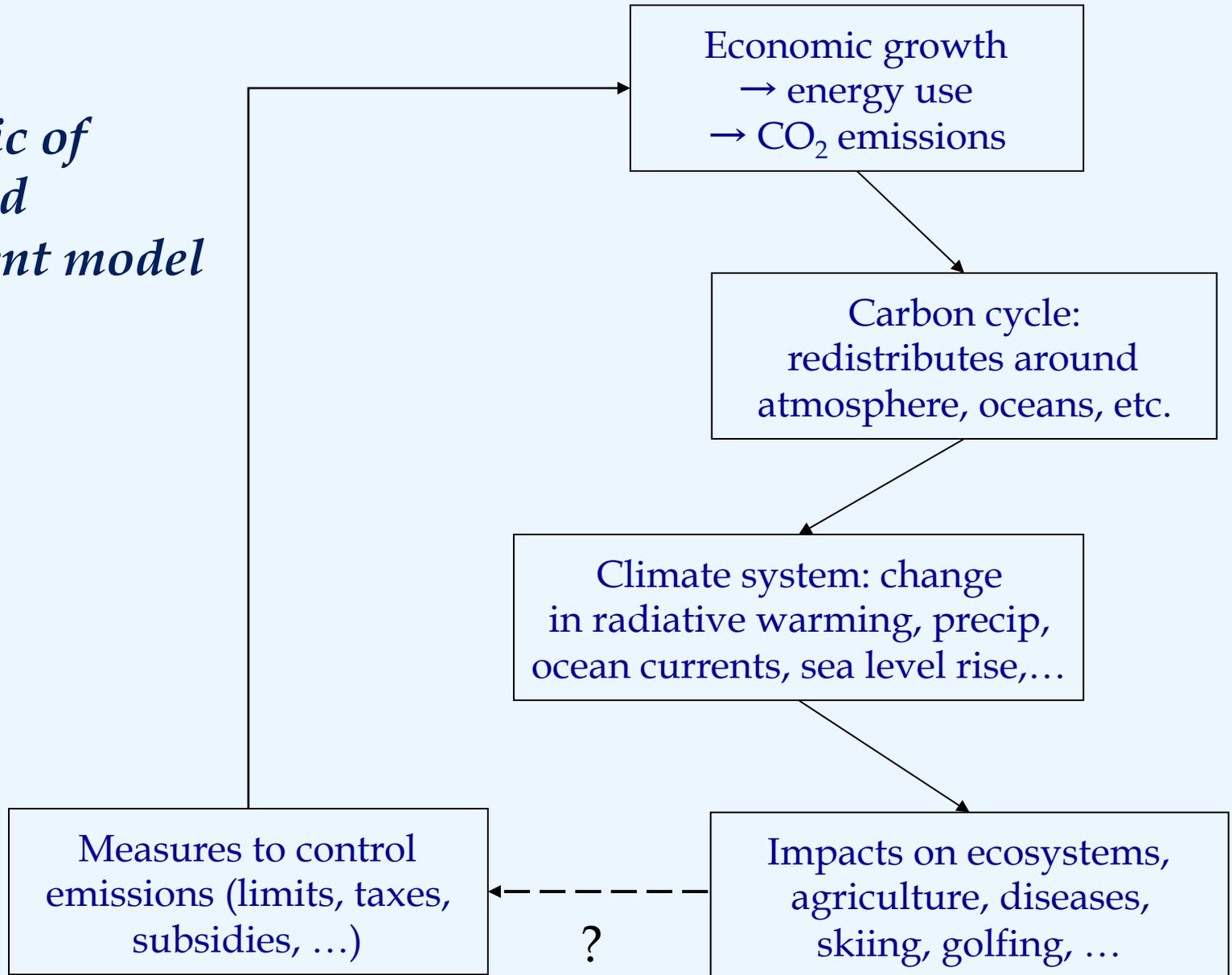# RICE model runs

Bill Nordhaus
Yale University

Model Uncertainty Group
Snowmass Meeting
July 30, 2012

Schematic of integrated assessment model

Economic growth
→ energy use
→ CO_2 emissions

Carbon cycle: redistributes around atmosphere, oceans, etc.

Climate system: change in radiative warming, precip, ocean currents, sea level rise,…

Measures to control emissions (limits, taxes, subsidies, …)

?

Impacts on ecosystems, agriculture, diseases, skiing, golfing, …

RICE-2010 model structure

Economic module:

- Ramsey-Cass-Koopmans model with labor, capital, abatement, damage
- Climate variable is externality and market underinvests in climate capital
- 12 regions, no trade, limited carbon energy

Environmental module:

- Emissions = f(Q, carbon price, time)
- Concentrations = g(emissions, 3 C reservoirs)
- Temperature change = h(GHG forcings, lag T, …)
- Economic damage = F(output, T, CO_2, sea level rise)

Some detail on how output and emissions are generated

Twelve regions (j = US, China, India, EU, Africa, ...)

1. Population exogenous: $\Delta L_t^j = L_{t-1}^j G_t^j$

2. Total factor productivity exogenous: $\Delta A_t^j = A_{t-1}^j H_t^j$

3. Production is Cobb-Douglas in A, L, K: $Y_t^j = A_t^j \left(K_t^j\right)^\alpha \left(L_t^j\right)^{1-\alpha}$

4. CO_2 emissions are function of output, intensity, and carbon price (p)

$$E_t^j = \sigma_t^j Y_t^j \left(p_t^j\right)^\lambda$$

5. Carbon price is determined by Hotelling rents and carbon-pricing policy

6. National investment rate is endogenous and optimized per the Ramsey model, over per capita consumption (c), and countries are combined using the "Negishi algorithm."

