Non-market Damages from Climate Change

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TOPICS

- IAM damage functions – a brief history
- Approach based on sectoral analyses + CGE
- What are non-market damages? What is the metric of damage?
- Finding the right spatial/temporal scale of analysis
- Extreme events
- Probabilistic damages
- Approach based on GDP regressions
- Weather vs climate

The IAMs

- Three IAMS have received most attention in this literature, all developed in the 1990s.
  - –DICE, first version appears in 1991/1992.
  - –PAGE, first version appears 1991/1992.
  - –FUND, first version appears ~1994.

- Two problematic areas:
  - Modeling of the global climate system
  - Modeling of the damages.
- I will focus on the damage function.

Damage functions at a cross-roads

- The existing IAMs have been forcefully criticized by Pindyck (2013) and others
- The US Government's use of the models in 2010/2013 to estimate a Social Cost of Carbon (SCC) has drawn attention, criticism, and litigation, which is a reason why this Committee was convened.
- A growing theoretical literature challenges the way damages are formulated (Weitzman, Traeger and others).
- A growing empirical literature estimates impacts of weather on GDP and finds starkly different results from what the IAMs predict (Hsiang, Dell et al., Burke and others).
- This presents the question: do we keep using updates of DICE, FUND and PAGE, or is a new approach required?
  - In my view, a new approach is required.

Some history

- The first economist to assess the impacts of climate change was an American economist, Ralph C. D'Arge, University of Wyoming, in the early 1970s.
- The context was concern, dating to the 1960s, that human activities – especially the supersonic transport -- might be harming the stratospheric ozone layer.
- Congress dropped funding for a US SST program in 1971. But development of the Concorde was proceeding, and it was ready for service by the mid-1970s.
- The US Department of Transportation funded a major study of SST and related issues as part of its climate change impacts assessment program (CIAP).
- As part of CIAP, D'Arge produced a report in 1975 on the economics of human impacts on climate.
- The 1200-page report was the work of about 60 researchers using a variety of sectoral process models. The report considered the consequences of anthropogenic impacts on the stratosphere more generally, including not just increased ultraviolet radiation but also changes in precipitation and temperature.

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EPA Report to Congress: Potential effects of Global Climate Change on the United States 1988-1989

- Massive study, two-volume report plus 9 appendices, > 100 researchers.
- Sectoral analyses, mainly using process models, covered impacts on water resources; sea level rise; agriculture; forests; biological diversity; air quality; human health; urban infrastructure; and electricity demand.
- This report served as the basis for a wave of estimates of climate change demands that appeared over the next few years.
- Nordhaus used data from this report to populate his table of sectoral damages in his EJ 1991 paper.

An outpouring of damage estimates

- Nordhaus (1991)
- Cline book (1992)
- Titus (1992)
- PAGE model originates as a report to the EU in 1992
- Hope et al. (1993)
- Fankhauser 1993, 194
- Nordhaus book 1994 (DICE)
- Tol (1995)
- These estimates are cited in 2nd Assessment Report, 1995.
- Smith (1996)
- PAGE update, 1995
- DICE update 1999

- DICE updates in 1999, 2007, 2010, 2013.
    - The sectoral decomposition was abandoned in 2007.
    - A separate representation of sea level rise damage was added.
    - But all the other components of damage were aggregated into a non-sea-level-rise component.
    - Has one region – the world.
- PAGE updates in 1995, 2002 and 2009.
    - Has four sectors: sea level-rise, economic, non-economic and discontinuity.
    - Has 8 regions
- FUND multiple updates. Version 3.5 used in 2010; version 3.8 used in 2013.
    - Has 14 sectors, based mainly on equations idiosyncratically generated by Tol.
    - Has 16 regions.

- While these models have undergone various refinements and updates, and some details have changed, their general structure has stayed same.
    - Updating has focused more on the carbon cycle than on the damage function
- Two features are of particular concern:
    - The sectoral decompositions of damages vary idiosyncratically
    - The updates seem to have lost touch with a growing impacts literature

Sectoral decomposition of damages is highly idiosyncratic across IAMs

- Where (and when) sectoral disaggregations were given by the IAMs, they seem odd (e.g., DICE, FUND).
- The sectoral decomposition varies among IAMs in a highly idiosyncratic manner.
- Thus while the IAM estimates of aggregate impact differ somewhat, the estimates of impacts on specific sectors differ in a more extreme manner.
- This casts some doubt on the validity of the estimate of aggregate impact.

