Modelling and the economics of climate change

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CLUSTER OF EXCELLENCE
CLIMATE, CLIMATIC CHANGE, AND SOCIETY (CLICCS)

DFG

Climate change ...

- will affect the well-being of human and non-human beings around the world for centuries.
- causes damages that are not adequately reflected in the prices of fossil fuels burned today, or of how land is used and waste is treated. It has therefore been termed:

  "the greatest market failure the world has ever seen" (Stern, 2007).

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... is a key challenge for sustainable development.

$\Rightarrow$ The extent of this market failure is summarized by the **'social cost of carbon' (SCC)**: the present value of all future impacts from an additional ton of CO_2 emissions.

The social cost of carbon (SCC) ...

- has been termed *"the most important number you've never heard of"* (New York Times 2021; Michael Greenstone, President Obama's Chief Economist)

U.S. INTERNATIONAL CANADA ESPAÑOL 中文

The New York Times

OPINION

PETER COY

'The Most Important Number You've Never Heard Of'

Sept. 17, 2021

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    - Applied globally social cost of climate change >8% of global GDP

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- is often used for informing & demanding appropriate levels of carbon prices

FRIDAYS FOR FUTURE

Entscheidend für die Einhaltung des 1,5°C-Ziels ist, die Treibhausgasemissionen so schnell wie möglich stark zu reduzieren. Deshalb fordern wir ab sofort:

- Das Ende der Subventionen für fossile Energieträger
- **1/4** der Kohlekraft abschalten
- Eine CO2-Steuer auf alle Treibhausgasemissionen. Der Preis für den Ausstoß von Treibhausgasen muss schnell so hoch werden wie die Kosten, die dadurch uns und zukünftigen Generationen entstehen. Laut UBA sind das **180€** pro Tonne CO2

The social cost of carbon (SCC) ...

- is typically estimated using Integrated Assessment Models (IAMs), such as the Dynamic Integrated Climate-Economy (DICE) model by Bill Nordhaus.
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- is extremely challenging to quantify.
  - rife with uncertainties and disagreements; requires interdisciplinary collaboration.

$\Rightarrow$ IAMs have been criticized on various grounds.

- inaccurate climate modelling,
- ignoring uncertainties, irreversibilities and tipping points,
- relying on outdated science on climate damages,
- too restrictive ethical frameworks

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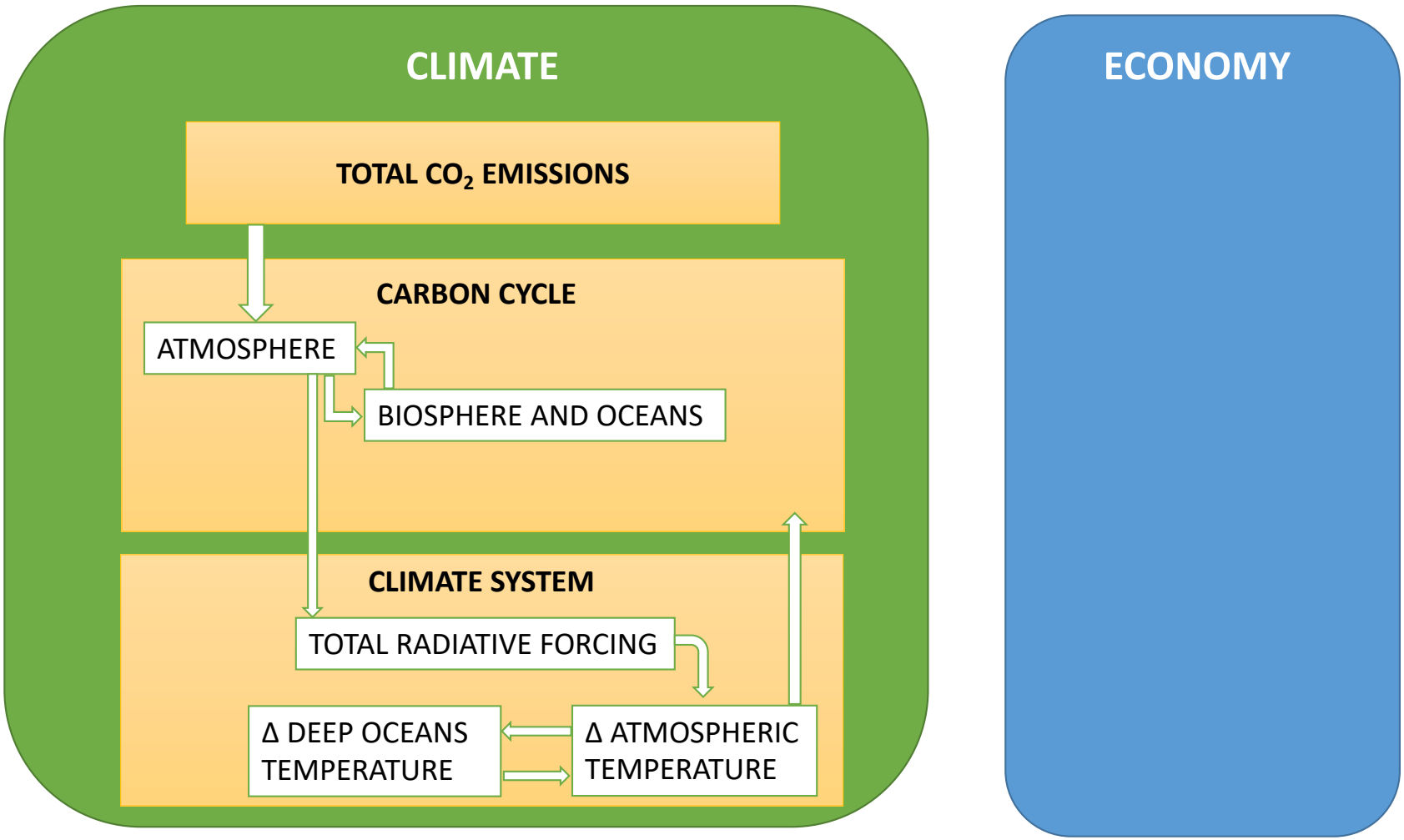
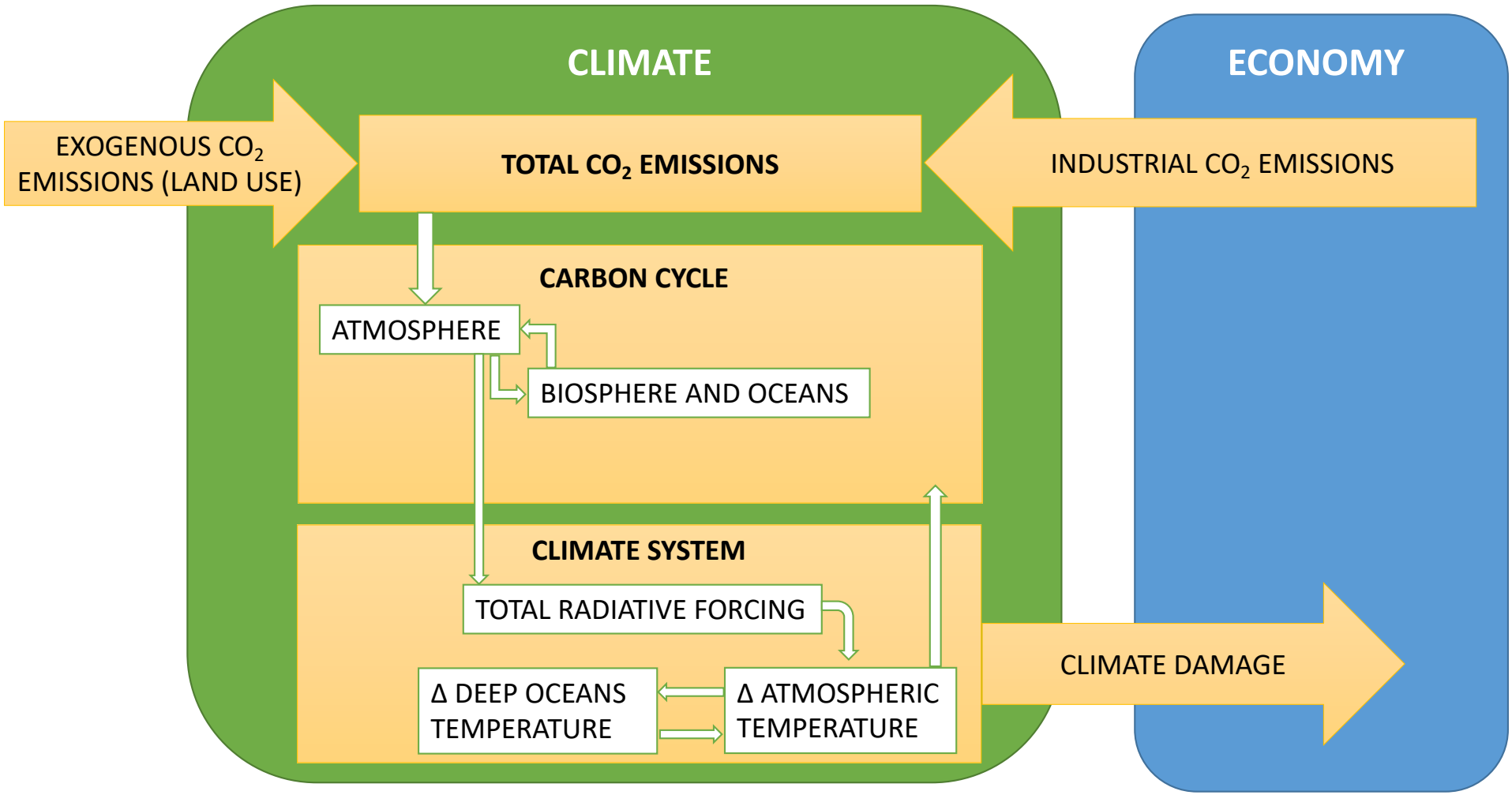
$\Rightarrow$ Nobel committee: This year's Laureate *"does not deliver conclusive answers"*. *"What models can do is to translate different value judgments into different paths for policy."*

Source: Scientific Background on the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2018: 4-5.

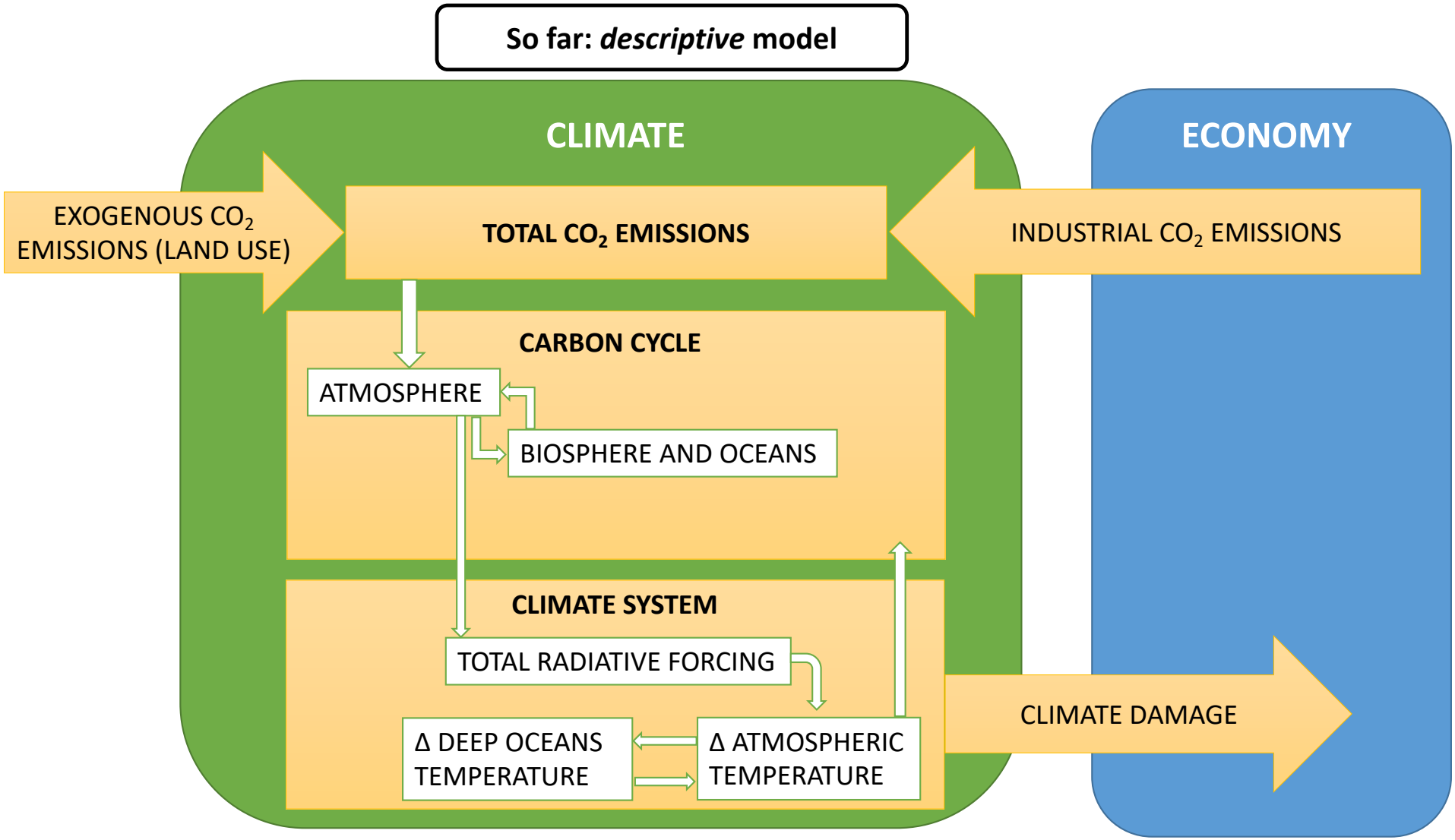
DICE model (Nordhaus, 2018 American Economic Journal (AEJ))