$$\max_{c_t^j} W = \sum_{j=1}^{12} \left[\sum_{t=1}^{\infty} \varphi_t^j \left\langle U(c_t^j, L_t^j) R(t) \right\rangle \right]$$
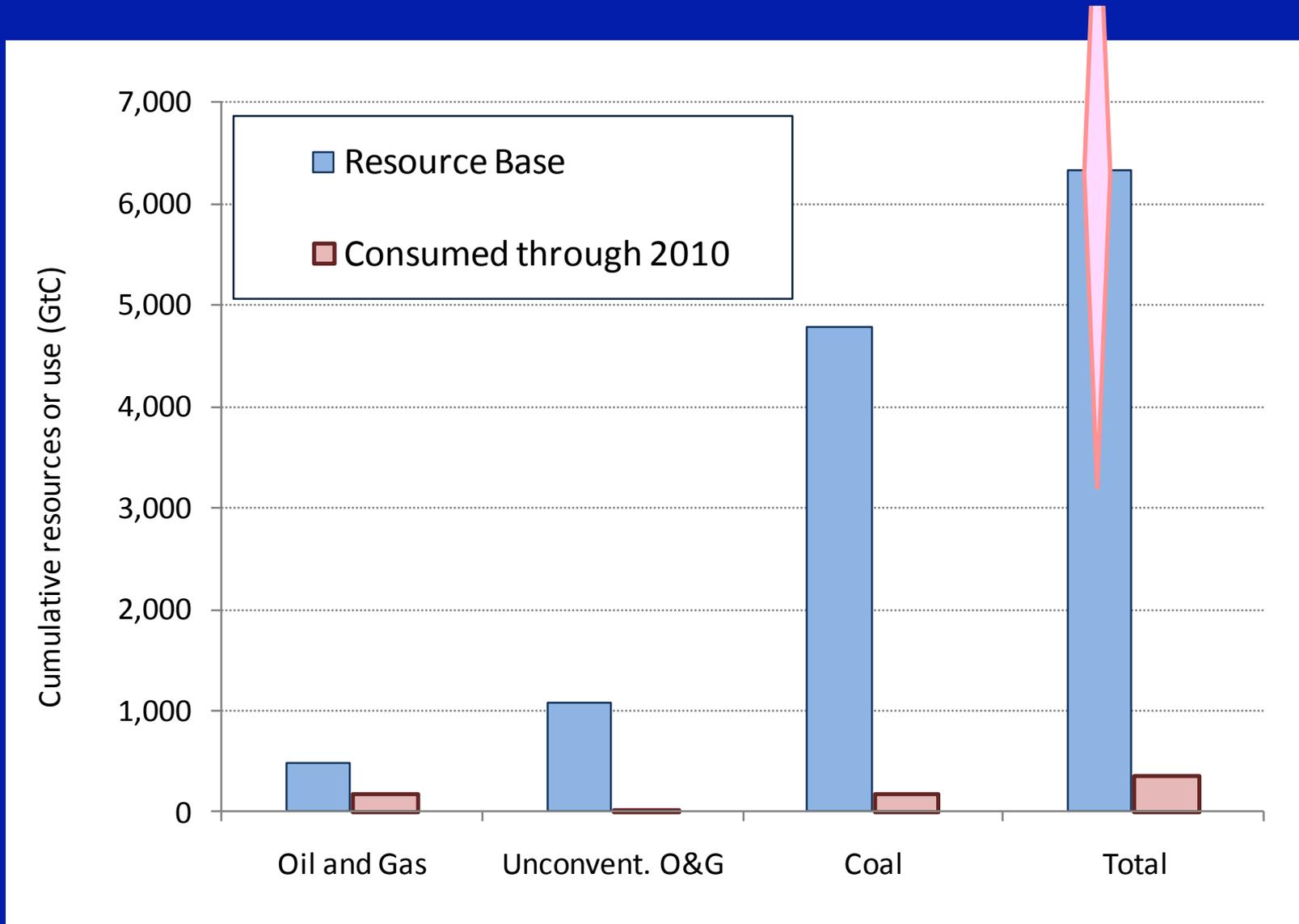
7. Current version is solved on Excel-Solver, with approximately 155 lines per country.