- DICE (1999) US impacts of 2.5 warming in 2100 expressed as annual willingness to pay per US household (2006$)

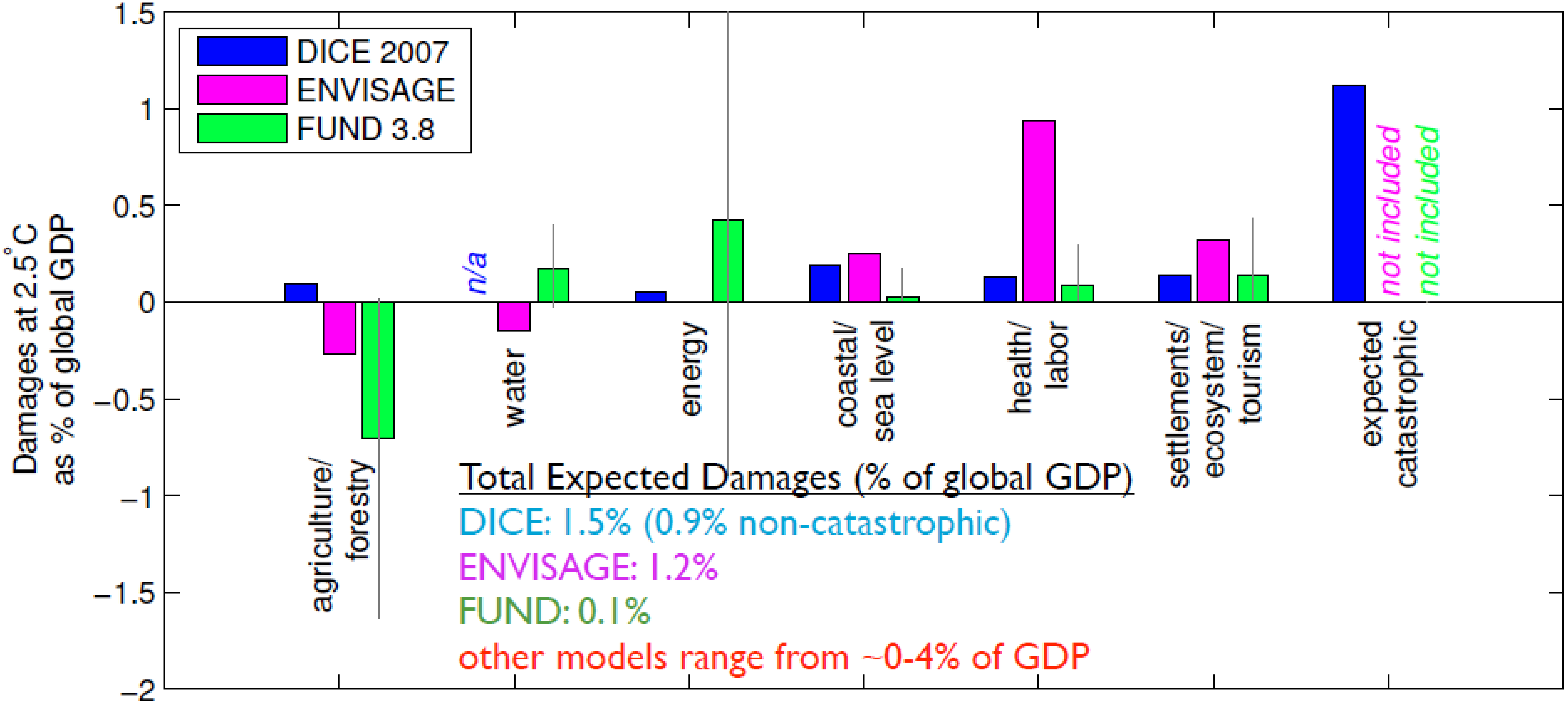
– Market impacts	$126
– Non-market net benefits	-$103
– Subtotal: net damage	$ 23
– Global climate catastrophe impacts	$298
– TOTAL DAMAGE	$321

Divergent decompositions of global damage

- FUND:
  - Single largest component is damage to energy (2/3 total)
  - Second largest is water
  - Health impact is small component of "other"
  - The damages are offset by a large *gain* to agriculture, which reduces the total cost by half
- DICE:
  - no damage to water
  - almost zero damage to energy
  - a small loss to agriculture.
  - health and human life is small, amounting to half of agricultural impact
- ENVISAGE (a European model)
  - Health/labor supply by far the largest component of impact

Limited agreement among IAM damage estimates

Global damages at 2.5°C as % GDP



IAMs use an outdated literature

- In 1990s, when IAMs first developed, the damage functions were in line with the economic estimates of damages then available.
- But, the IAMs have not kept up with the literature appearing since 2001.
- DICE (2010) cites ~25 studies, almost all pre-2001
- FUND cites 32 studies, 28 before 2002
- These IAMs cite ~50 studies in total, most dating from before ~2001
- PAGE (2009) cites 8 studies, 7 from 2006-9
- But the literature on impacts has become vast.

A large and growing literature on impacts (Web of knowledge)

- "Climate change," "damages," "economic impacts"
  - 39 papers through 1999
  - 136 papers, 2000-2009
  - 209 papers, 2010-2013
- "Climate change, "cost"
  - 48,22 papers
- "Climate change," "impacts"
  - ~75,000 papers

- The newer studies tend to be spatially downscaled, temporally disaggregated, and show higher damages.

- Thus, while the literature on impacts has mushroomed, the IAMs have failed to keep up with it.
- This is a matter for concern.
- There are two issues.
- First, it is no longer possible for one economist, no matter how brilliant and how hard working, to keep up with the literature or to be able to make a meaningful assessment of what matters in the new literature and what should be discarded.
- Second, many of the scientists studying impacts go out of their way to avoid any monetary endpoint.
  - While there is a large literature covering physical and biological impacts, except for agriculture and forestry only a tiny portion of the literature carries the analysis to the point of measuring an economic value.
- Impacts that are not represented in monetary terms tend to be invisible to the economists working on the damages from climate change.

