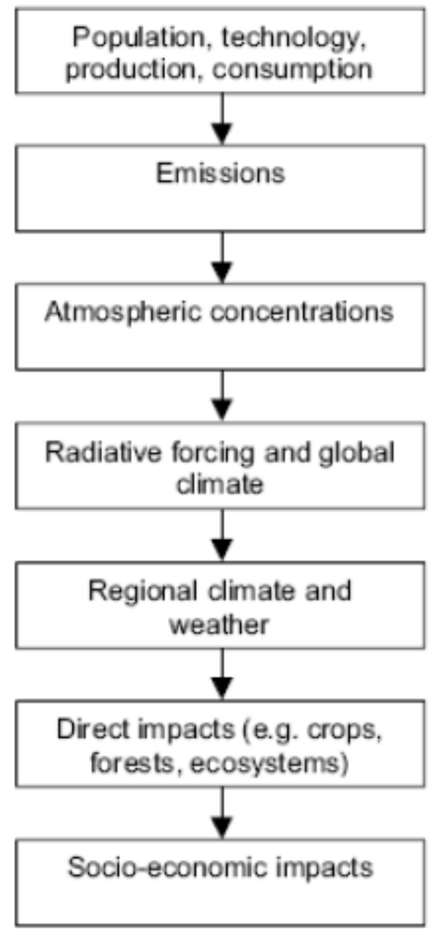
Types of economic impact to be valued

- In the climate context, the market impacts include:
  - a direct change in income,
  - a change in the price of a market commodity or input,
  - a change in the availability (other than price) of a market commodity or input, and
  - a change in the quality of a market commodity or input.

- In addition, there is the change in wellbeing due to changes in non-market items:
  - human health and mortality,
  - amenity from quality of life or quality of the environment,
  - impacts on ecosystems and biodiversity, etc.
- The nonmarket impacts are valued in terms of the WTP or WTA equivalents: the amounts of money that an individual would exchange for these effects, if he could.

The damage function

- The damage function serves as a summary representation of the economic impact of climate change in Integrated Assessment Models (IAMs) and other analyses.
- It gives the "bottom line."



- There is daunting uncertainty at each step.
- For all of the difficulties with projecting future global emissions and modeling their impacts with global circulation models, those are not where the greatest uncertainty lies.
- Nor is the economic valuation necessarily the most uncertain component of the analysis.
- The greatest uncertainty is with translating the GCM projections to the things that affect people's lives and incomes at particular locations and at particular points in time (the "physical" impacts as noticed by people).

Issues

- How are damages represented
- How is the damage function calibrated

A bottom-up assessment

- Time (decade) t. E_t global emissions at t.
- W_{ckt} climate variable c at location k, time t.(c = temperature, precipitation, sea level, etc)
- Global climate models give: $W_{ckt} = F_{ckt}(E_{-T}, E_{-T-1}, \ldots, E_0, \ldots, E_t)$
- I_{ikt} i^{th} type of physical, biological or social impact at location k in period t; D_{ikt} the monetized value of the that impact.
- $G_{ikt}(\cdot)$ mapping from the W_{clt}'s to I_{ikt}.
- I_{ikt} may depend may depend on climate outcomes at location k, either currently (W_{ckt}) or in the past ($W_{ck\tau}$, $\tau < t$) or at other locations; it may depend on changes ($W_{ckt} - W_{ckt-1}$), rates of change ($[W_{ckt} - W_{ckt-1}]/ W_{ckt-1}$), or cumulative changes ($W_{ckt} - W_{ckt-N}$).
- $H_{ikt}(\cdot)$ mapping from the I_{ilt}'s to D_{ikt}.
- D_{ikt} may depend not only on the impact itself, I_{ikt} , but also on related impacts in preceding periods (I_{ikt-1}) or other locations (I_{ilt}).