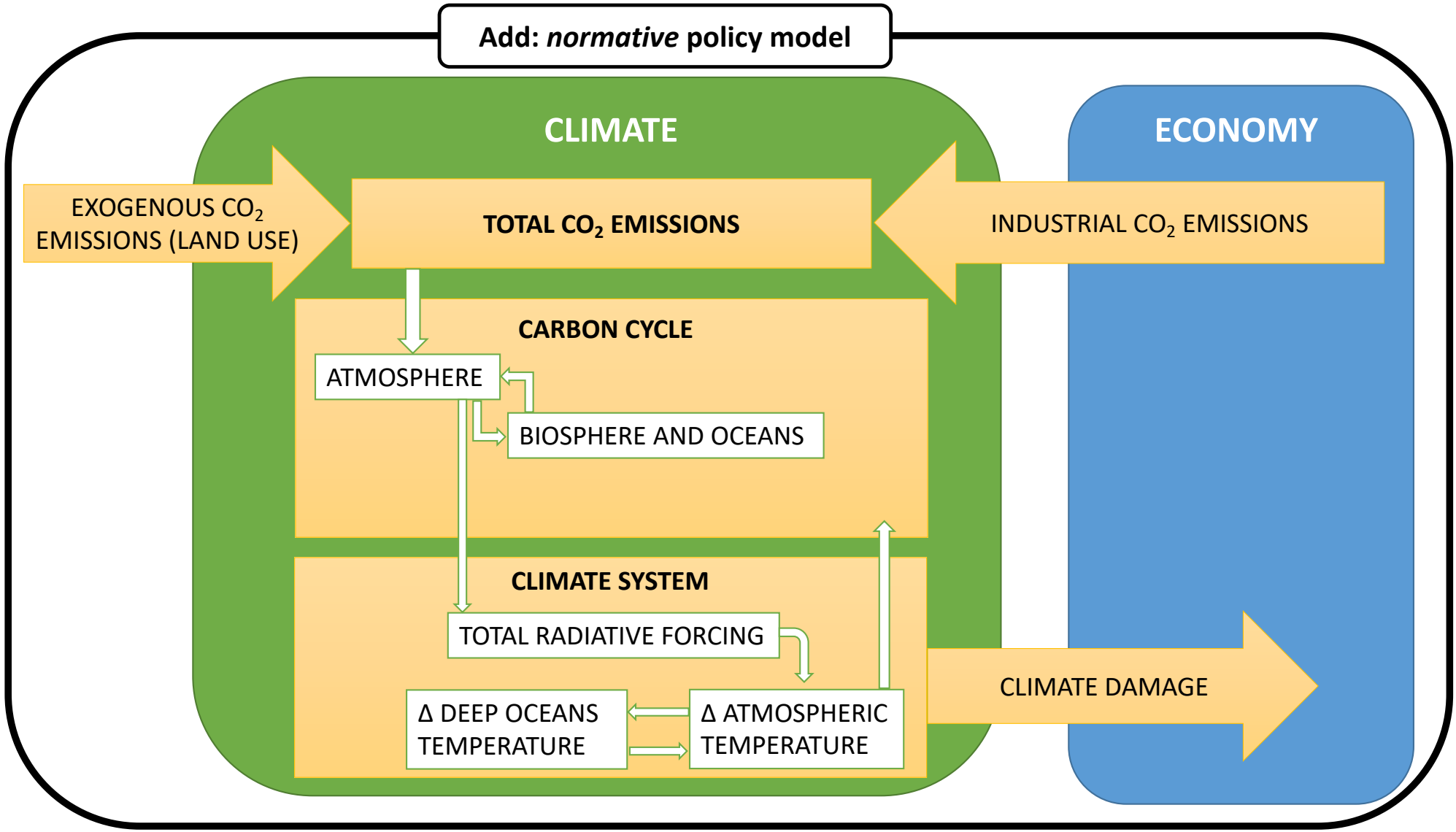
DICE model


CLIMATE
ECONOMY
EXOGENOUS CO_2 EMISSIONS (LAND USE)
TOTAL CO_2 EMISSIONS
INDUSTRIAL CO_2 EMISSIONS
CARBON CYCLE
ATMOSPHERE
BIOSPHERE AND OCEANS
CLIMATE SYSTEM
TOTAL RADIATIVE FORCING
Δ DEEP OCEANS TEMPERATURE
Δ ATMOSPHERIC TEMPERATURE
CLIMATE DAMAGE

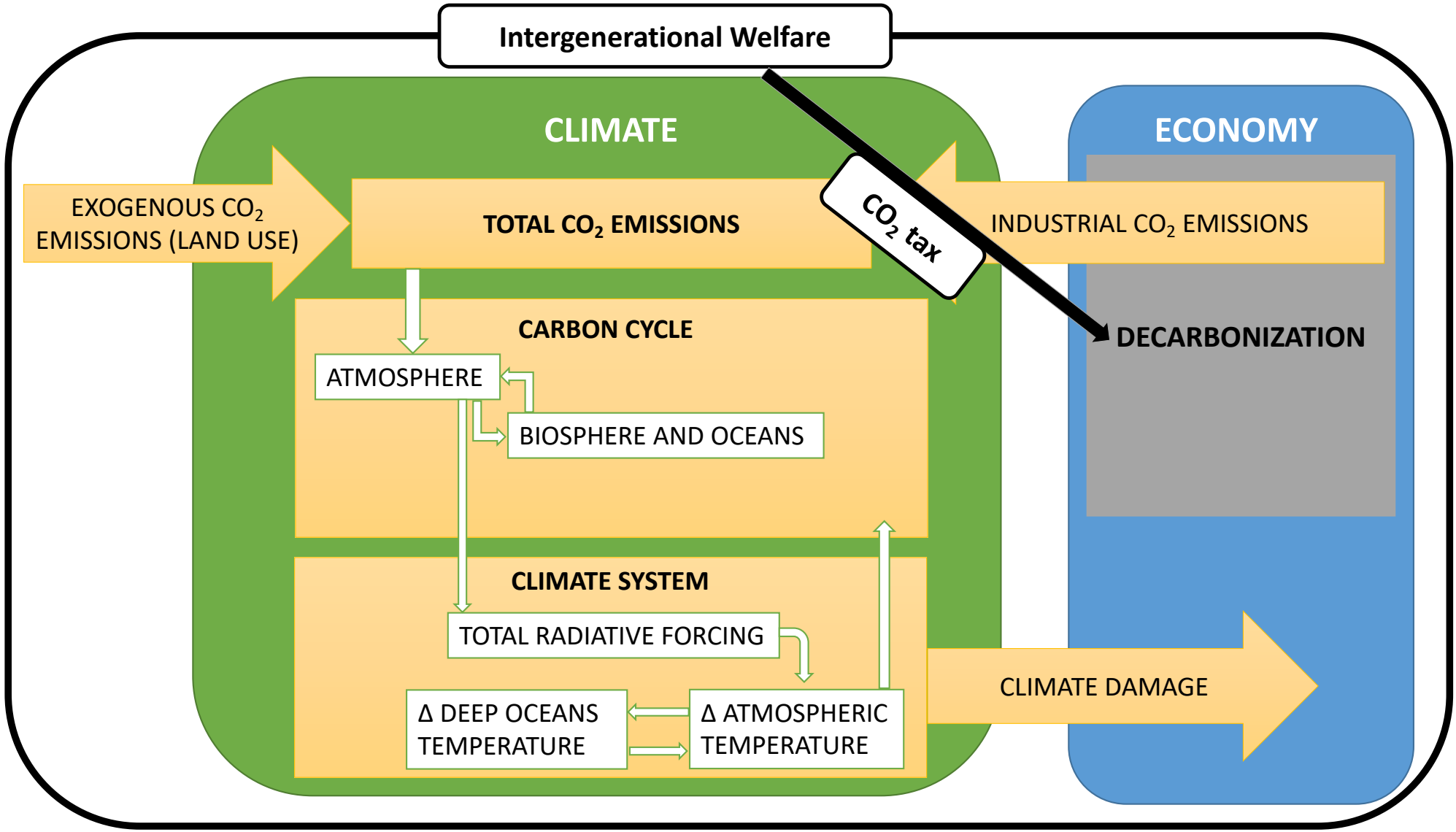
DICE model

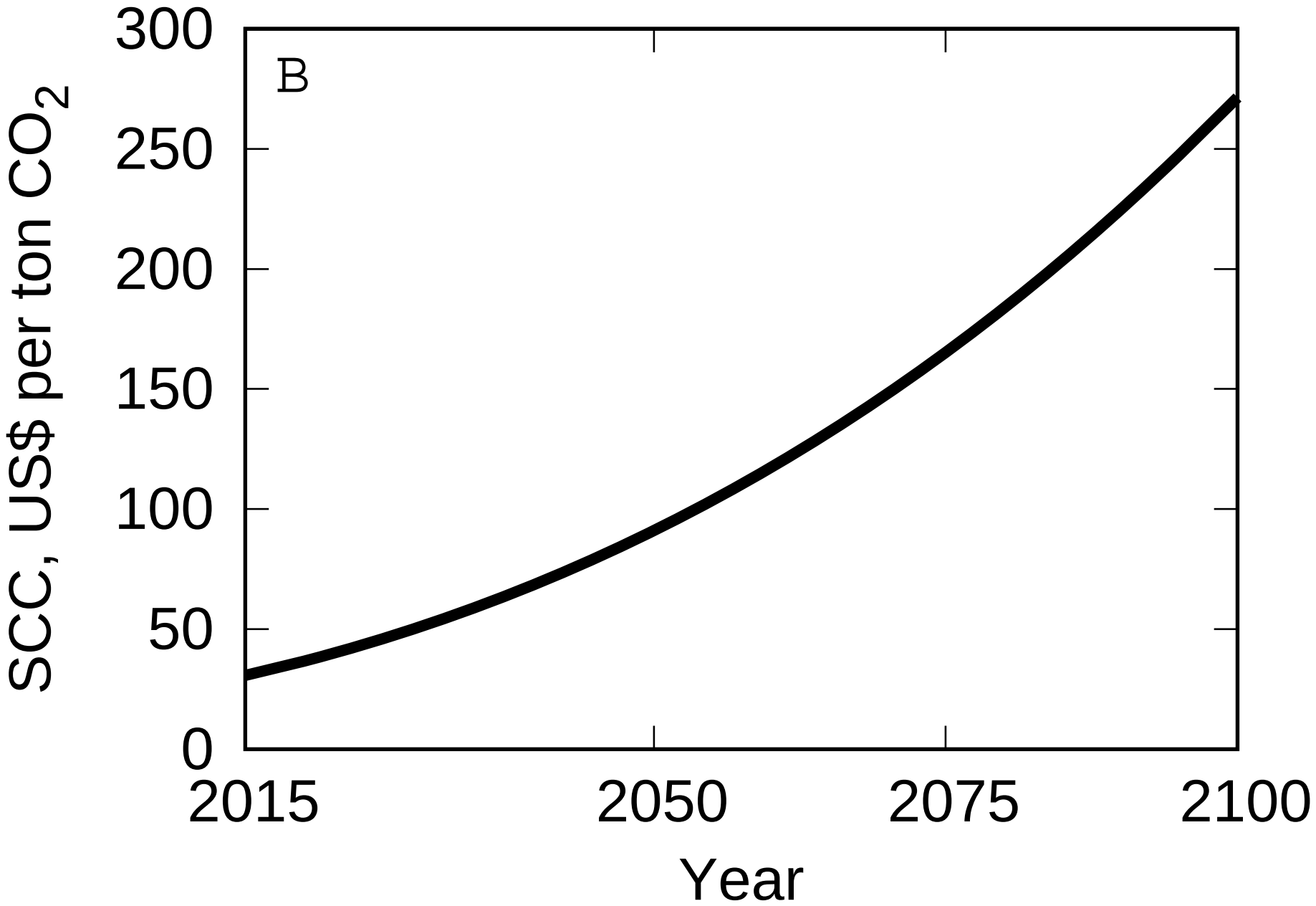

So far: *descriptive* model
CLIMATE
ECONOMY
EXOGENOUS CO_2 EMISSIONS (LAND USE)
TOTAL CO_2 EMISSIONS
INDUSTRIAL CO_2 EMISSIONS
CARBON CYCLE
ATMOSPHERE
BIOSPHERE AND OCEANS
CLIMATE SYSTEM
TOTAL RADIATIVE FORCING
Δ DEEP OCEANS TEMPERATURE
Δ ATMOSPHERIC TEMPERATURE
CLIMATE DAMAGE

DICE model


Add: *normative* policy model
CLIMATE
ECONOMY
EXOGENOUS CO_2 EMISSIONS (LAND USE)
TOTAL CO_2 EMISSIONS
INDUSTRIAL CO_2 EMISSIONS
CARBON CYCLE
ATMOSPHERE
BIOSPHERE AND OCEANS
CLIMATE SYSTEM
TOTAL RADIATIVE FORCING
Δ DEEP OCEANS TEMPERATURE
Δ ATMOSPHERIC TEMPERATURE
CLIMATE DAMAGE