An institutional problem

- This disconnect between the work of impact scientists and the attention span of economists thinking about damage functions is reflected in the existing IAMs, but it also extends far beyond them.
- It is reflected in the IPCC itself
  - The sectoral groups in WGII contain almost no economists.
  - WGIII contains no representation of impact science.
- There exists no institutional forum where the scientists studying impacts sit down with economists capable of translating them into monetary endpoints.

What are non-market damages?

- Climate change impacts affecting non-marketed items.
  - Ecosystems, biological diversity, habitats
  - Human health
  - Wildlife/outdoor recreation
  - Amenity values

- Monetary measure of the loss of well-being to consumers from changes affecting market items.
  - Change in consumer’s surplus due to changes in price, quantity, availability or quality of marketed commodities.
    - Tends to be derived form sectoral (“process”) models with representation of demand and supply curves

Some recent damage assessments

- PESETA II Project EU Countries report (2014)
- Austrian Climate Impact report (2014)
  - Both of these combine sectoral impact assessment with CGE analysis to measure to account for economic linkages which transmit impacts throughout the economy.
- US National Climate Assessment (2014)
  - No economic metrics presented
- Dell, Jones & Olken (2012)
  - Panel data regression measuring GDP change
- Risky Business report (2014)
  - Bayesian model averaging to combine estimates

These raise important questions of methodology.

Austrian study

Table 23.1: Climate and weather induced damage, across sectors, quantified "known knowns" impact chains only, average annual totals for Austria (for periods 2016-2045 and 2036-2065)

Damage in €m p.a. (2010 prices, undiscounted)	2016-2045	2036-2065
A) Stock of current damages (extremes)		
Damage observed to date (market & non-market)	850 to 1090	850 to 1090
Annual average of extreme weather event damage (MunichRe, only larger damage, Ø for period 2001 to 2010)	705	705
Non-market damage:		
Heat induced premature deaths (monetary value)	145 to 385	145 to 385
Evaluation using Value of Statistical Life	385	385
Evaluation using Value of Life Years Lost	145	145
B) Additional Future damages		
Damage induced by future climate change	995	1,955
Welfare loss (reference socioeconomic development, mid-range climate change, see Chapter 22, Table 22.2)		
Additional damage induced by future socioeconomic change	270	825
Energy additional investment	99	299
Road infrastructure additional investment	8	20
Riverine flooding additional damage	163	506
Non-market damage:		
Heat induced premature deaths (monetary value)	95 to 255	570 to 1,300
Evaluation using Value of Statistical Life (€ 1.6m per SL)	255	1,300
Evaluation using Value of Life Years Lost (€ 63000 per LYL)	95	570
C) Total annual average (comprising current level plus future additional damages)	2,210 to 2,610	4,201 to 5,170

The conventional approach to damage estimation (PESETA, Austrian study)

- Break impacts down by sector.
- Employ process models to analyze individual sectors (partial equilibrium models that provide finer spatial/temporal scale).
- Aggregate results to annual and national basis, sector by sector.
- Run the sectoral impacts into a CGE model to account for economic linkages which transmit impacts throughout the economy.
- If the CGE model contains a utility function, this can track the non-market (i.e., consumers surplus) impacts of changes in market goods.
- The standard practice is to assume that the non-market component of utility is separable from the consumption of market commodities.

- However, there is no evidence to justify the assumption of separability between the market and non-market components of utility, and significant evidence to challenge it.
- It is *not* an innocuous assumption.
- Carbone and Smith (2013) calibrated a simple non-separable CGE model and demonstrated that overlooking the non-separability can lead to significant error in calculating the CGE consequences of sectoral changes.
- This becomes all the more important when one recognizes that climate change impacts affect non-market commodities as well as market goods.

Areas for improvement in CGE analysis

- The CGE analysis should therefore investigate a non-separable formulation of the utility function.
- CGE analysis should also allow for supply bottlenecks as in Hallegatte et al. (2007) analysis with non-equilibrium dynamics.
- The CGE analysis is usually deterministic. It may be possible to make it probabilistic.
  - Follow the current practice of doing a sectoral/CGE analysis using average ΔT, assuming no occurrence of a local extreme event during the period.
  - Also conduct a separate analysis conditioned on the occurrence of a local extreme event.
  - Combine the two analyses using weights to reflect (i) the probability of occurrence, and (ii) the area affected.

What is the metric by which damage is measured?

- Economic theory says the metric is consumer's surplus (compensating/equivalent variation) plus producer's surplus.
- Sometimes this is evaluated through a two-step procedure.
  - E.g., With health effects, there is a projection of mortality, and then this is monetized using a VSL.
- In other cases a metric is used that is not a meaningful welfare measure.
  - E.g., Increased household expenditures on energy (expenditure change does not measure welfare)
  - Increased profit/land value in agriculture (measures gain to producer, but not loss to consumer).
  - Change in GDP (GDP is not a metric of welfare).