Metrics

- Total cost, expressed as an equivalent reduction in GDP

$$D_t = \sum_{ik} H_{ikt}[\, G\{ F(E_{-T},..,E_{-0},..,E_t)\}]$$

- Discounted present value of the stream of present and future damages, $\delta_t = (1+r)^{-t}$

$$D_0 = D_0\,(E_{-T},..,E_{-0},..,E_t) \equiv \sum_{t \geq 0} D_t\text{-}\delta_t$$

- Social cost of carbon (SCC)

$$\partial D_0/\partial E_0$$

- A vast amount of data would be needed to construct the mappings $G_{ikt}(\cdot)$ and $H_{ikt}(\cdot)$.
- Rather than doing this, the IAMs use a highly simplified analysis,
  - Simplified spatially
    - The spatial unit of analysis in DICE and PAGE is the entire world; in FUND the world is divided into 16 broad regions.
  - Simplified with regard to climate variable
    - The climate parameter, W_{kct}, is simply the change in global annual mean temperature, ΔT.
  - Simplified with regard to specification of functional relationship of damage to that variable.

Table R. The regions in FUND.

Acronym	*Name*	*Countries*
USA	USA	United States of America
CAN	Canada	Canada
WEU	Western Europe	Andorra, Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Sweden, Switzerland, United Kingdom
JPK	Japan and South Korea	Japan, South Korea
ANZ	Australia and New Zealand	Australia, New Zealand
CEE	Central and Eastern Europe	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, FYR Macedonia, Poland, Romania, Slovakia, Slovenia, Yugoslavia
FSU	Former Soviet Union	Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
MDE	Middle East	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, West Bank and Gaza, Yemen
CAM	Central America	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama
SAM	South America	Argentina, Bolivia, Brazil, Chile, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela
SAS	South Asia	Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka
SEA	Southeast Asia	Brunei, Cambodia, East Timor, Indonesia, Laos, Malaysia, Myanmar, Papua New Guinea, Philippines, Singapore, Taiwan, Thailand, Vietnam
CHI	China plus	China, Hong Kong, North Korea, Macau, Mongolia
NAF	North Africa	Algeria, Egypt, Libya, Morocco, Tunisia, Western Sahara
SSA	Sub-Saharan Africa	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo-Brazzaville, Congo-Kinshasa, Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea- Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe
SIS	Small Island States	Antigua and Barbuda, Aruba, Bahamas, Barbados, Bermuda, Comoros, Cuba, Dominica, Dominican Republic, Fiji, French Polynesia, Grenada, Guadeloupe, Haiti, Jamaica, Kiribati, Maldives, Marshall Islands, Martinique, Mauritius, Micronesia, Nauru, Netherlands Antilles, New Caledonia, Palau, Puerto Rico, Reunion, Samoa, Sao Tome and Principe, Seychelles, Solomon Islands, St Kitts and Nevis, St Lucia, St Vincent and Grenadines, Tonga, Trinidad and Tobago, Tuvalu, Vanuatu, Virgin Islands

Representation of damages

- The compound of the mappings $G_{ikt}(\cdot)$ and $H_{ikt}(\cdot)$ is replaced by a simple reduced form equation, calibrated to damages estimated at some benchmark temperature change, ΔT^*

$$D_t = a[\Delta T/\Delta T^*]^b$$

- At benchmark ΔT^*, $D_t = a$. Coefficient b is set at b=2 in DICE; in FUND, b set at more specific values (see next slide). In PAGE, b is random variable taking values 1, 2 or 3.

Study	Warming in °C	Impact in % GDP
Nordhaus (1994a)	3.0	−4.8 (−30.0 to 0.0)
Nordhaus (1994b)	3.0	−1.3
Fankhauser (1995)	2.5	−1.4
Tol (1995)	2.5	−1.9
Nordhaus & Yang (1996)[a]	2.5	−1.7
Plamberk & Hope (1996)[a]	2.5	−2.5 (−0.5 to −11.4)
Mendelsohn et al. (2000a)[a,b,c]	2.5	0.0[b] 0.1[b]
Nordhaus & Boyer (2000)	2.5	−1.5
Tol (2002a)	1.0	2.3 (1.0)
Maddison (2003)[a,d,e]	2.5	−0.1
Rehdanz & Maddison (2005)[a,c]	1.0	−0.4
Hope (2006)[a,f]	2.5	0.9 (−0.2 to 2.7)
Nordhaus (2006)	2.5	−0.9 (0.1)

Limited sectoral disaggregation

- DICE: single global damage function.
- PAGE: Four separate global damage functions, for economic damages, for non-economic damages, for sea-level rise damages, and for climate discontinuity damages.
- FUND: Separate, region-specific deterministic damage functions for each of 8 macro sectors (agriculture, forestry, water, energy, sea-level rise, ecosystems, human health, and storms).
  - The functions are dependent on both magnitude of temperature change and, in some cases (e.g., agriculture, ecosystems) the rate of temperature change.
  - Sectoral vulnerability also assumed to depend on factors such as the level of per capita income, population growth, and the passage of time (representing technological change or improved adaptation).
  - Coefficients estimated from cross-section data for countries or groups of countries.