DICE model


Intergenerational Welfare
CLIMATE
ECONOMY
EXOGENOUS CO_2 EMISSIONS (LAND USE)
TOTAL CO_2 EMISSIONS
CO_2 tax
INDUSTRIAL CO_2 EMISSIONS
DECARBONIZATION
CARBON CYCLE
ATMOSPHERE
BIOSPHERE AND OCEANS
CLIMATE SYSTEM
TOTAL RADIATIVE FORCING
Δ DEEP OCEANS TEMPERATURE
Δ ATMOSPHERIC TEMPERATURE
CLIMATE DAMAGE


B
300
250
200
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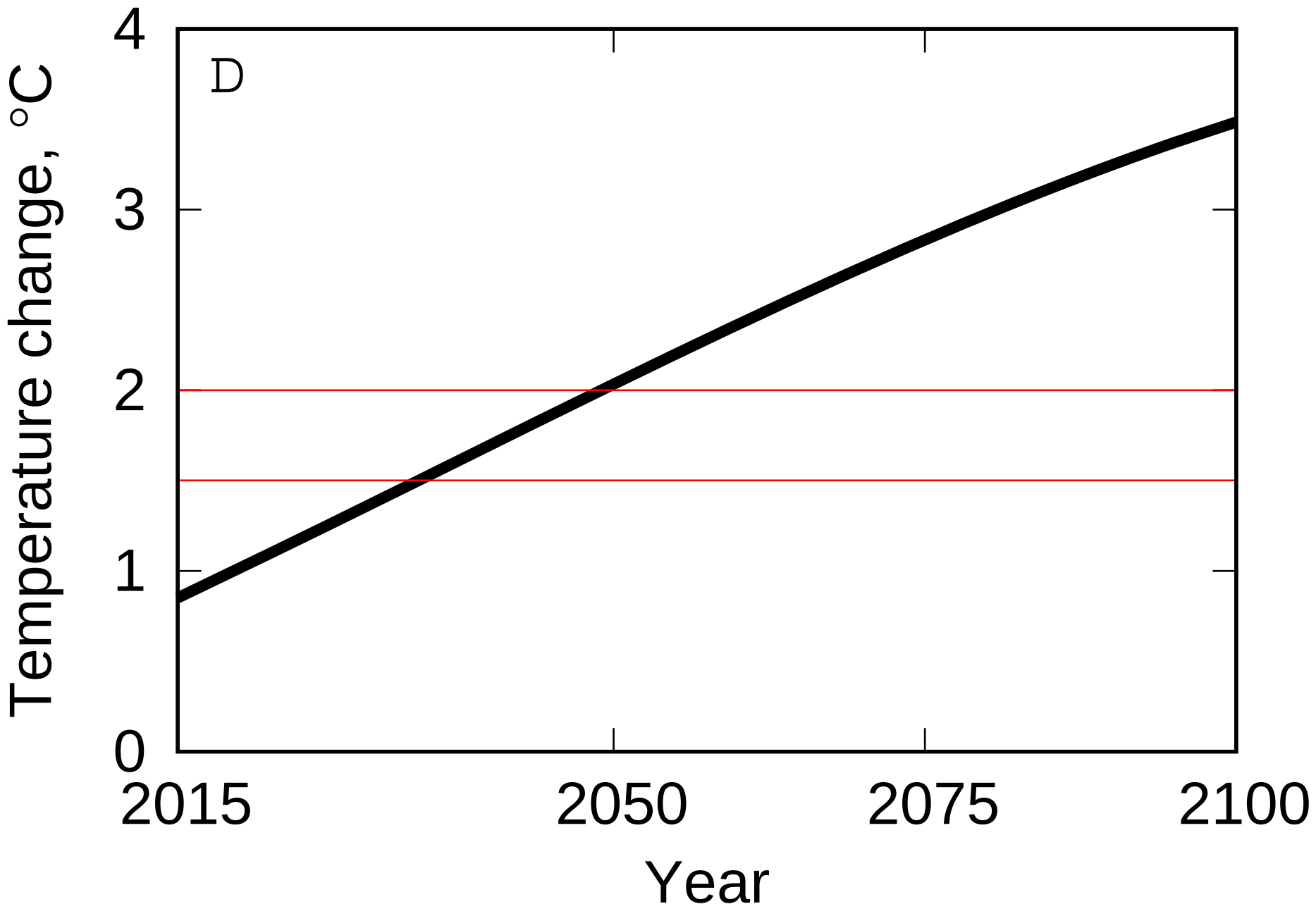
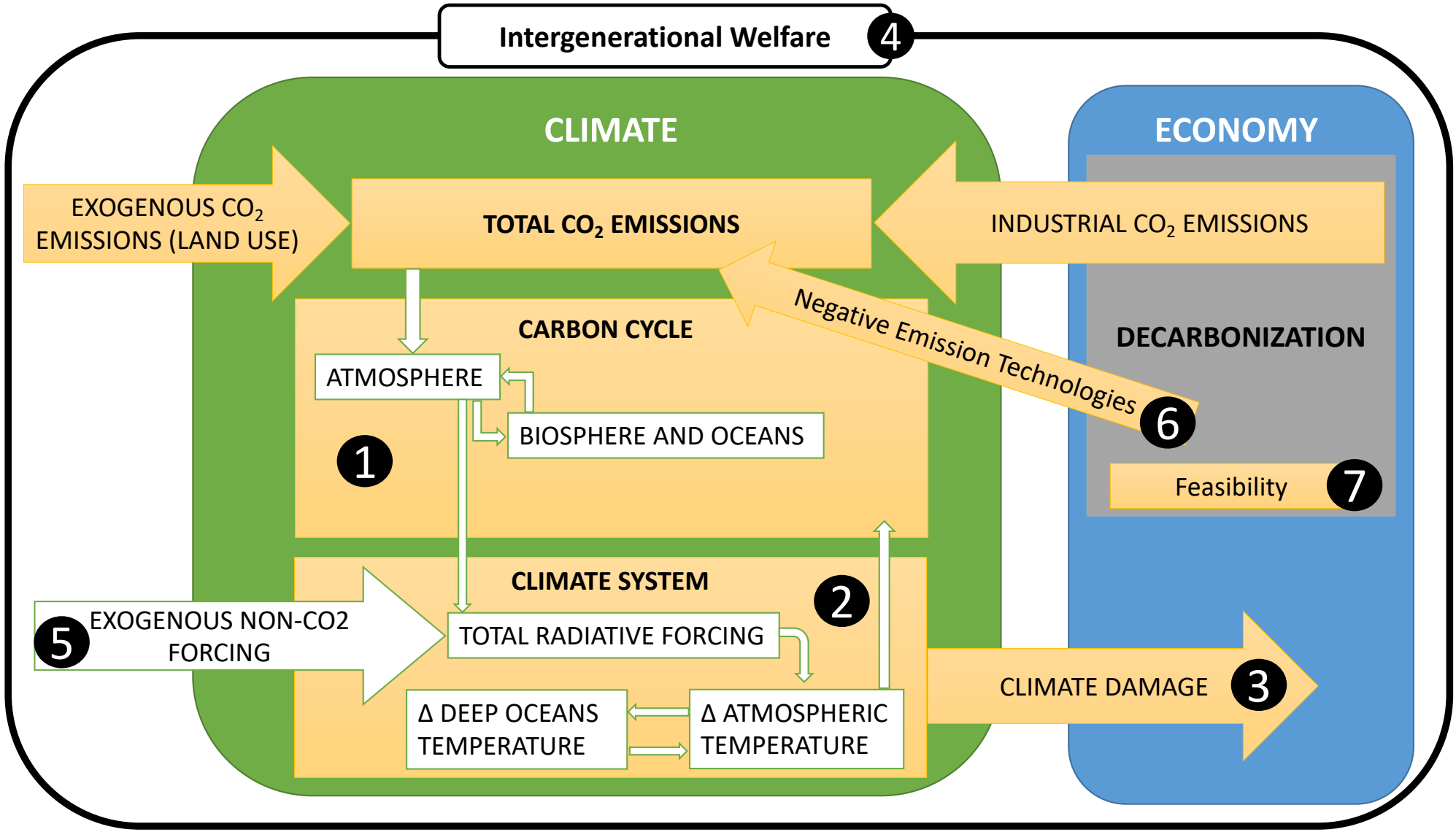
100
50
0
SCC, US$ per ton CO_2
2015
2050
2075
2100
Year


D
Temperature change, °C
0
1
2
3
4
2015
2050
2075
2100
Year

Updated DICE (Hänsel et al. 2020 Nature Climate Ch.)



Climate damages in DICE (Nordhaus, 2018 AEJ)

$$D_t = \phi \, T_t^2$$

- ϕ aggregate scaling parameter for the damages on consumption via production-damages
- T_t is the change in atmospheric temperature compared to pre-industrial levels.

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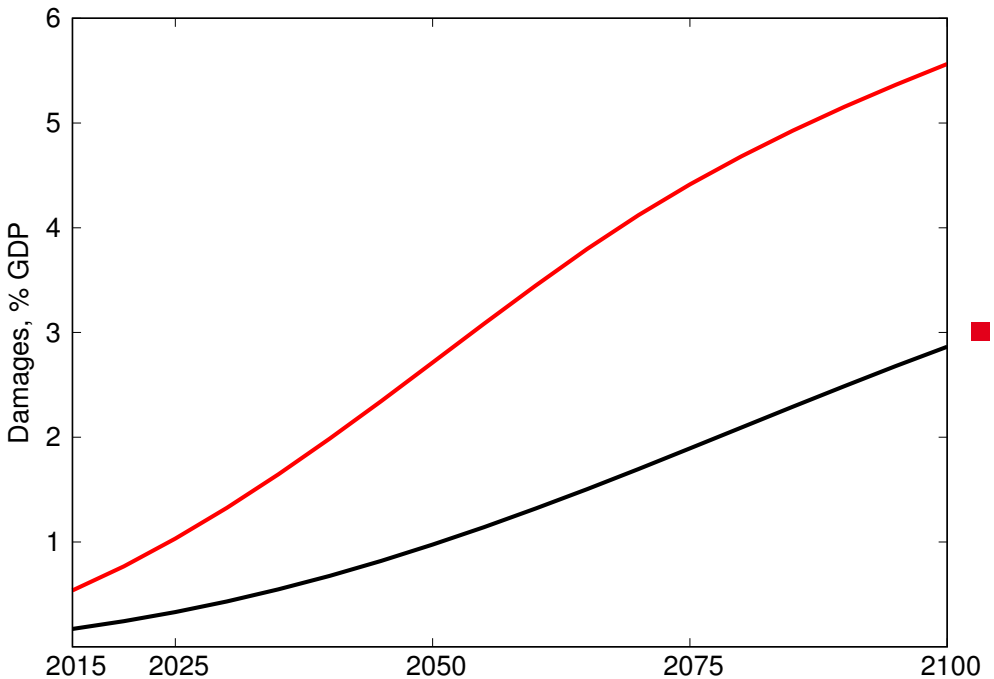

- **DICE:** climate damages amount to 2.1% of GDP for 3°C of warming.

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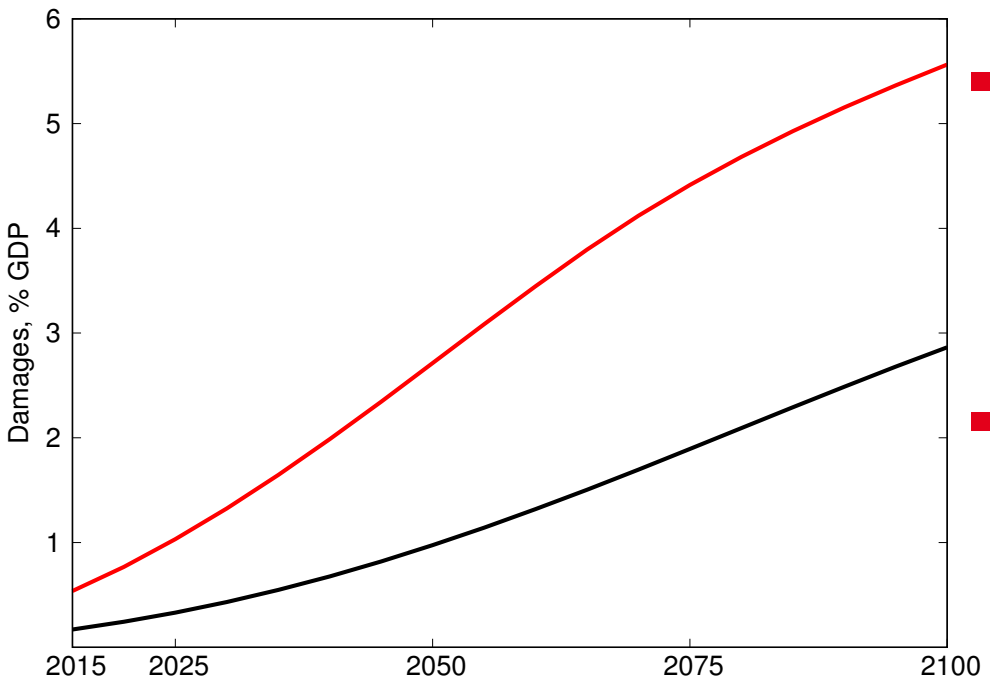

- **Update:** Howard&Sterner (2017 EARE) corrected meta-anlysis: $\rightarrow$ 6.7% of GDP, closer to recent microeconometric estimates (Burke et al., 2015 *Nature*) of $>$10% of GDP.
- **DICE:** climate damages amount to 2.1% of GDP for 3°C of warming.