Taking welfare measurement seriously

- GDP is a measure of economic activity; it is not a measure of economic welfare.
- Changes in well-being arise from changes in prices, changes in income, changes in non-market utility.
- The use of GDP may account for change in income but it does not reflect non-market commodities nor the change in consumer surplus from changes in marketed commodities.

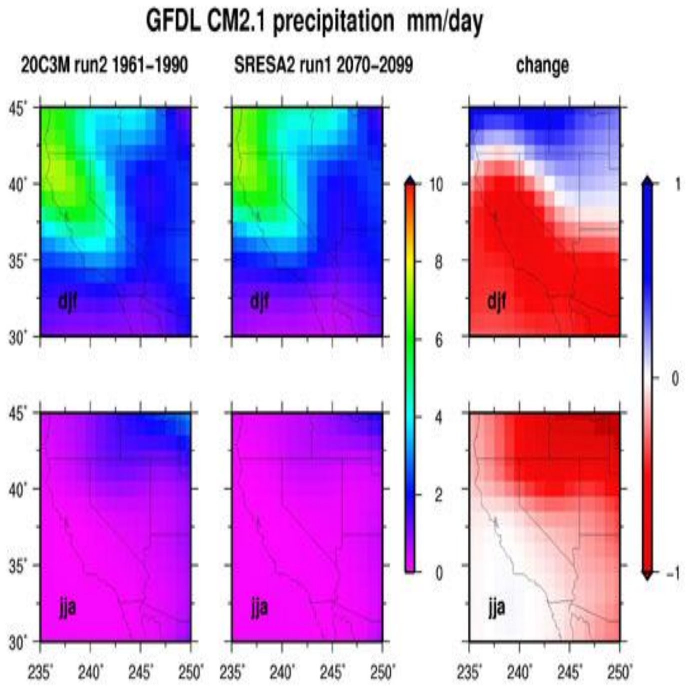
- This issue is illustrated by what was done in Nordhaus (1991) to translate the results from the EPA 1989 sectoral studies to a National Income Account-oriented framework.

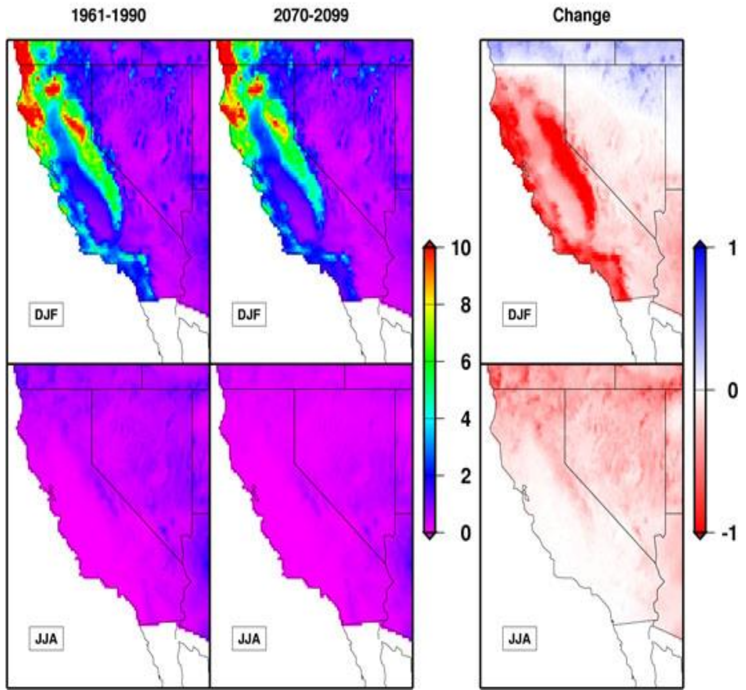
Shoe-horning consumers + producers surplus into National Income Accounts

- With agriculture, for example, the sectoral study identified a loss to consumers of -$6.69 billion, but a gain of $1.11 billion to producers, because of the price rise triggered by a negative supply shock when demand is inelastic.
- Nordhaus treated the net change – a change of -$5.58 billion in consumers plus producers' surplus – as a reduction in National Income.
- However, most of the impact is consumer's surplus and would not show up in a National Income Account.

The challenge of scaling damages to sync with IAM

- The climate system component of the IAMs operates on a very aggregate spatial scale (broad regions, the world) and temporal scale (change in annual average daily temperature over a year or a decade).
- Climate, changes in climate, and impacts occur at a much finer spatial scale (e.g., a watershed) and temporal scale (hours, days, weeks).
- The sectoral analyses of impacts function on something closer to these fine spatial/temporal scales,
- They need to be translated into a damage function on the coarse scale of the IAM.
- This translation of scale is a challenge – and a potential source of bias,





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 stream flow, soil moisture and other hydrologic properties