Two key features of damage estimates in IAMs

- High level of spatial aggregation
- Overwhelming reliance on expert judgment and heroic extrapolation by the model developer.

FUND 3.5 (2010)

5.7. Human health: Diarrhoea

The number of additional diarrhoea deaths $D^d_{r,t}$ in region r and time t is given by

$$\text{(HD.1)} \quad D^d_{t,r} = \mu^d_r P_{t,r} \left(\frac{y_{t,r}}{y_{1990,r}} \right)^{\varepsilon} \left(\frac{T_{t,r}}{T_{pre-industrial,r}} \right)^{\eta}$$

where

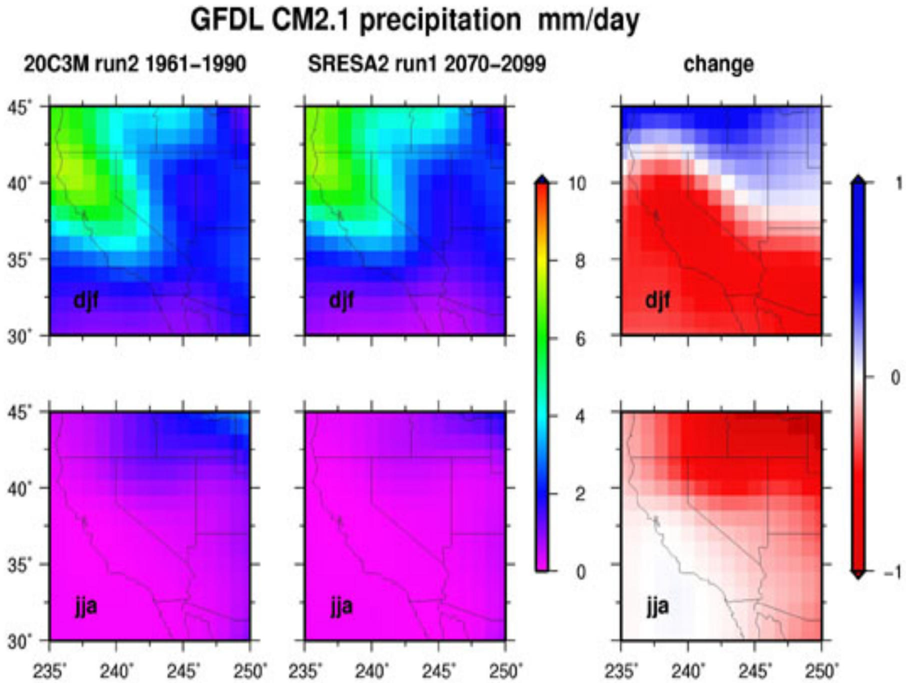
- $P_{r,t}$ denotes population,
- r indexes region
- t indexes time,
- $y_{r,t}$ is the per capita income in region r and year t in 1995 US dollars,
- $T_{r,t}$ is regional temperature in year t, in degrees Celcius (C);
- μ_r^d is the rate of mortality from diarrhoea in 2000 in region r, taken from the WHO Global Burden of Disease (see Table HD, column 3);
- ε = -1.58 (0.23)is the income elasticity of diarrhoea mortality
- η = 1.14 (0.51) is a parameter, the degree of non-linearity of the response of diarrhoea mortality to regional warming.