'Optimal' climate policy in DICE (Nordhaus, 2018 AEJ)

The Discounted Utilitarian social welfare function:

$$W_0(\widetilde{c}_t, L_t) = \sum_{t=0}^{100} L_t \frac{1}{(1+\delta)^{5t}} \frac{\widetilde{c}_t^{1-\eta}}{1-\eta}$$

- L_t is period $t's$ population size
- $\widetilde{c}_t$ is an index of generalized consumption
- δ is the rate of pure time preference
- η is the elasticity of the marginal utility of consumption

Intergenerational Welfare in DICE (Nordhaus, 2018 AEJ)

Discounted Utilitarianism and the simple Ramsey Rule:

$$\text{Social Discount Rate (SDR)} = \delta + \eta\, g$$

- Found in policy guidance around the world (UK, France, Germany, IPCC)

$\Rightarrow$ Choosing the *"central normative parameters"*, δ & η, (Nordhaus 2008, 33) is *"one of the most critical problems in all of economics"* (Weitzman 2001 *AER*)

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– δ is the rate of pure time preference

  – To what degree do we discriminate against the future?

    ○ A pure time preference of 1% (cf. UBA) implies that the well-being of someone born 100 years from now has a $\approx 3^{rd}$ of the value the same well-being today.

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– η is the elasticity of marginal utility of consumption, or (intergen.) *"inequality aversion"*

– g is the expected per-capita real growth rate of consumption

  – To what degree should the relatively poorer (richer) present invest to support the relatively wealthier (poorer) future?

    ○ Suppose that the economy grows at 2%. Then the generation living in 100 years will be ≈7 times richer. If inequality aversion is the only reason for discounting, a value of η of 1 (cf. UBA) would weight an additional dollar of benefits 100 years from now by only a 7^{th} compared to the same benefit today.

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$\Rightarrow$ **Substantial disagreement among experts, who are**

- stumbling around in the *"...dark jungles of the second best..."* Baumol (1968 *AER*)
- accused of *"stoking the dying embers of the British Empire"* Nordhaus (2007 *JEL*)

Expert views on Intergen. Welfare (Drupp et al., 2018 AEJ)

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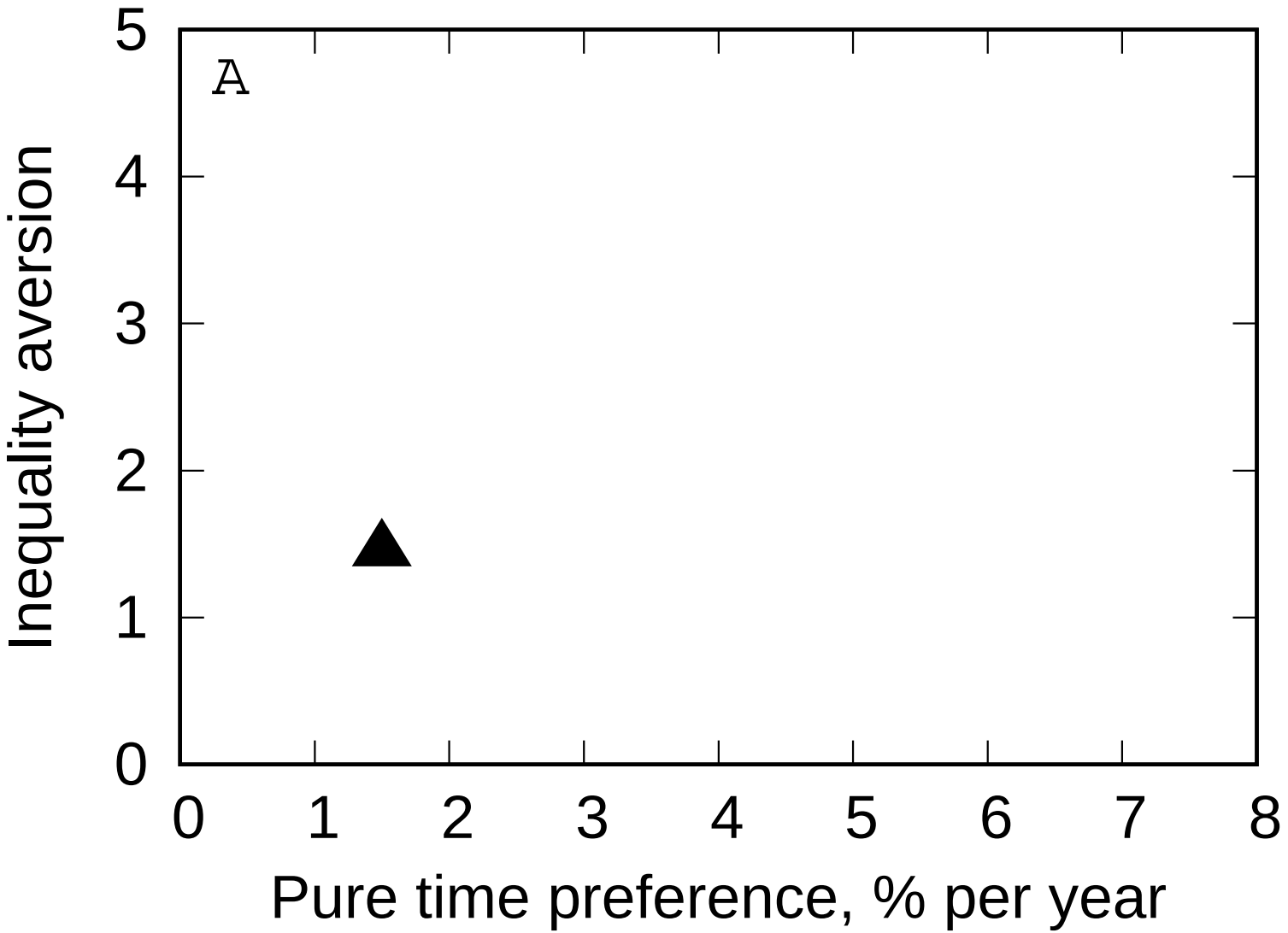
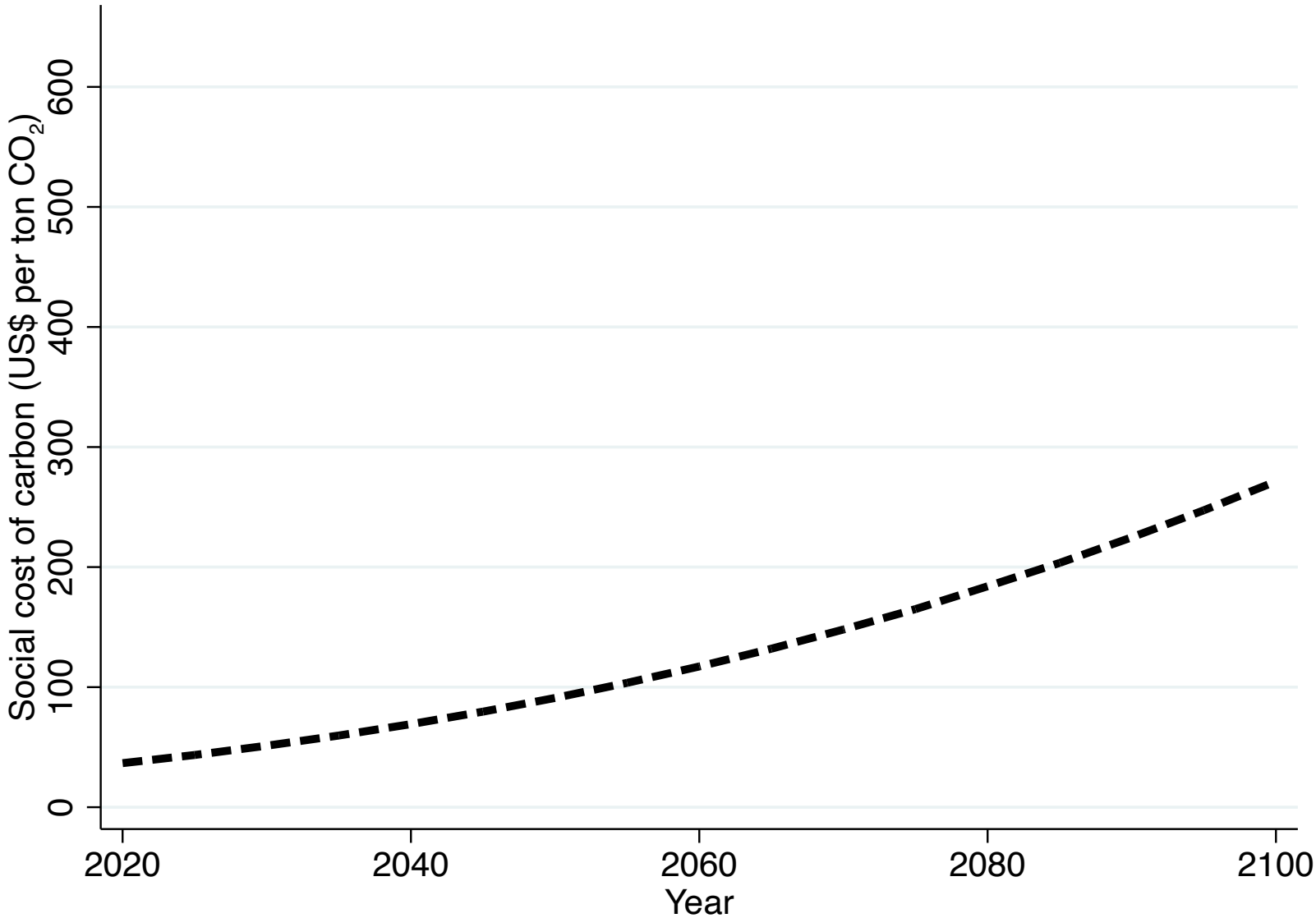
$\Rightarrow$ **Expert survey to quantify disagreement (Drupp et al. 2018 AEJ)**

- We survey ≈200 economic experts (incl. 12/13 authors of Arrow et al. 2013 *Science*) on individual components of the Simple Ramsey Rule, incl. on key value judgements

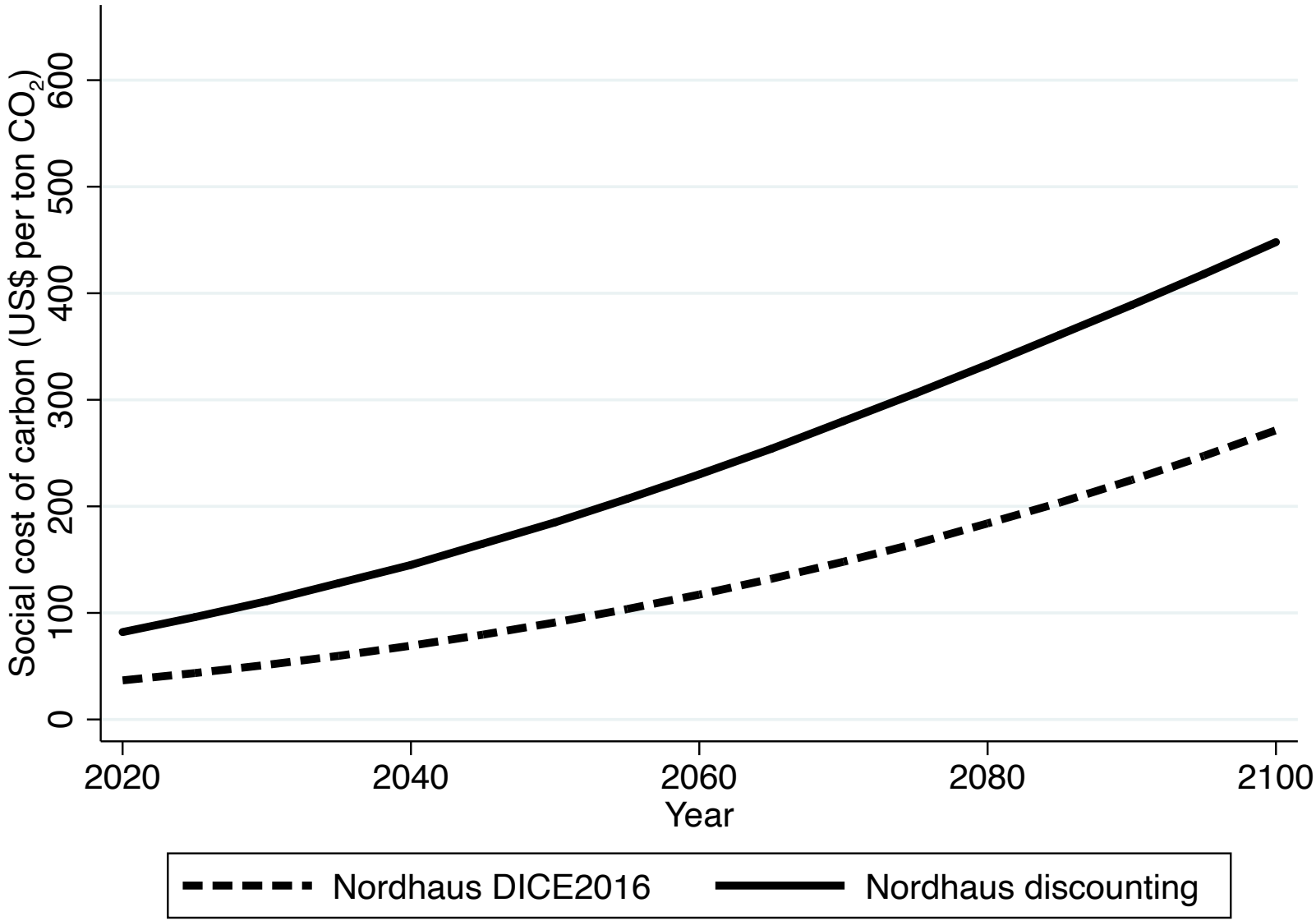
Intergenerational Welfare in DICE (Nordhaus, 2018 AEJ)