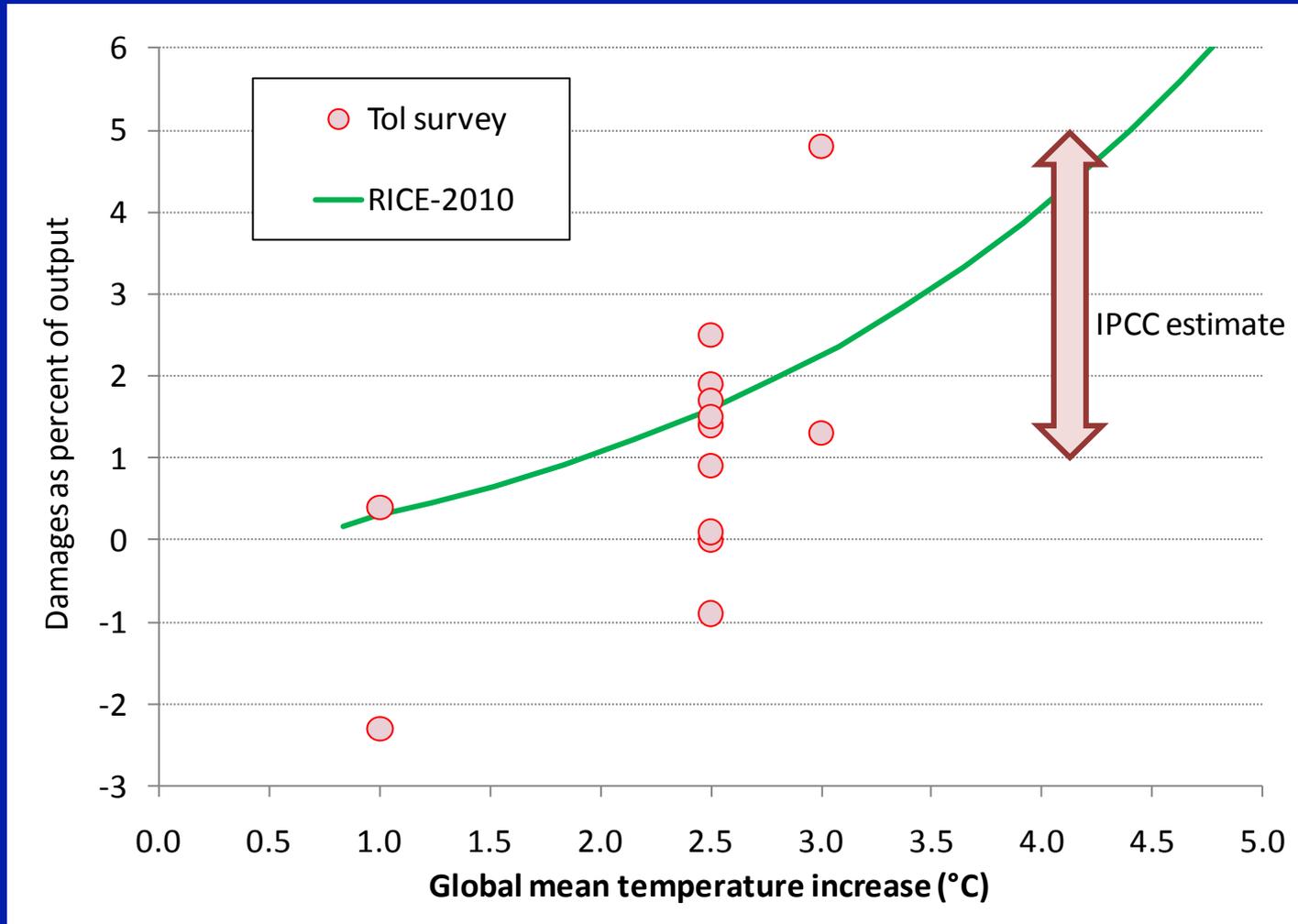# Output growth by RICE region
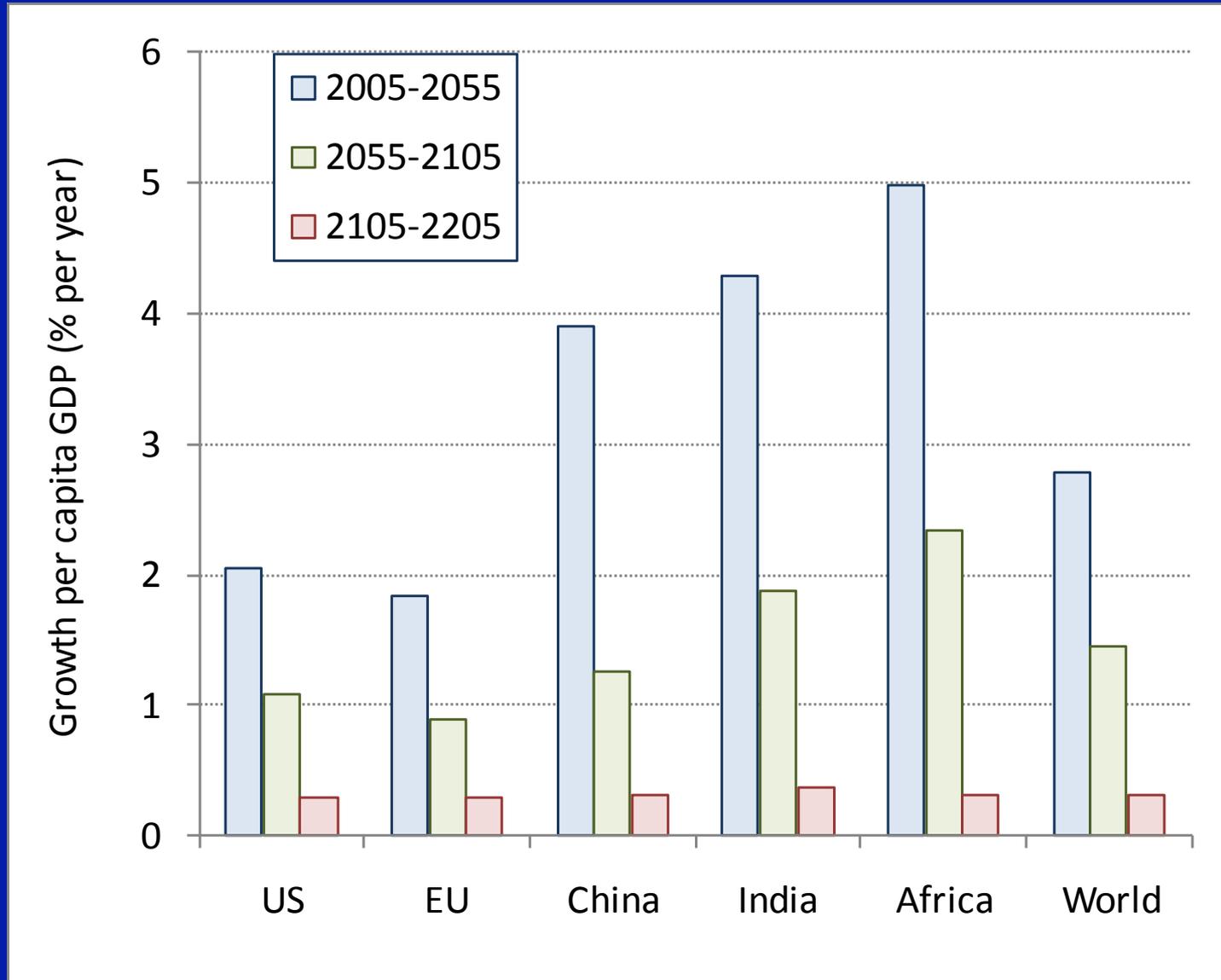
Source: Nordhaus, "Economics of Copenhagen Accord," *PNAS (US)*, 2010.