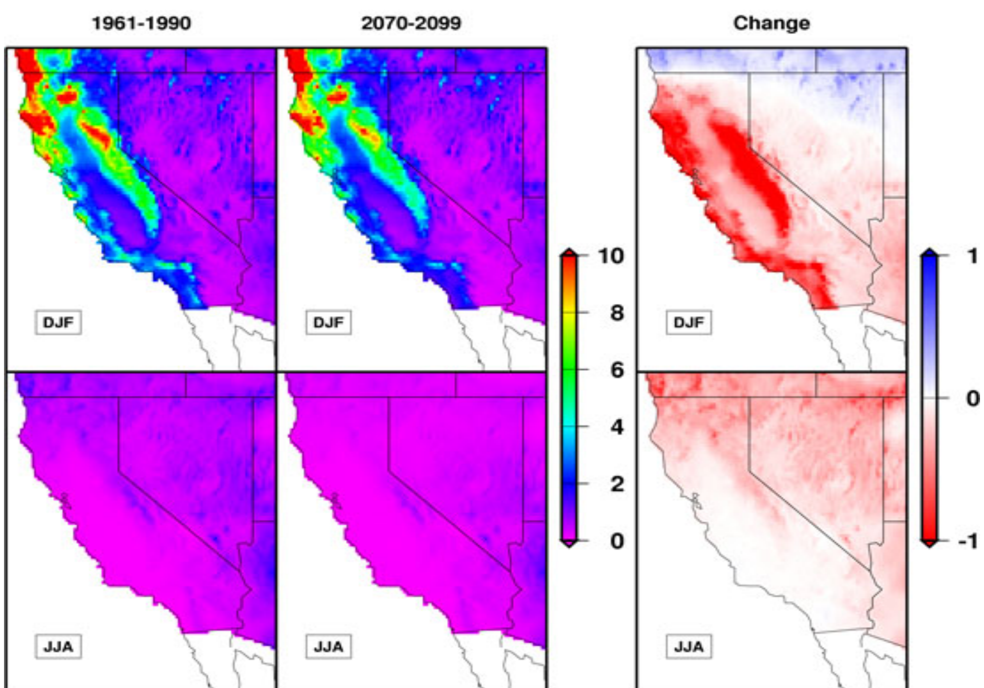
Problems

- Global annual average ΔT is the wrong summary statistic.
  - The degree of temperature increase is different for land and ocean areas and varies by latitude; as a generalization, it is higher on land and at the latitudes where most of the world's population live, and where the studies used for calibration are drawn from
- FUND has regional multiplier to translate global ΔT into a regional ΔT.
  - For example, multiplier for US is 1.1941. Thus 2^{o}C ΔT for global average = 2.39^{o}C ΔT for US.
  - This adjustment appears to be highly inadequate.

Aggregation distorts conception of temperature change Hayhoe et al PNAS 2004

HOW TO CHARACTERIZE THE CHANGE IN TEMPERATURE, 2070-2099, USING HADCM3			
		EMISSION SCENARIO**	
		A1fi	B1
Change in global average annual temperature		4.1	2
Change in statewide average annual temperature in California*		5.8	3.3
Change in statewide average winter temperature in California*		4	2.3
Change in statewide average summer temperature in California*		8.3	4.6
Change in LA/Sacramento average summer temperature		~10	~5
*Change relative to 1990-1999. Units are ˚C			





Global Climate Models compute Climate on a coarse grid

So, a "downscaling" procedure was used to provide temperature and precipitation over a finer mesh that is more commensurate with the California landscape

A hydrologic model is used to simulate streamflow, soil moisture and other hydrologic properties

- Spatial disaggregation is a major challenge for economic analysis.
  - CGE models are highly spatially aggregated.
- For given ΔT, yield effect differs by crop and location:
  - Impact on corn different than on wine grapes. Even for grapes, impact different in Napa County vs Fresno County.
  - Can't represent impact via one "representative farm"
- Two neighboring water districts:
  - Different water rights, different sources of supply, different cost structures, different crops grown, & different climate impact.
  - Water isn't fungible. Can't represent a heterogeneous area via a "representative farm" with a lumped, regional supply of water, without distorting the economic analysis.

Key message

- While mitigation is measured on a global scale, impacts and adaptation are local.
  - They typically affect subpopulations.

Aggregation systematically biases down the damage estimate

- With convex damage function (increasing marginal damage), aggregation understates damages:

$$E\{D(\Delta T)\} > D(E\{\Delta T\}).$$

- A local approximation:

$$E\{D(\Delta T)\} = D(E\{\Delta T\}) + \sigma_{\Delta}^{2} D''(E\{\Delta T\})$$

- The larger σ_{Δ}^{2} and the larger $D''(\circ)$, the more $D(E\{\Delta T\})$ understates the aggregate damage $E\{D(\Delta T)\}$.