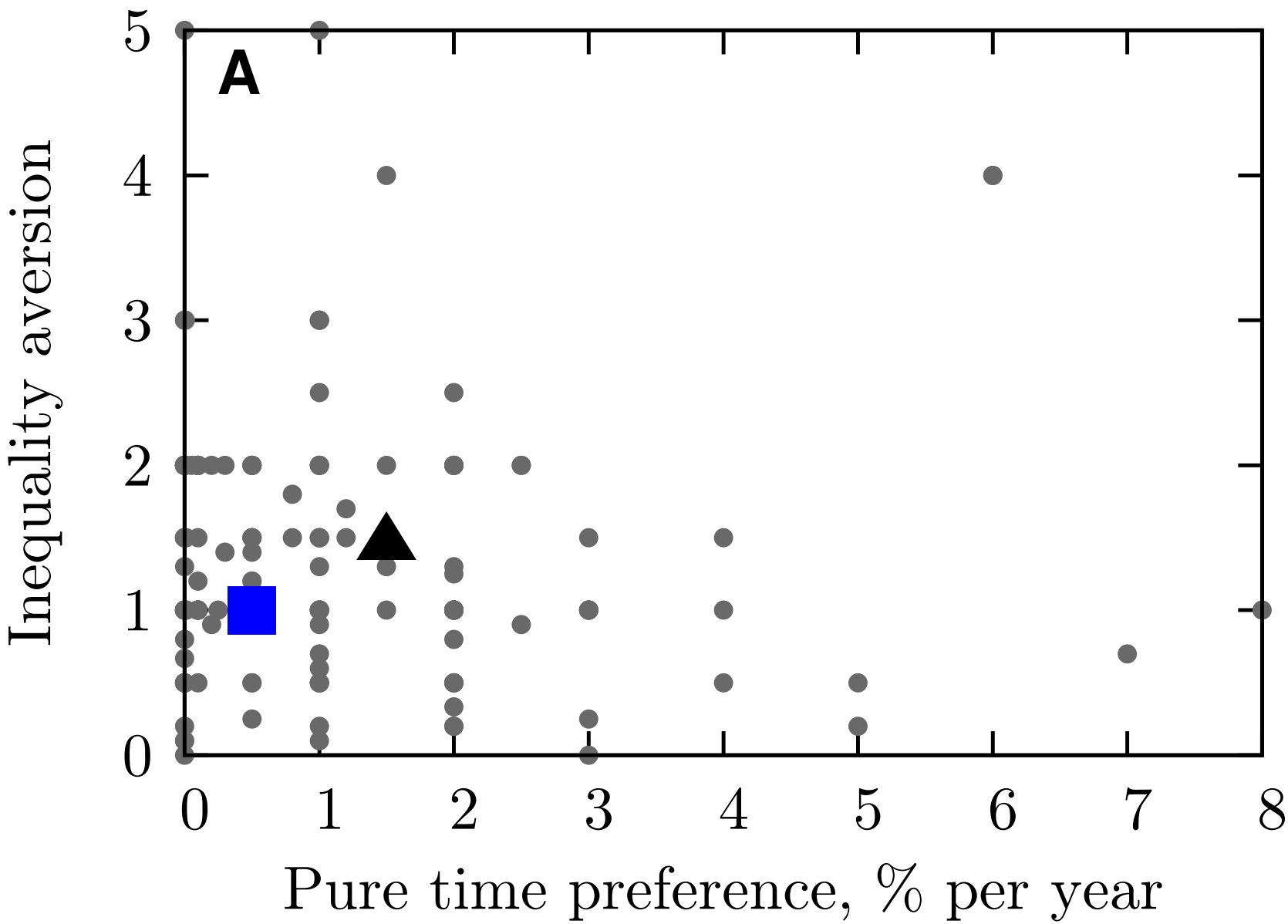
SCC in DICE-2016 (Nordhaus 2018 AEJ) $\rightarrow \approx$0.08€ l/gasoline



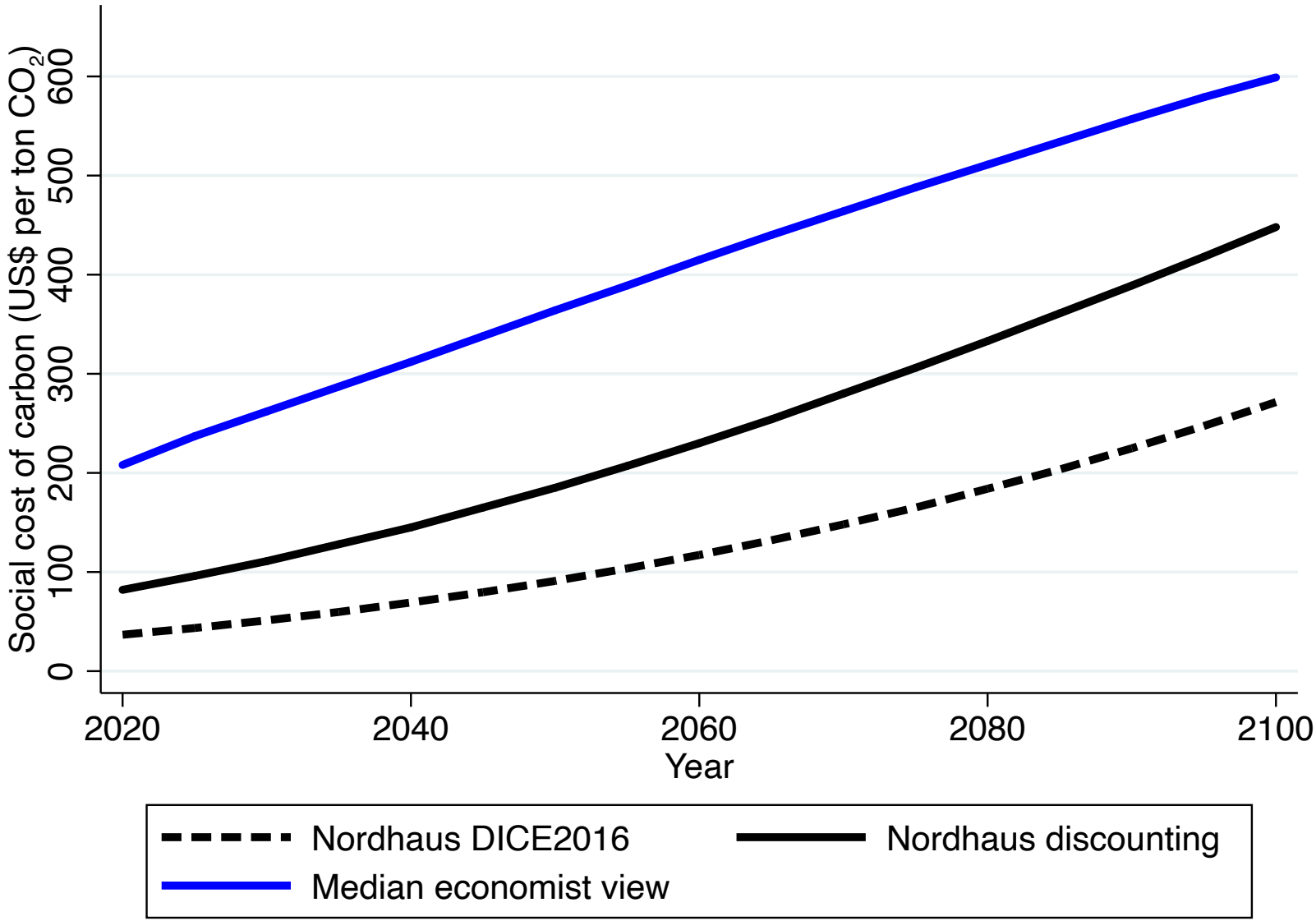
SCC in Updated DICE (Hänsel et al. 2020 NCC) $\rightarrow \approx$0.2€

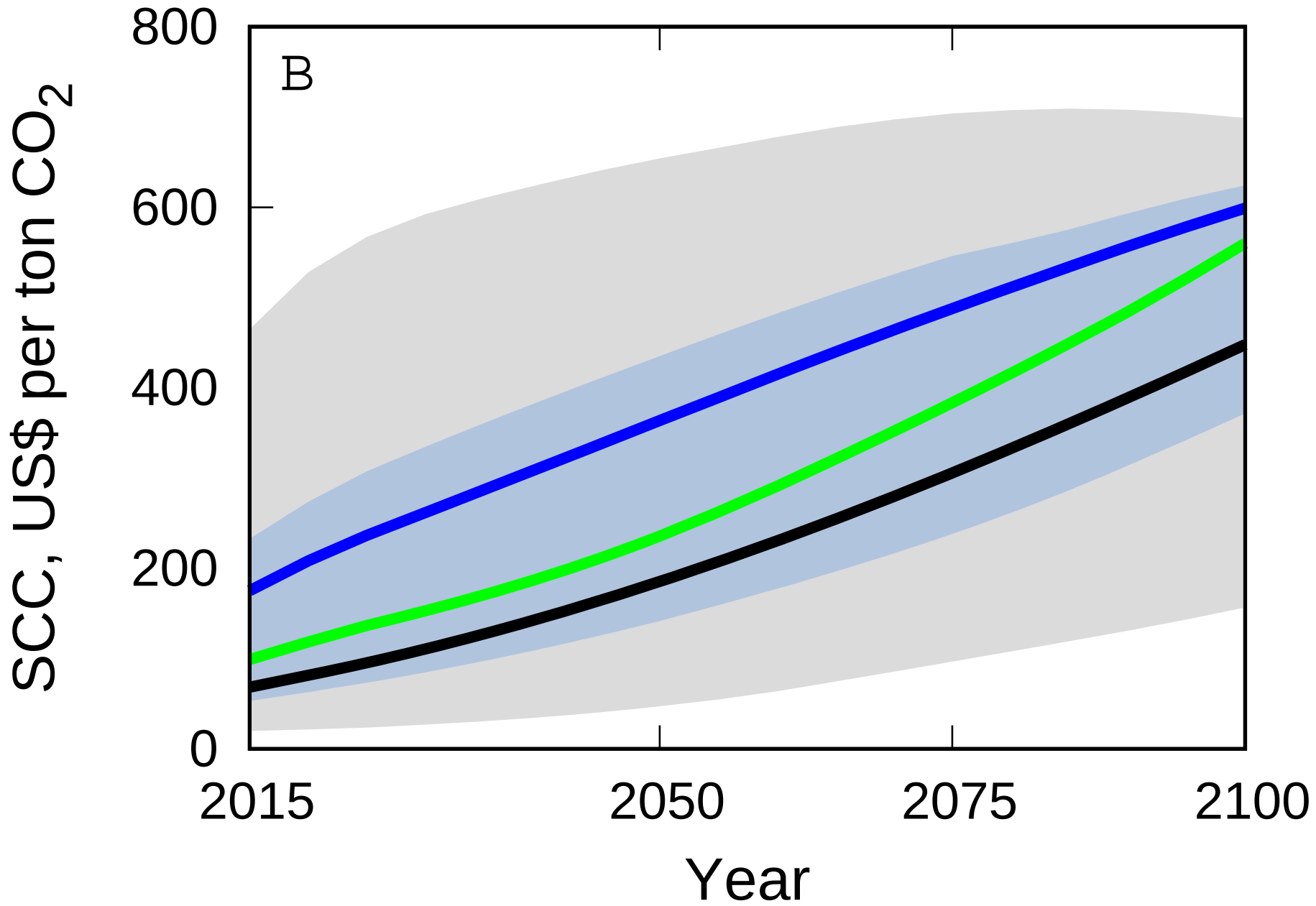


Economic expert recommendations (Drupp et al. 2018 AEJ)