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			

Aggregation systematically biases down the damage estimate

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

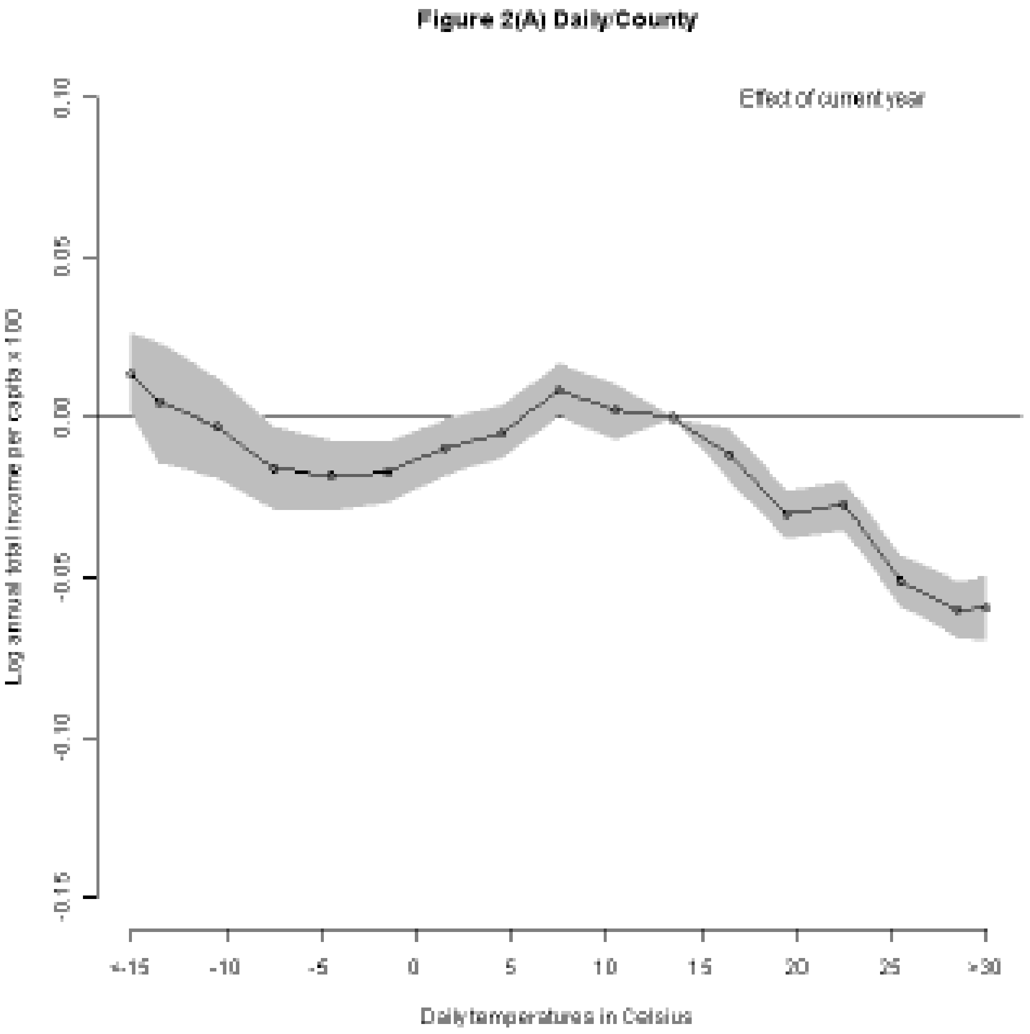
$$E\{D(\Delta T)\} > D(E\{\Delta T\}).$$

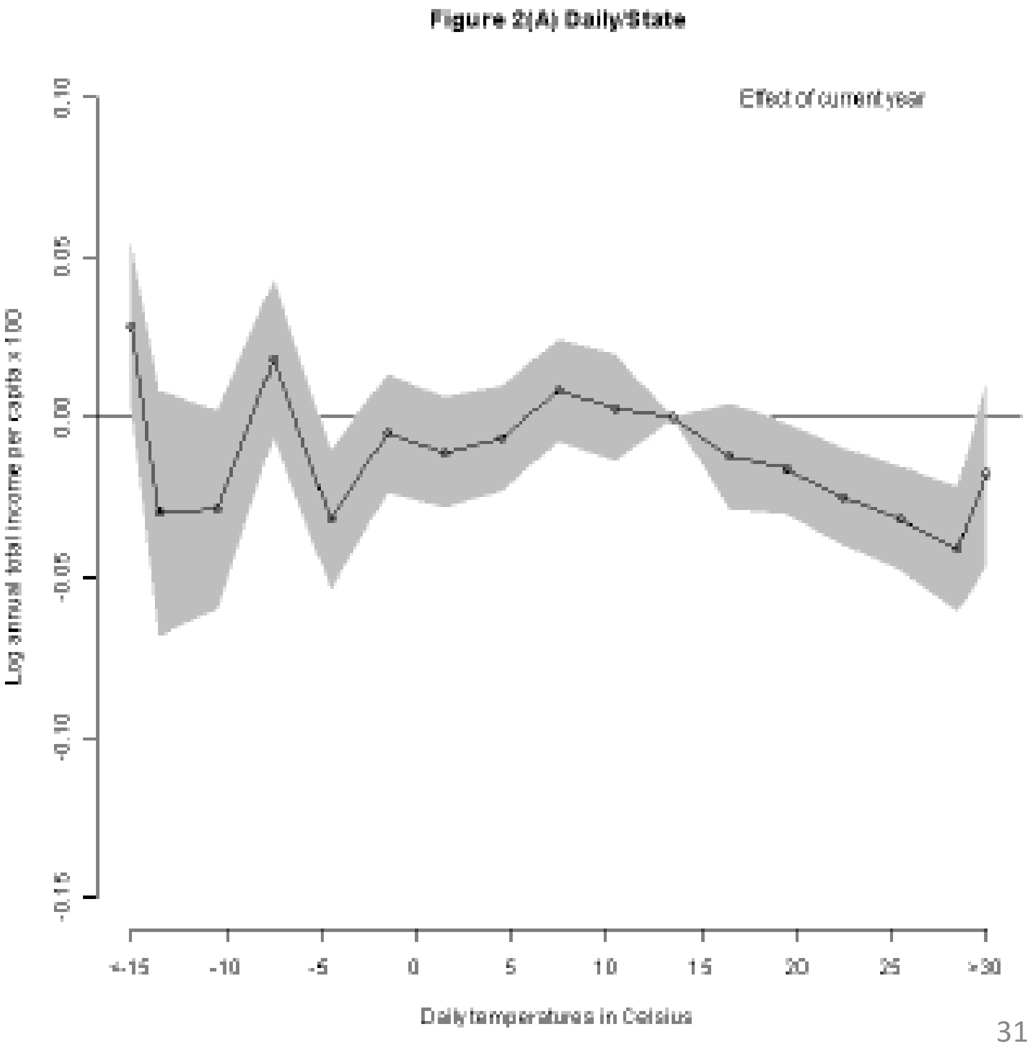
- A local approximation:

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

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

County vs state as spatial unit

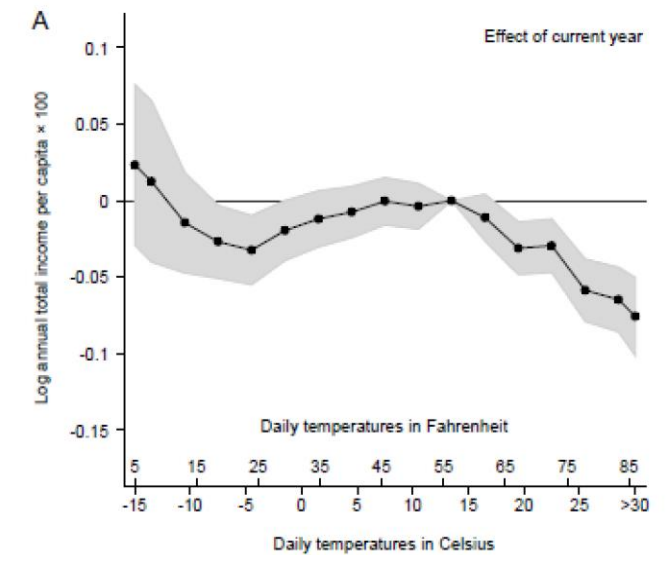




Need multiple time scales?

- Climate -- and climate change -- affects humans differently on different time scales.
- Need to distinguish chronic versus acute impacts from climate change. E.g., heat stress:
  - Chronic effect: reduced productivity of work in environment that deviates much from what is required to maintain body close to 98.6F.
  - Acute effect: die if exposed to extreme cold or extreme heat for period of several days.
- **LOCAL EXTREME EVENTS**
- The need for additional generating capacity depends on *hourly* peak power demand.
- Crops die when temperatures exceed a certain threshold for several days in a row.
- Coastal flooding occurs when a storm happens to coincide with a high tide.

- I call these *local* extreme events – they are local in time and in space – to distinguish them from the catastrophic tipping point events discussed by Lenton et al. (2008), which play out over much vaster spatial and time scales.
- A clever way to capture these finer temporal scale events, developed by Deschenes & Greenstone and Schlenker & Roberts, counts the number of days (hours, etc.) falling in different temperature intervals.
- We saw an example after Deryugina & Hsiang



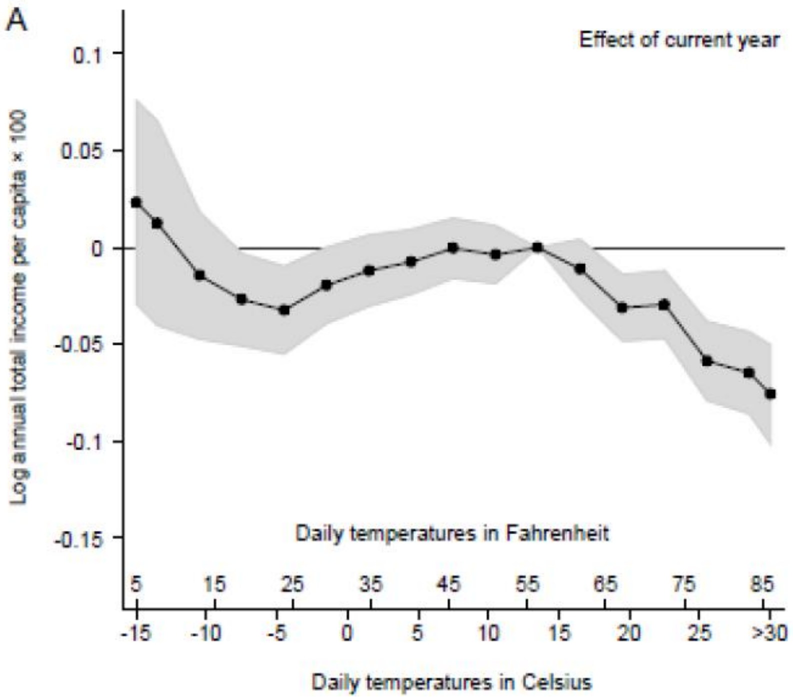
Such extreme events can to account for a large fraction of damages.