Are the IAMs reliable?

- DICE, FUND and PAGE draw on the same literature for calibration, much of which involves studies published prior to 2000.
- More recent assessments of climate change tend to involve a more disaggregated spatial scale; they find larger damages at the low levels of temperature change considered
- DICE, FUND, and mean estimates from PAGE give fairly similar conclusions about the total economic damage associated with specific emissions scenarios.
- But DICE and FUND differ markedly in their assessments of the *sectoral composition* of damages.
- This casts some doubt on their credibility.

- In FUND, the single largest component of the social cost of carbon is damages from *energy*, which account for two thirds of total, followed by water, which accounts for 1%. The damages are offset by a large *gain to agriculture*, which reduces the total cost by half.
- In DICE, there is no impact on water, almost *zero impact on energy*, and a *small loss to agriculture*; two thirds of the gross damage is attributed to catastrophic climate events rather than to market or other non-market impacts.

- At the aggregate level, the IAM damage functions are probably too low.
- There is a growing literature which suggests that they are also too flat.
  - The observation that most of damages currently considered are associated with extreme weather events.
  - The concern about tail probabilities was triggered by the work of Weitzman, but goes well beyond it.
    - There is massive uncertainty about the value of the climate sensitivity, a key parameter in global climate models. Has a distribution with a heavy right tail.
    - Increased scientific concern about tipping points and abrupt climate change.