SCC of median economist view (Drupp et al. 2018 AEJ) $\rightarrow \approx$0.5€




B
800
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SCC, US$ per ton CO_2
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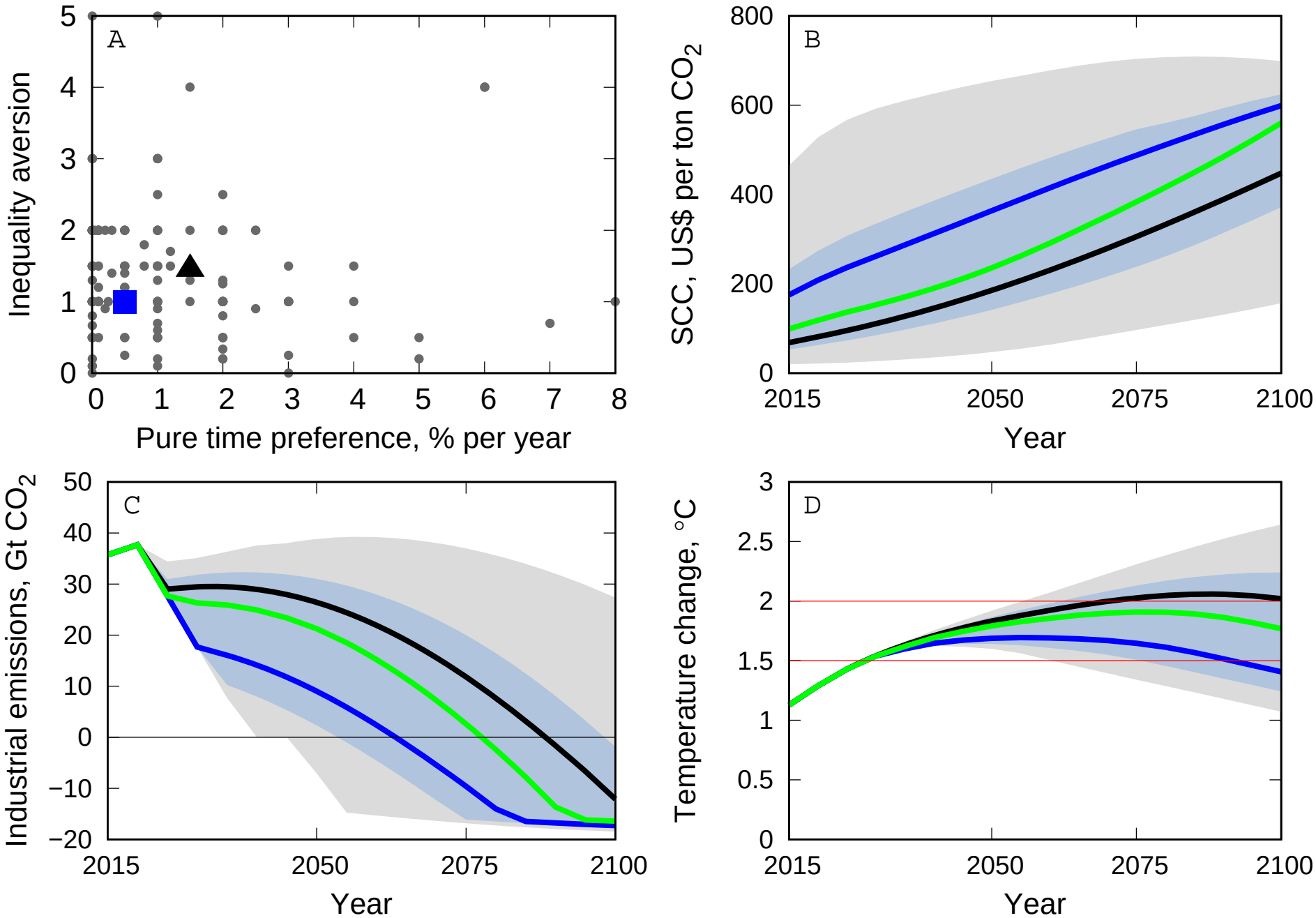
A
Inequality aversion
Pure time preference, % per year
B
SCC, US$ per ton CO2
Year
C
Industrial emissions, Gt CO2
Year
D
Temperature change, °C
Year

Beyond economists (Nesje et al. 2023 NCC)

- Governmental discounting guidance almost exclusively influenced by economists (Groom/Hepburn 2017 *REEP*); unclear that they possess any special ethical expertise

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  - We survey views of disciplinary experts most trained in ethical matters: Philosophers

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Pubquiz: Economist or philosopher? (Nesje et al. 2023 NCC)

Pure time preference:

(a) *I see no reason to treat generations not equally.*

(b) *I think it's morally acceptable—and in many contexts even required—for us to give greater weight to the concerns of those nearer and dearer to us than to those further away.*

Pubquiz: Economist or philosopher? (Nesje et al. 2023 NCC)

Limited substitutability of non-market goods:

(a) *If future costs/benefits accrue, e.g., to environmental amenities, I would argue for a very low discount rate, based on an expectation of increasing relative prices for these goods.*

(b) *As the discount rate is dependent on assumptions about future scarcities and capacities [...] etc., there should be no single discount rate [...]. Natural assets, monetary investments [...] etc. should be discounted at different rates.*

Pubquiz: Economist or philosopher? (Nesje et al. 2023 NCC)

Alternative approaches:

(a) *Instead of imposing a Social Welfare Function and calculate the corresponding optimum, it is "better" to depict a set of feasible paths of consumption, production, temperature, income distribution, etc., and let the policymaker make a choice.*

(b) *Instead of cost-benefit analysis, long-term future assessments should be made according to a "sustainability index," which gives primary consideration, not to "market preferences," but rather to sustaining environmental conditions and resource availability.*

Pubquiz: Economist or philosopher? (Nesje et al. 2023 NCC)

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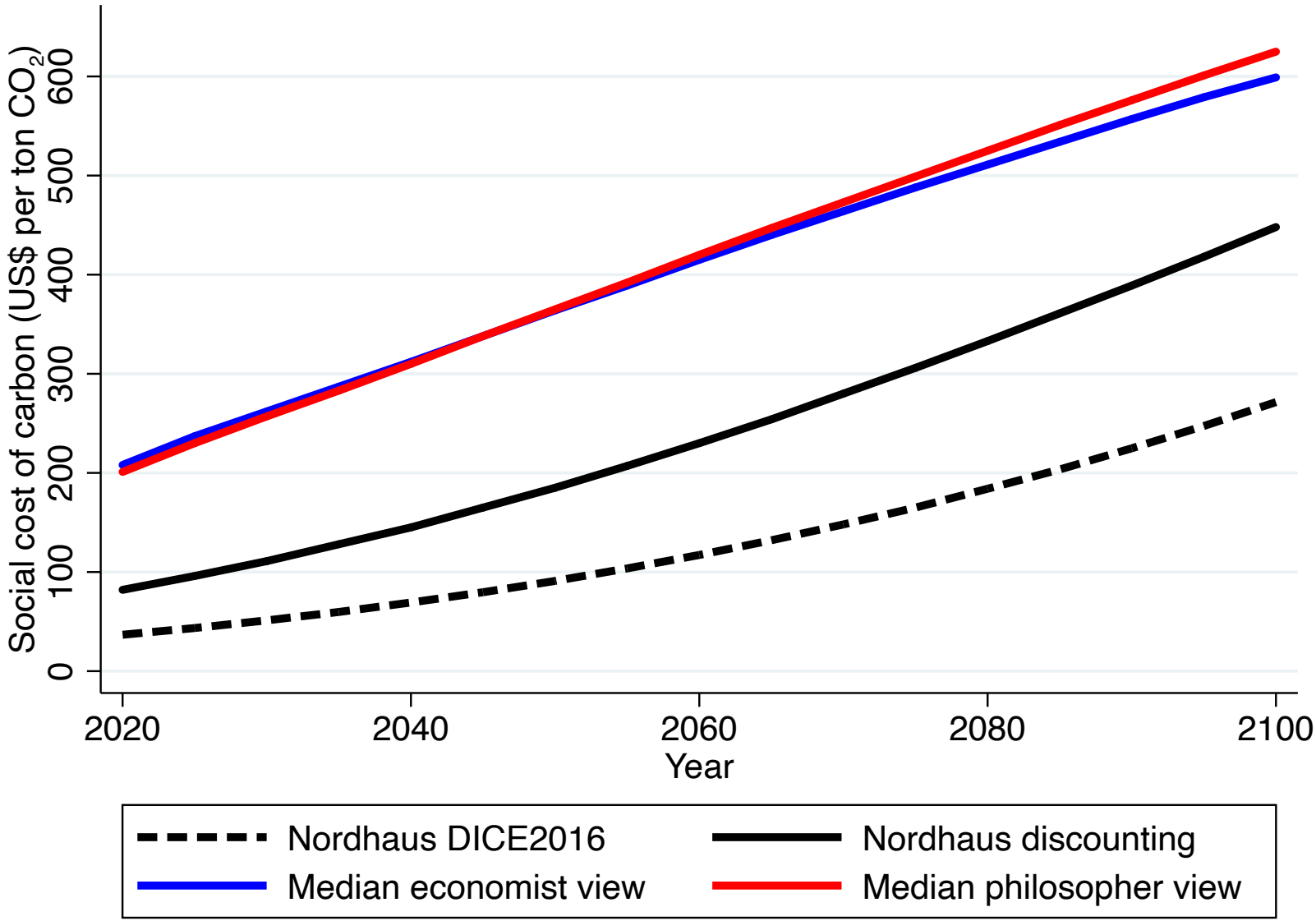
- Need for broader multidisciplinary input (Wagner et al., 2021 *Nature*)
  - We survey views of disciplinary experts most trained in ethical matters: Philosophers

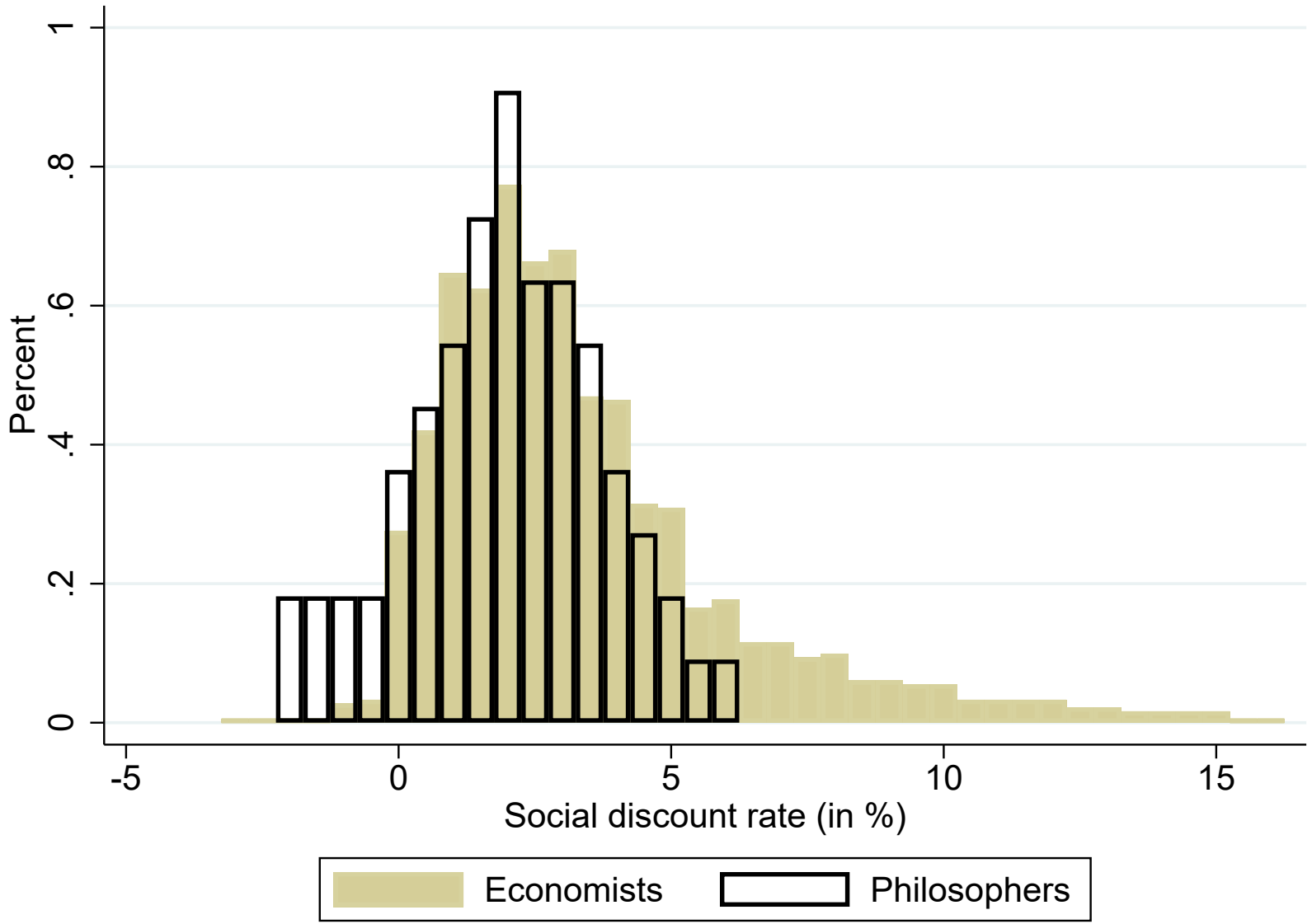
- Philosophers give responses on discounting determinants that reflect a stronger preference for a normative approach and for societal decisions to be more strongly rooted in an egalitarian perspective:
  - Lower median pure time preference, δ ($\rightarrow$ Higher SCC)
  - Higher median inequality aversion, η ($\rightarrow$ Lower SCC)

$\Rightarrow$ How does the SCC for the median philosopher view relate to the median economist's?

SCC of median philosopher (Nesje et al. 2023 NCC)



Surprising degree of agreement on SDRs of Phil's & Econ's



Mean SDR:
Phil: 2.27%
Econ: 2.27%

Median SDR:
Phil: 2.4%
Econ: 2.0%

Ranksum test:
$p = 0.82$

Experts do NOT use the Simple Ramsey Rule (Drupp et al. 2018)

- For 81% of experts the Simple Ramsey Rule does not hold ($SDR \neq \delta + \eta\, g = SRR$)
- The SDR is, on average, 1.2%-points lower than the imputed Simple Ramsey Rule

  $\Rightarrow$ Experts put much more weight on the long-term future than simple theory suggests

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Reasons for divergence from Simple Ramsey Rule

- Alternative ethical approaches
- Intragenerational inequality
- Risk and uncertainties
- Limited substitutability of non-market goods
- ...