Cumulative resources and use of carbon fuels

Resources from Nakicenovic. Consumption from CDIAC, updated by author.

Aggregate damage estimates from different studies

Source: Richard Tol, *Jour. Econ. Persp.,* 2009

Implementation of experiments

Variable20	Change	Implemented
Emissions pulse	10 GTt CO2 pulse in 2020	10 Gt CO2 increase in emission from non-fuel sources.
Output pulse	5% in 2020 global	5 percent drop in TFP in 2025 in each region
Output growth	½% p.y. 2020-2100	½ % p.y. increase in TFP from 2010 to 2100 in each region
Temperature sensitivity	1 °C increase in TSC	Change in equilibrium TSC with no change in other climate parameters
Output growth	1% p.y. 2020-2050	1% p.y. increase in population growth from 2020 to 2050 in each region
CO2 tax	Per AMPERE experiment	CO2 tax in all regions and sectors without exclusions per AMPERE runs

Problems

1. Because of coarse time step, could not get exact timing.
2. Exogenous population and technology implies no reaction of those variables to related shocks (e.g., Malthusian or demographic transition response).
3. Should CO2 pulse be from a particular sources? Or a burp from the oceans or biosphere?
4. Model is not designed for sensitivity experiments (see below).

Output impacts

	Base	5% drop in output in 2020	Increased growth of 0.5%	Increase of 1 degc in TSC	Increase of pop growth by 1%	Carbon tax	Emissions pulse
Output (% from base)							
2010	0.00%	0.00%	1.52%	0.00%	0.00%	-0.03%	0.00%
2050	0.00%	-0.04%	29.08%	-0.20%	27.61%	-0.13%	-0.02%
2100	0.00%	0.00%	72.90%	-1.09%	35.12%	-0.03%	-0.03%
Consumption (% from base)							
2010	0.00%	0.00%	1.51%	0.00%	0.00%	-0.03%	0.00%
2050	0.00%	-0.04%	29.08%	-0.20%	27.61%	-0.13%	-0.02%
2100	0.00%	0.00%	72.90%	-1.09%	35.12%	-0.03%	-0.03%
Population (% from base)							
2010	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2050	0.00%	0.00%	0.00%	0.00%	33.15%	0.00%	0.00%
2100	0.00%	0.00%	0.00%	0.00%	36.52%	0.00%	0.00%

Emissions impacts

	Base	5% drop in output in 2020	Increased growth of 0.5%	Increase of 1 degc in TSC	Increase of pop growth by 1%	Carbon tax	Emissions pulse
Emissions CO2 (% from base)							
2010	0.00%	0.00%	1.23%	0.00%	0.00%	-9.18%	2.40%
2050	0.00%	-0.04%	27.81%	-0.03%	26.41%	-42.87%	0.00%
2100	0.00%	0.00%	73.82%	-0.23%	35.68%	-99.00%	-0.01%

Temperature impacts

	Base	5% drop in output in 2020	Increased growth of 0.5%	Increase of 1 degc in TSC	Increase of pop growth by 1%	Carbon tax	Emissions pulse
Atmospheric concentrations (CO2, difference ppm)							
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2050	0.00	(0.31)	22.26	(0.01)	16.82	(48.94)	3.68
2100	0.00	(0.22)	178.55	(0.33)	116.40	(269.26)	2.24
Atmospheric concentrations, CO2-e (difference, ppm)							
2010	-	-	0.00	-	-	(0.04)	0.01
2050	-	(0.32)	22.32	(0.01)	16.83	(49.13)	3.72
2100	-	(0.23)	181.46	(0.33)	118.43	(273.40)	2.29
Temperature (difference, deg C)							
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2050	0.00	(0.00)	0.09	0.21	0.07	(0.22)	0.02
2100	0.00	(0.00)	0.57	0.55	0.40	(1.17)	0.01

Damages

	Base	5% drop in output in 2020	Increased growth of 0.5%	Increase of 1 degc in TSC	Increase of pop growth by 1%	Carbon tax	Emissions pulse
Damages (% of output)							
2010	0.24%	0.24%	0.25%	0.24%	0.24%	0.24%	0.24%
2050	1.11%	1.11%	1.21%	1.28%	1.19%	0.95%	1.13%
2100	3.24%	3.24%	4.27%	4.14%	3.94%	1.83%	3.26%

Social cost of carbon

Social cost of carbon (2005 $)		$/tC	$/tCO2
Discounted to 2005		20.43	5.57
Compounded to 2020 at 5.5% / year		45.61	12.44

Inherent issues in modeling uncertainty: model calibration

1. Many models have either highly simplified or "reduced form" structures for some modules.

2. These are calibrated to larger structural models.

3. However, they are likely to be calibrated to first-order properties, not to second order properties.

4. Therefore, we may find that models are not designed for parametric uncertainty analyses.

Example of temperature sensitivity in DICE/RICE models. Examine the transient and equilibrium TS and compare with IPCC model range for Fourth AR (next slides).