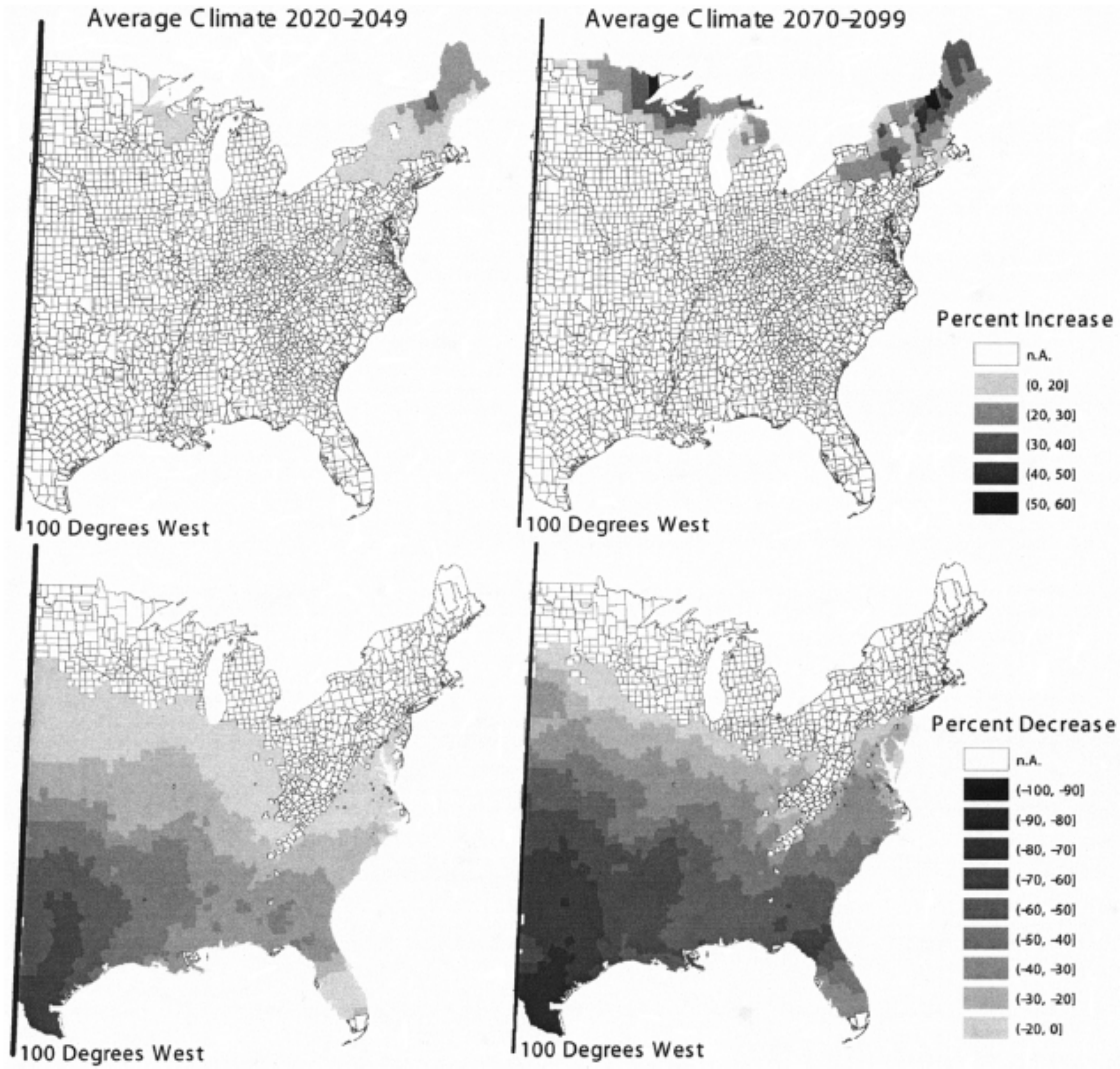
Potential tipping points

- Abrupt loss of Arctic summer sea-ice, irreversible meltdown of the Greenland ice sheet
- Disintegration of the West Antarctic ice sheet
- Reorganisation of the Atlantic thermohaline circulation
- Increased amplitude of the El Niño Southern Oscillation
- Disruption of the Indian summer monsoon
- Collapse of the West African monsoon
- Dieback of the Amazon rainforest and boreal forests
- Abrupt changes in Antarctic bottom water formation
- Release of methane form melting of permafrost

Distributional issues

- Climate change is a massive engine for redistribution of wellbeing and wealth, both within countries and between countries.
- We can no longer ignore spatial distribution of impacts. The Kaldor-Hicks criterion is hardly valid within a country, and entirely inappropriate between countries.
- For assessing climate impacts, is the status quo irrelevant? Are gains and losses counted equally?

FIGURE 1.—COUNTIES WITH STATISTICALLY SIGNIFICANT GAINS AND LOSSES EAST OF THE 100TH MERIDIAN UNDER THE HADLEY HADCM3 B2 SCENARIO



Reframing climate change in terms of risk

- Because the largest part of the damages from climate change is likely to be associated with local extreme events, one should think of climate policy in terms of risk assessment and risk management.
- In assessing potential damages, there needs to be an allowance for risk aversion. This is largely absent in most of the existing economic literature on climate.

- DICE (but not FUND) allows for risk aversion, but only for collapse of the thermohaline circulation; not with regard to ordinary market and non-market losses.
- These are local impacts (fire, flooding, drought etc), but the local population which is exposed to them is likely to have some degree of risk aversion and some WTP to lower their exposure to these risks.
- There are limits to the extent to which these risks can be pooled
  - Non-financial outcomes (pain and suffering, etc)
  - Tail dependence
- Therefore, there should be some allowance for the public's risk aversion premium to avoid these local risks.
- Moreover, the relevant risk concept is *downside* risk aversion rather than standard risk aversion.

Model uncertainty & risk aversion

- Some literature does consider model uncertainty concerning parameters such as
  - Climate sensitivity
  - Coefficients a or b in damage function
  - Time preference / risk aversion
- This is typically handled by a form of sensitivity analysis in which the IAM is solved by many different parameter values, and the results averaged over model runs.
- If risk aversion is introduced into the analysis it is through the formulation in which the single-period utility function is $u(c) = y^{\eta}/(1-\eta)$.
  - The same parameter η represents both risk aversion and aversion to income variation (income inequality aversion).

- Crost and Traeger (2012) show both aspects are problematic.
- Sensitivity analysis produces averaged values for variables of interest such as social cost of carbon (SCC), optimal rate of abatement, optimal expenditure on abatement that are mutually inconsistent and incoherent.
- Instead, therefore, one has to solve a full blown optimization of the IAM model with parameter uncertainty.
  - When this is done it produces higher estimates of the SCC than the sensitivity analysis.
- When one switches to an Epstein-Zinn (1991) formulation of the utility function, which provides separate parameters to represent risk aversion and income inequality aversion, this more than doubles the SCC compared to the utility function $u(c) = y^{\eta}/(1-\eta)$.