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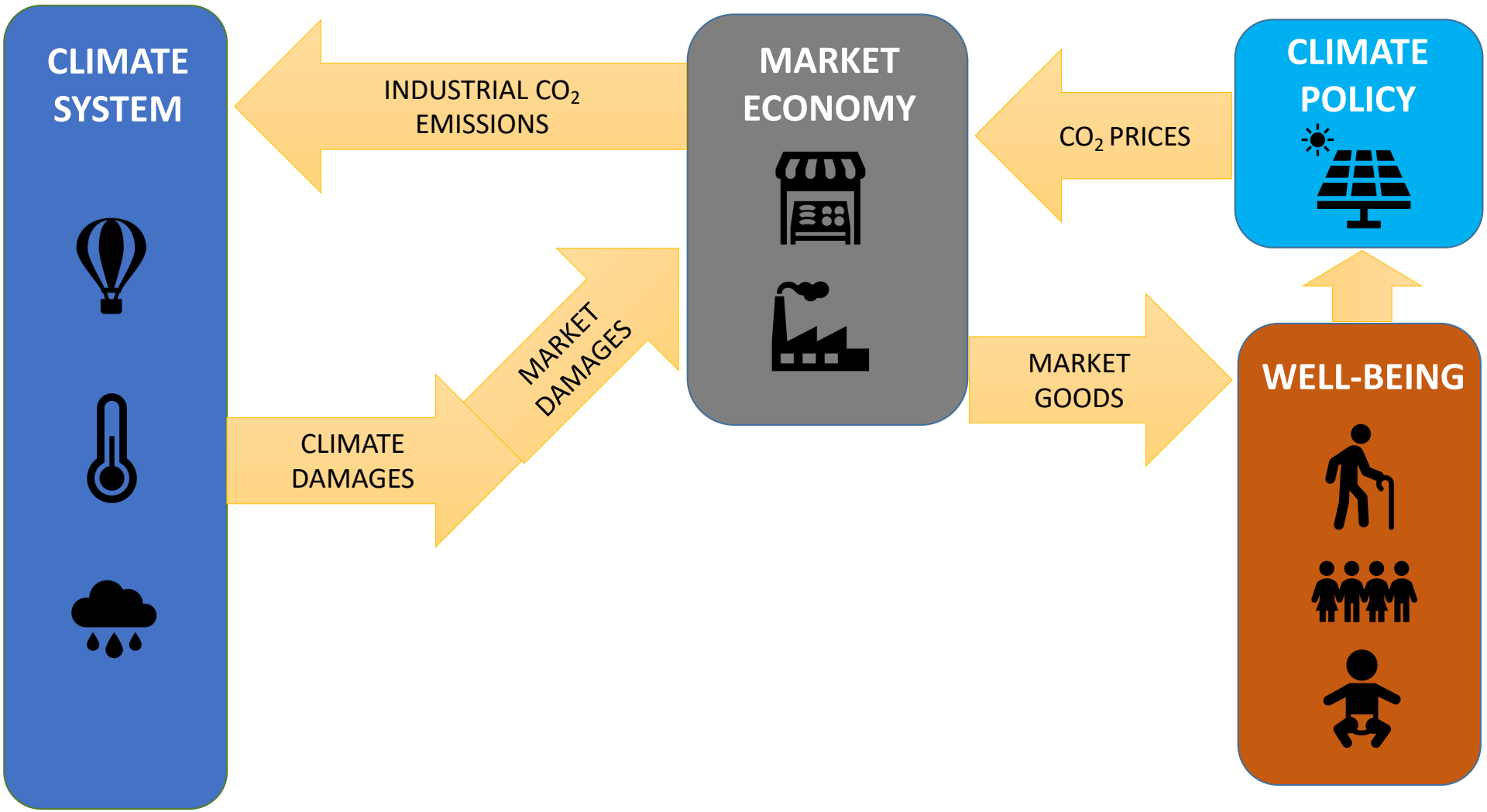
$\Rightarrow$ These all call for extensions of the basic model!

Limited substitutability (Drupp/Hänsel 2021 AEJ)



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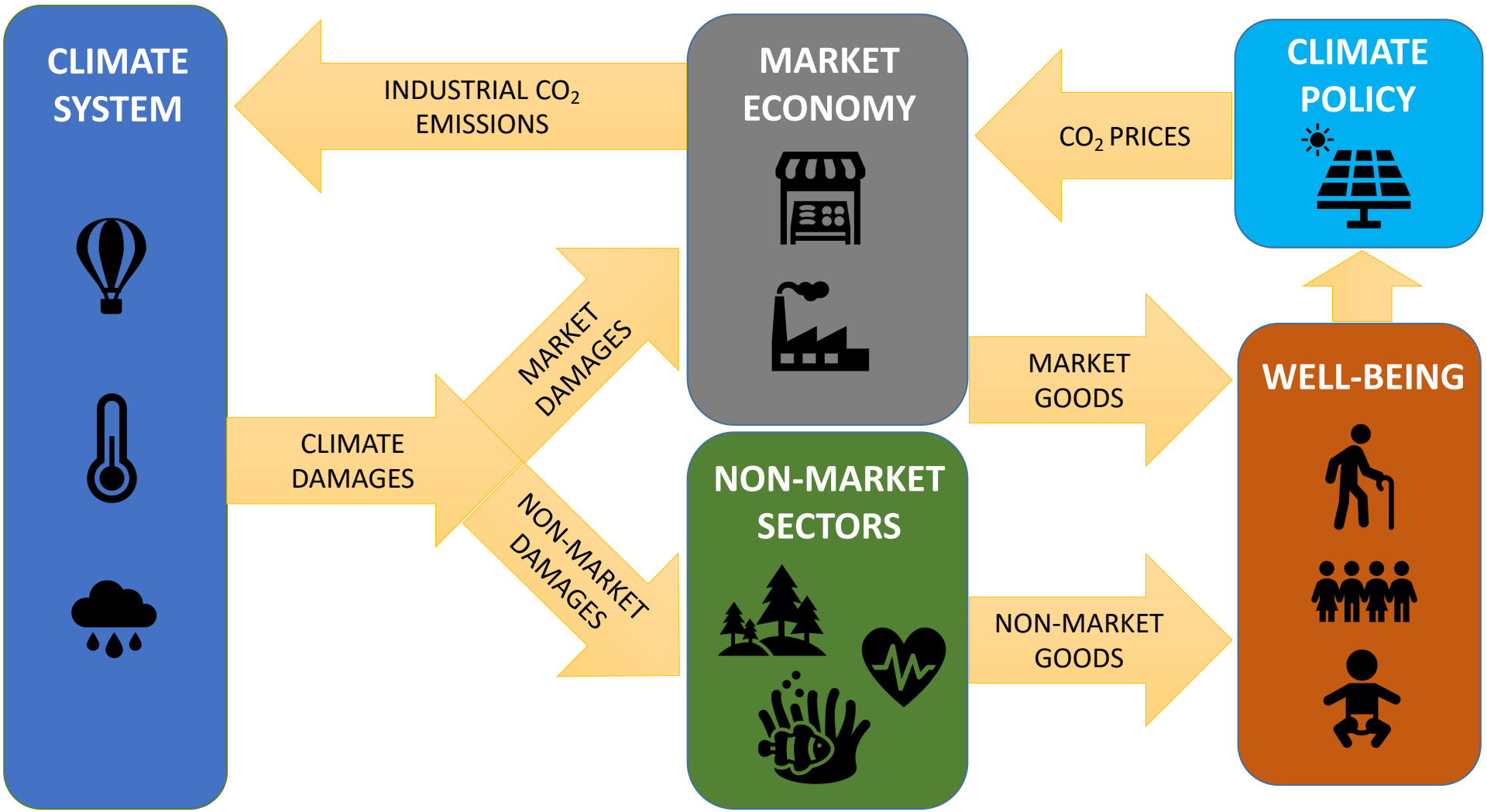

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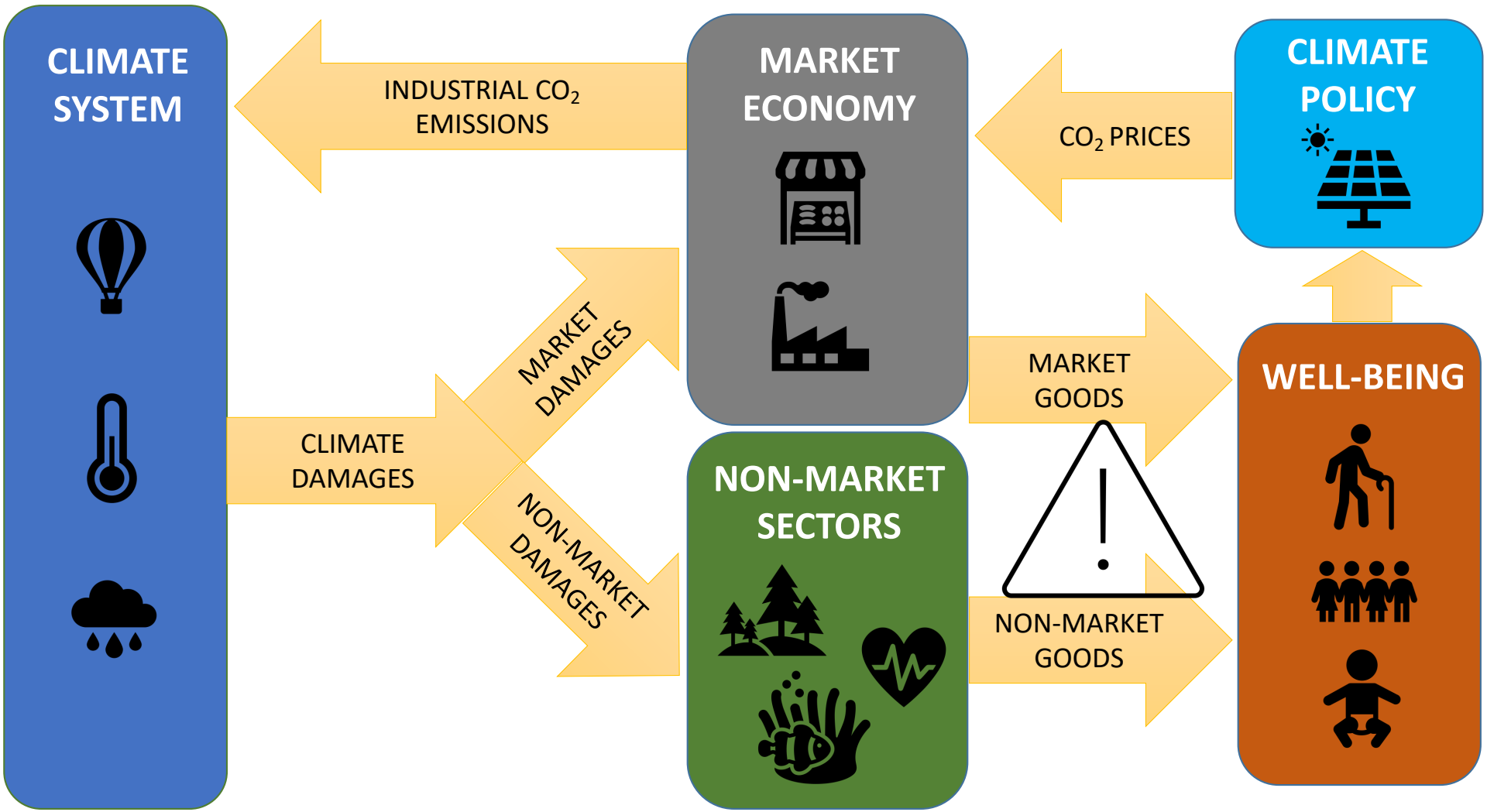