Example of DICE/RICE climate model

-
-

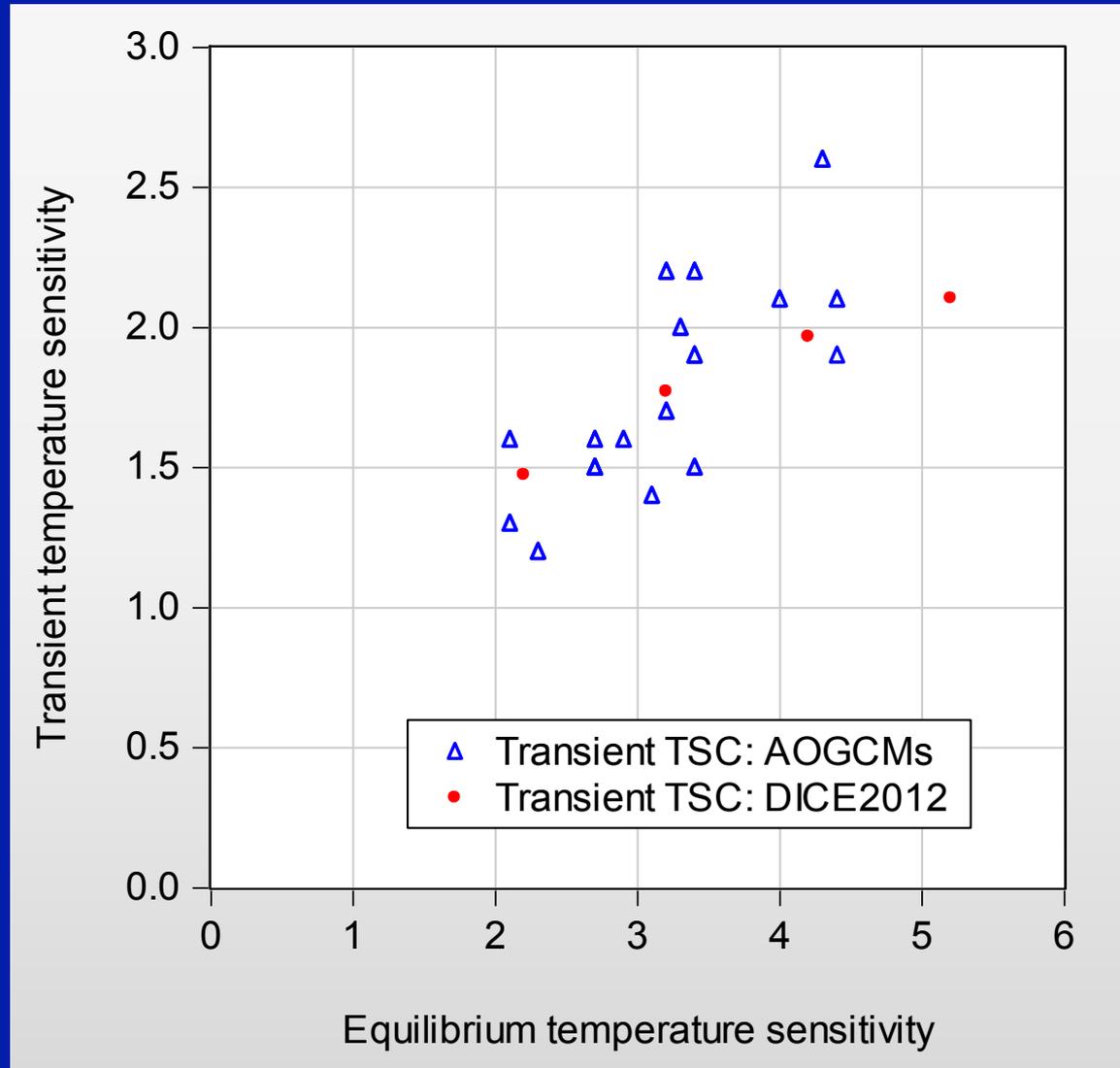| Atmosphere		Biosphere
	Shallow ocean	
	Deep ocean	
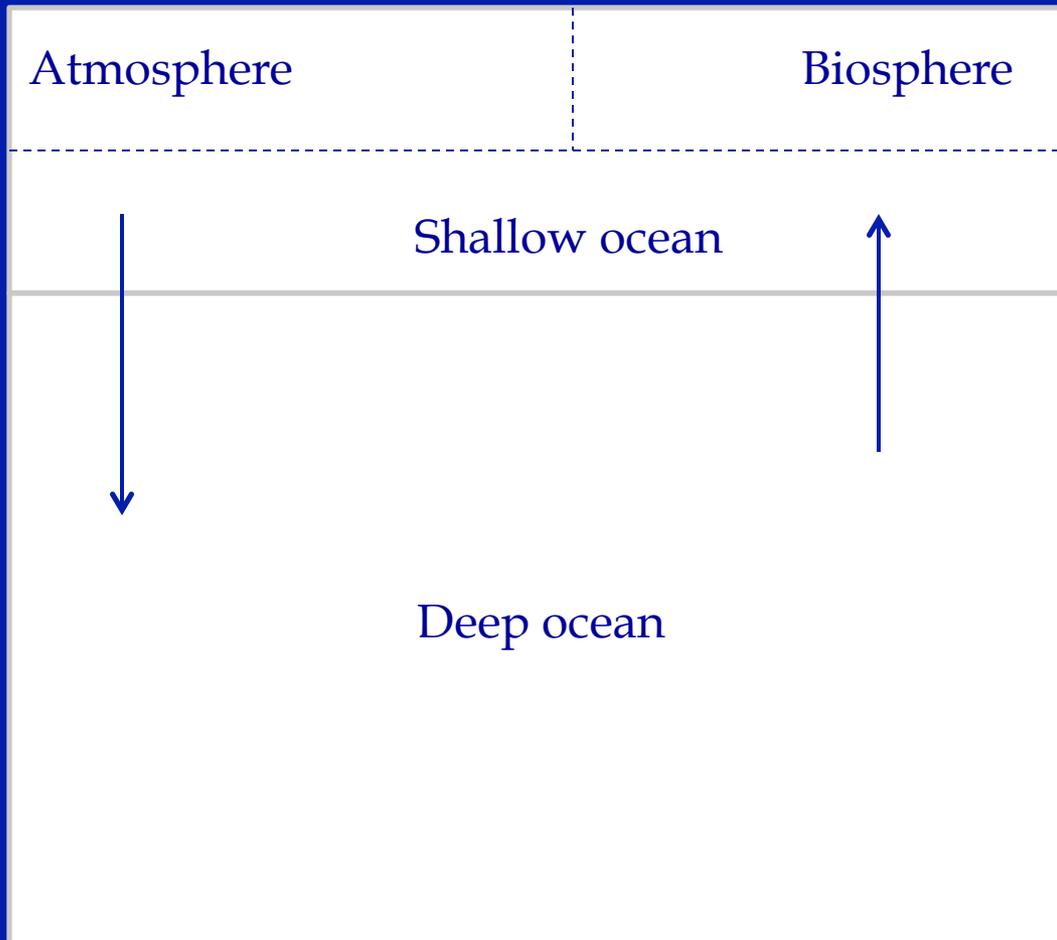
T_{up}