- Impact on US Agriculture (Schlenker et al. 2006)

Proportion of net economic loss to US agriculture due to change in:

	Precipitation & degree days 8-32C	Degree days over 34C
2020-2049 both emission scenarios 2070-2099 B1 scenario	10-20%	80-90%
2070-2099 A1Fi scenario	40%	60%

- Impact on personal income (Deryugina & Hsiang 2014)



IAM damage functions presently omit local extreme events

- The challenge is: how to incorporate from such extreme events into the damage function of IAMs like DICE operating not on a daily scale but on a 5-year time step.
- There needs to be some adjustment function to rescale damages projected from an annual/multi-year time scale to account for harmful events on a finer time scale.

Extreme events, risk and risk aversion

- One of several creative innovations introduced in the *Risky Business* study was to frame damages probabilistically.
- This was done for three reasons:
  - The damage estimates came from econometrically estimated average treatment effects, which provided not just a point estimate but also a confidence interval.
  - Bayesian model averaging was introduced as a means of combining different estimates found in the literature, and that naturally generates a posterior probability distribution with a variance as well as a mean.
  - It draws attention to climate *risk*. Climate mitigation policy is, above all, an exercise in risk management. When engaged in risk management it does not make sense to focus just on the mean outcome: it makes sense to focus on the tail of the distribution – this is where the risk lies.

- The theoretical literature has grappled with framing an IAM-style analysis in terms of risk, starting with Weitzman (2007), and continuing more recently with important contributions by Traeger and Cai and Judd et al.
    - Epstein-Zin preferences not reflected in current IAMs
- In some of the theoretical analyses, uncertainty enters through the working of the climate system (e.g., the climate sensitivity is random), but in others there is a random component – i.e., uncertainty – in the damages.
- The *Risky Business* approach links up with these theoretical developments from the direction of the empirical estimate of the damage function.
- But, at least so far, it omits two elements that might naturally fit in:
    - Extreme events, whose occurrence is uncertain, but which could account for a preponderance of the damage in coming decades.
    - Risk aversion – adding a risk premium to the estimate of expected damage.

Risk aversion and downside risk aversion

- In a forthcoming paper (Hanemann et al., 2016) I have argued that, in California's Central Valley agricultural water users and agricultural water suppliers are likely to be significantly *downside risk* averse.
    - We calculate the downside risk averse risk premium for reduced water supply.
- This is a modification of the conventional theory of risk aversion.
- It is based on the notion that there is some asymmetry in risk attitudes towards outcomes. Downside outcomes are weighed more heavily than upside outcomes.
- The concept was first applied in the financial literature in the 1970s – going bankrupt is viewed differently than making an unusually large profit.
- This potentially has some relevance to the question of whether the IWG should treat both tails of the SCC distribution symmetrically.

Methodology: process models vs econometric regressions

- Starting with work by Hsiang (2010), and Dell et al. (2009, 2012) there has been a new interest in running regressions of GDP on weather/climate.
- In effect, these researchers are estimating a treatment effects for weather/climate.
- Dell has argued that this is a more reliable approach than reliance on process models.

The use of sectoral models has been questioned starting by Dell et al (2012) and others.

- Dell, Jones and Olken (2012) critique of the IAM damage function approach

sions. A fundamental challenge for this approach is complexity. The set of candidate mechanisms through which temperature may influence economic outcomes is large and, even if each mechanism could be enumerated and its operation understood, specifying how they interact and aggregate poses substantial difficulties. The climate literature, at the micro level, suggests a wide array of potential temperature effects, including influences on agricultural productivity, mortality, physical performance, cognitive performance, crime, and social unrest, among other outcomes, many of which do not feature in current implementations of the enumerative models.[1]

- They advocate an alternative approach

temperature and precipitation to identify their effects.[2,3] By examining aggregate outcomes directly, we avoid relying on a priori assumptions about what mechanisms to include and how they might operate, interact, and aggregate. By utilizing fluctuations

Which approach to use?

- The macroeconomic approach offers an advantage of simplicity; it avoids "a priori assumptions" about pathways and mechanisms.
- Instead of attempting to track down the myriad individual effects, it provides a reduced form summary of how weather variation affects GDP.
- It reflects the current trend in econometrics to eschew structural models and to estimate average treatment effects as the more robust approach

- This macro-economic approach is attracting much attention and has value. It has led to important insights.
  - There are multiple pathways -- more than usually considered.
  - Higher temperatures can reduce rates of growth, not simply the level of output. They have a lingering impact.
    - The impact can be due to disruption of human capital formation as well as destruction of physical capital.
  - Higher temperature affects numerous sectors of poor countries' economies, including reducing industrial output as well as agricultural output, and causing political instability.