T_{lo}
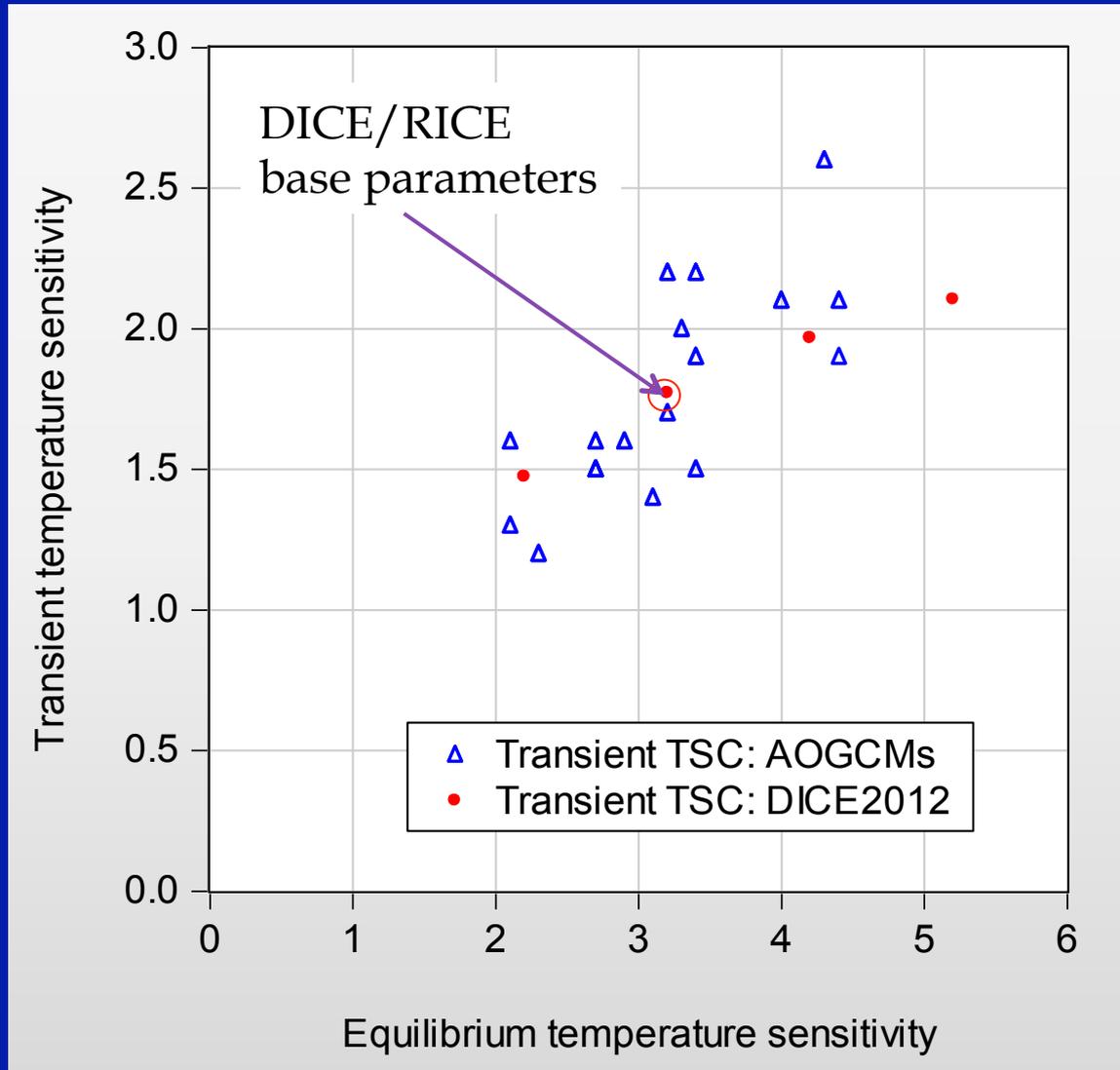
Equilibrium v. Transient response in DICE/RICE

Transient response is T response at 70 years for a 1% per year CO2 increase up to 2x.
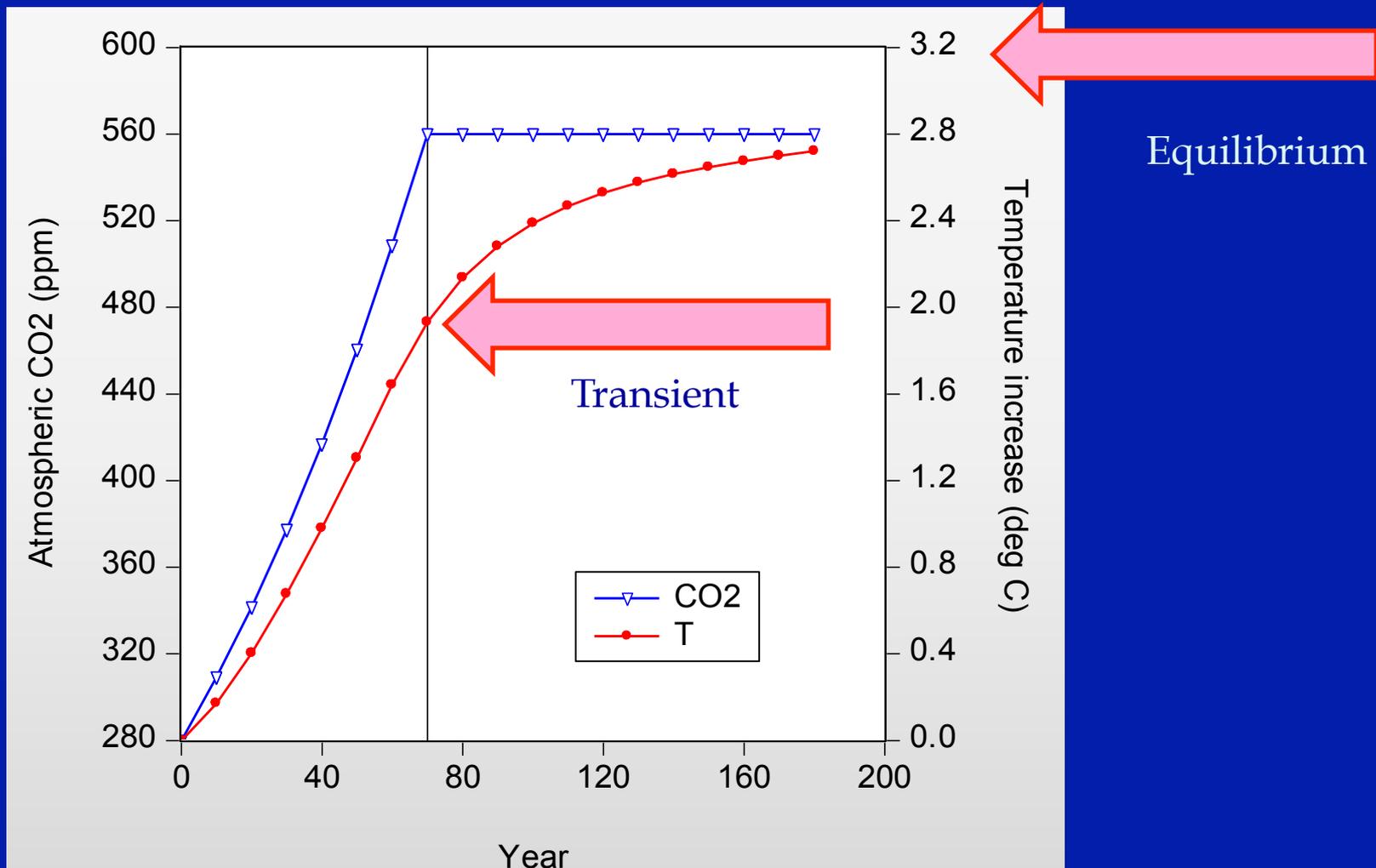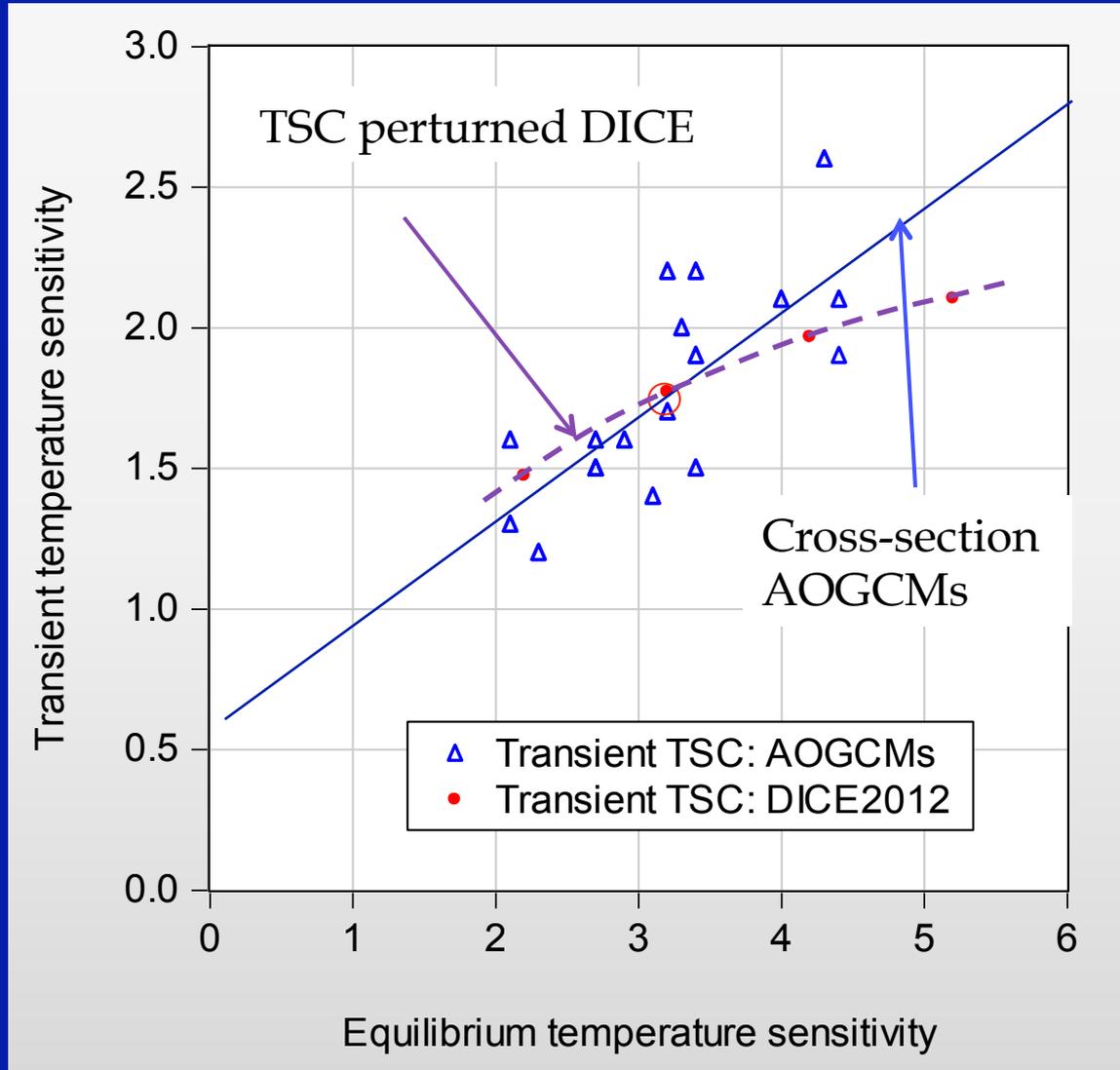
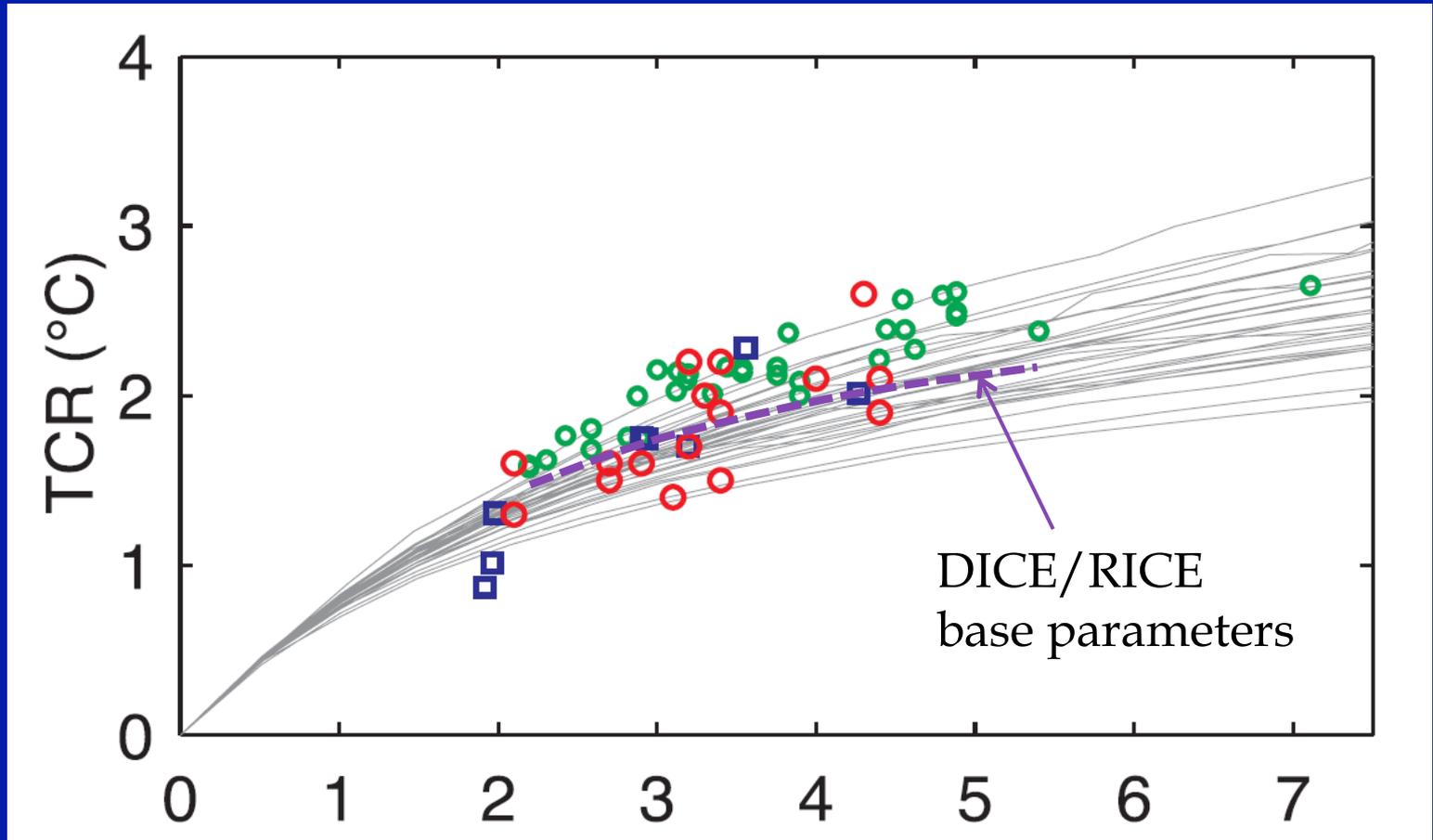# TSC: IPCC models DICE-2012

TSC: IPCC models DICE-2012

TSC: IPCC models DICE-2012

Broader set of models

From IPCC, Science, AR4. Red = all AOGCMs; blue = EMICs; green = perturbed Hadley; grey = perturbed EMICs; dashed = TSC perturbed DICE-2012.

21

How to think about this?

1. Basic math of calibration theory:

   - Have underlying function $y = g[\alpha(\lambda_1, \lambda_2, ...)]$.

   - Approximate it by $y = g(\beta_1 \lambda_1)$, where $\beta_1 = \partial \alpha / \partial \lambda_1$.

   - However, this will be misspecified in general, so will not produce correct moments of y.

   - Will need to construct the functions to capture the uncertainty function correctly, i.e., so that the β_1 is the uncertainty transformation.

2. Note that large structural models cannot do this because they do not actually have the α parameter.

3. Will need to construct model where the parameters are designed to calculate the correct transformation (see my introductory slides).