Limits to the macroeconomic regression approach

- GDP is not a reliable metric of welfare.
- Predicting the effect of weather on GDP raises several questions:
  - Is the measured treatment effect stable across time and across circumstances?
- Dell et al. assert their approach is more robust, and therefore reliable, precisely because it is a reduced form.
- It avoids assumptions about what mechanisms are involved and how they operate. They assert that one does not need to know this.
  - But, is the effect invariant with respect to policy interventions (e.g., adaptation)?
  - Is it invariant with respect to the type of causal pathway (local extreme events, annual warming, flooding, precipitation; impact on current output versus on stocks of physical capital, human capital, or natural capital)?
  - How adequately does it handle the curvature of the damage function?

Impact pathways and the functional specification of the damage function

- The question of impact pathways ties in with the issue – discussed in the theoretical literature – of the functional specification of the damage function.
- The IAM damage function formulation implies that damages are:
    1. Reversible from period to period as output varies
    2. Independent of past levels or rates of warming, or of the cumulative degree of warming in the past.
    3. Devoid of lingering effects, including impacts on stocks of capital, whether physical, human or natural.
- Current versions of the econometric approach correct for (3) but not yet (1) and (2).

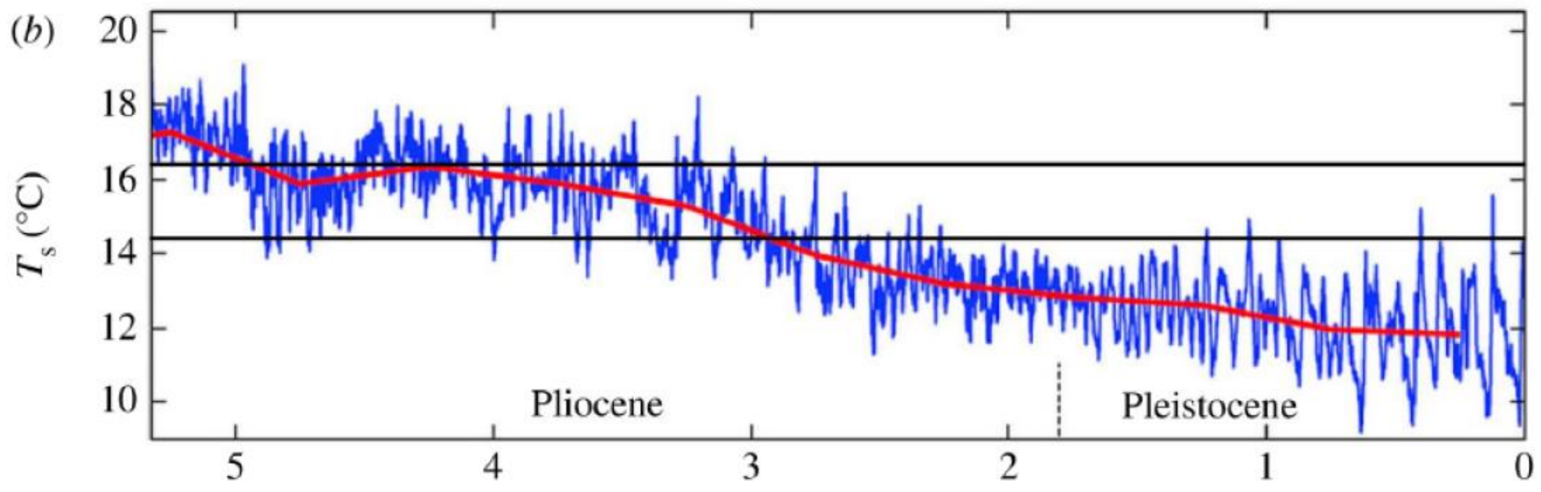
Weather vs climate

- Using weather with panel data offers a way to measure a treatment effect, holding all else constant.
- Does that measure the impact of a change in climate?
- If the LeChatelier principle holds, the long-run harm from a change in climate would be smaller than the short-run impact from a change in weather.
- But, does it hold?
  – Not if there are stock-effects (e.g., can pump groundwater to make up for a loss of stream-flow in the short-run, but not necessarily in the long-run).
  – When climate changes, does all else stay constant?

Caution is called for in attempting to use panel data regressions across countries with different weather or climate in order to predict the consequences of a substantial change in global temperature unprecedented in human history.

2C warming was last experienced 3-5 million years ago

Hansen et al. (2012)



Some recommendations

1. There is now considerable ferment in the economic analysis of the damages from climate change. It certainly is time to try some new approaches as an alternative to the existing IAM damage functions.
2. It makes sense to employ multiple approaches to measurement.
   - Aim to better understand strengths and weaknesses of alternative approaches.
3. Pay attention to meaningful measurement of welfare change.
4. Try to capture the impact of (local) extreme events.
5. Consider the use of calibration factors to adjust for weaknesses with regard to (3) and (4).
6. Explore the possibility of interaction (non-separability) between climate impacts on nonmarket commodities and impacts on the demand/supply of market commodities.