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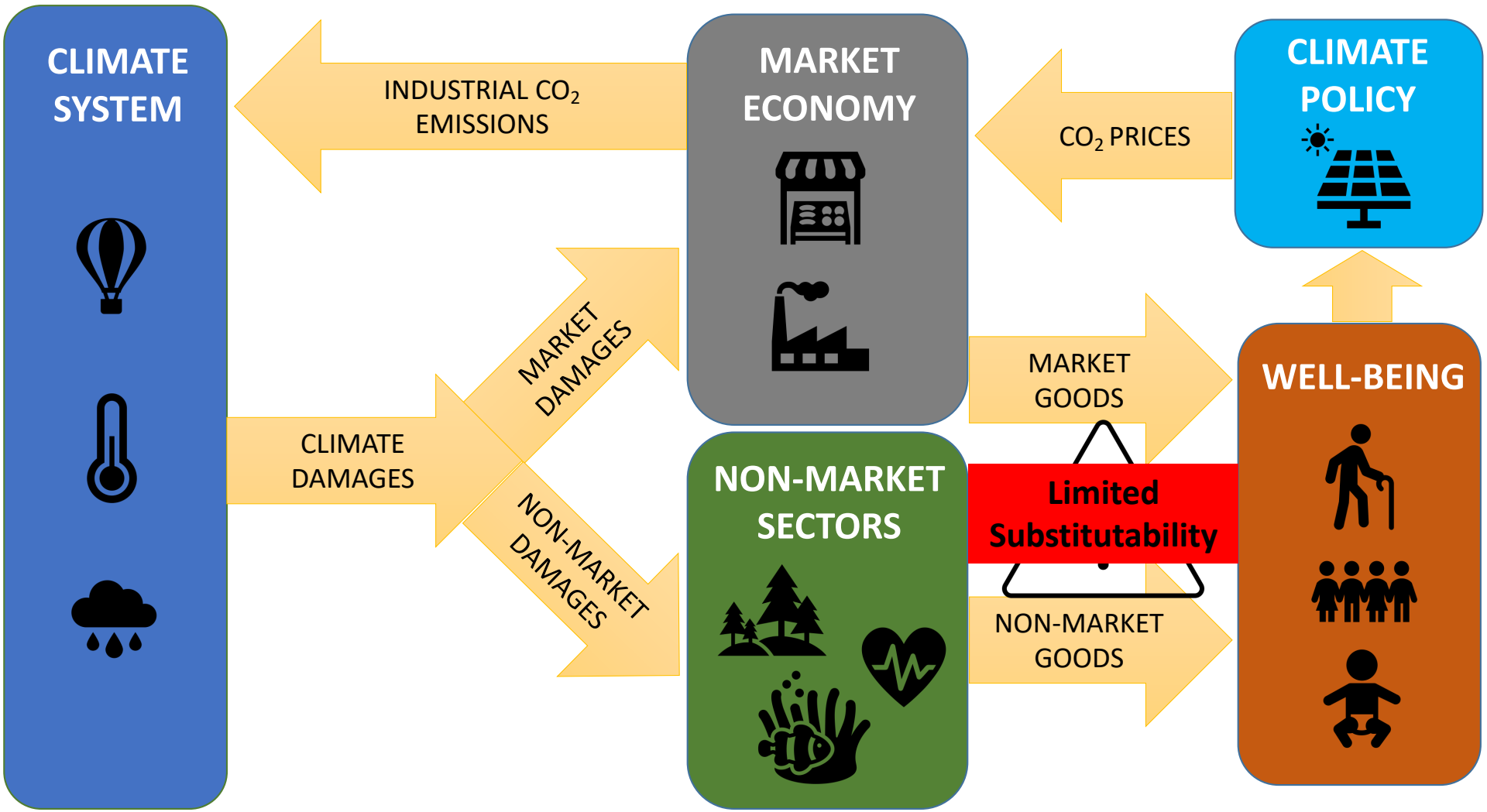
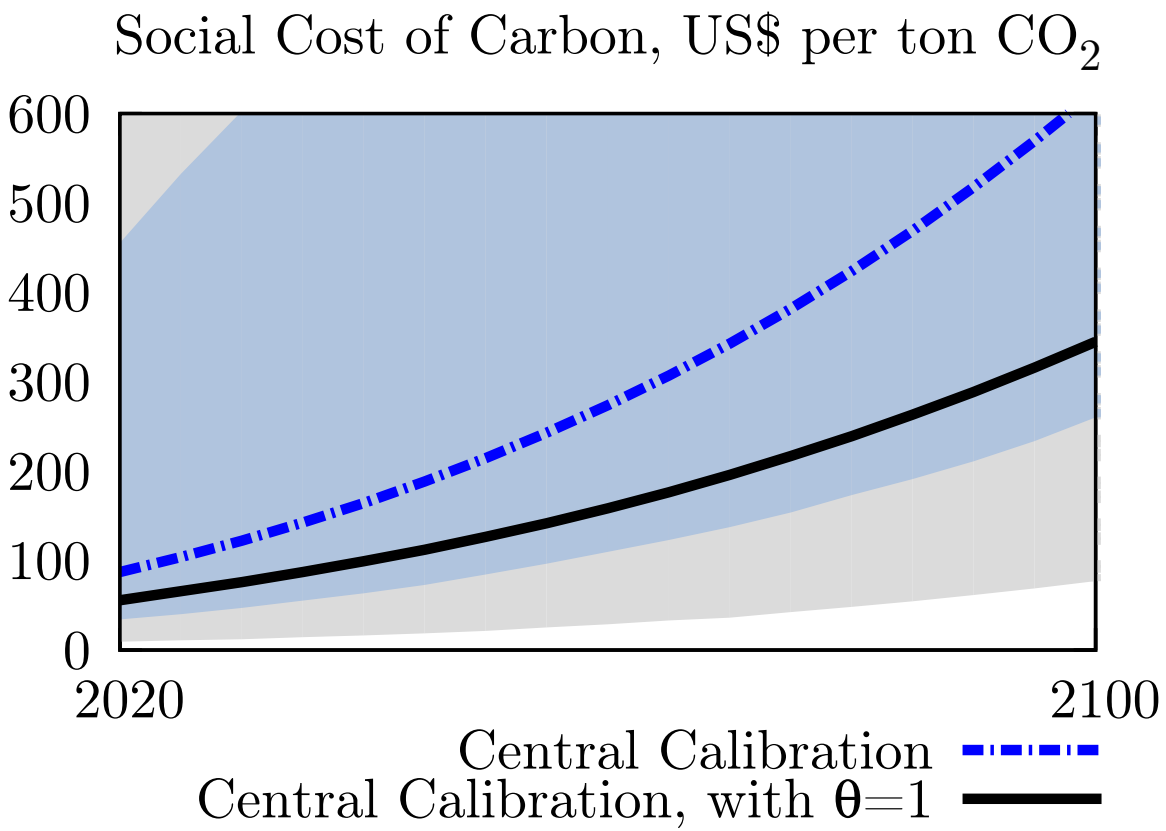


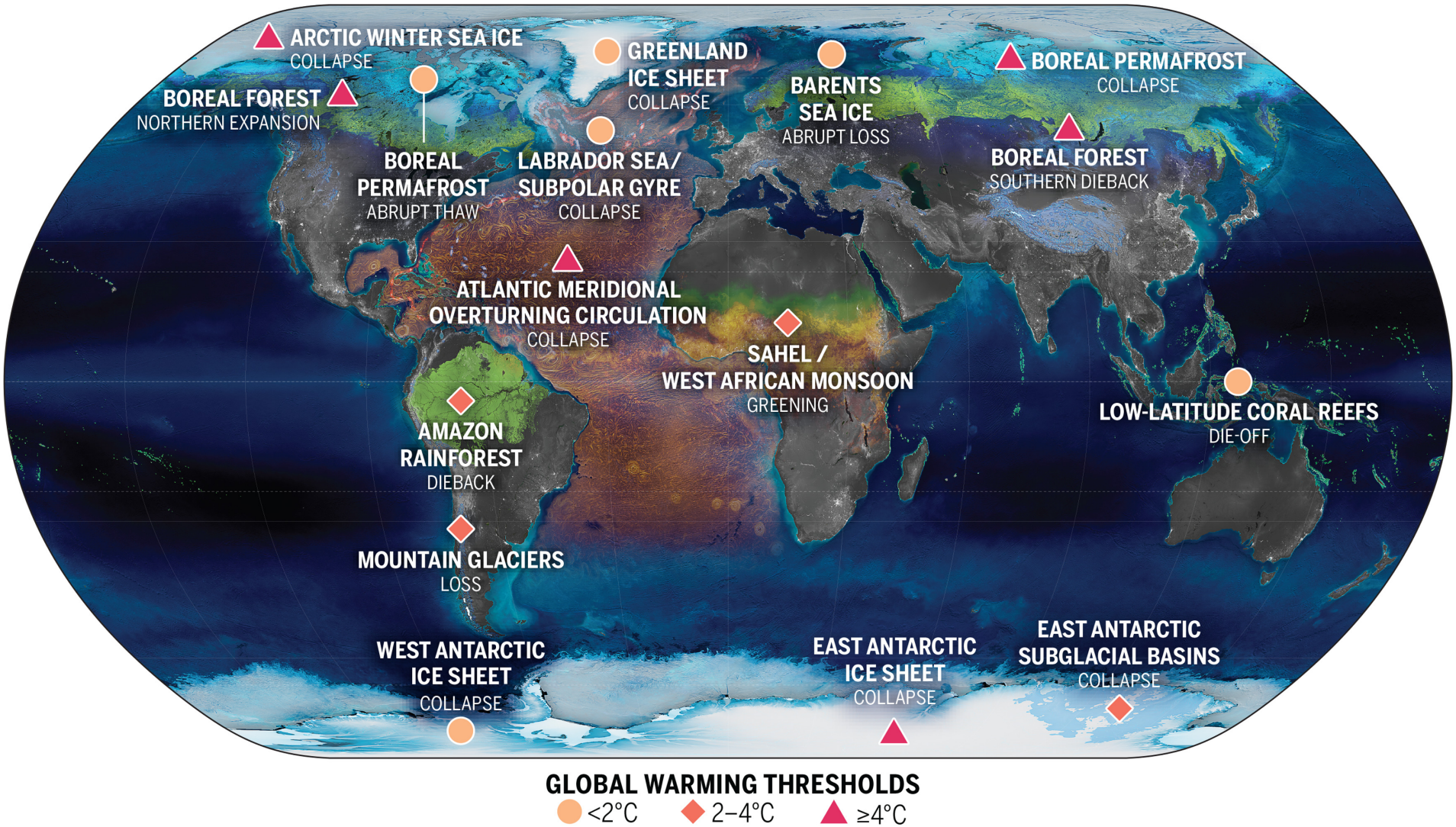
Limited substitutability and the SCC (Drupp/Hänsel 2021 AEJ)

⇒ Degree of limited substitutability of non-market goods (environment & health) informed by expert assessments and non-market valuation studies

⇒ Neglecting *limited substitutability* in our central calibration would underestimate the SCC in 2020 (2100) by >50% (80%) as compared to perfect substitutability

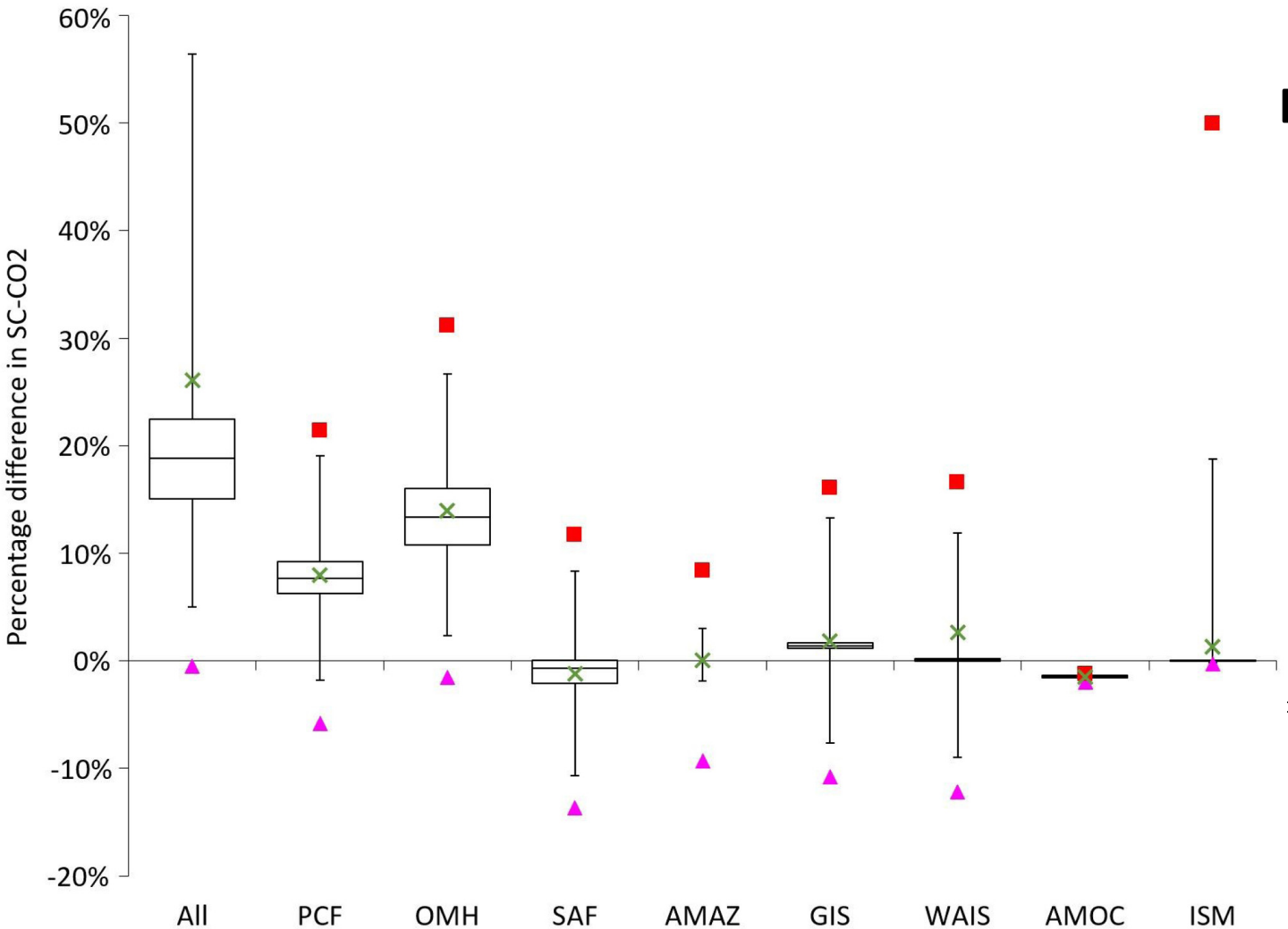


Tipping points in the climate system



Source: McKay et al. (2022 *Science*)

Tipping points (Dietz et al. 2021 PNAS)



Effect on the SCC:

- Permafrost carbon feedback (PCF): SCC + 8.4%
- Greenland ice sheet disintegration (GIS): SCC + 1.8%
- ...

$\Rightarrow$ All combined: SCC + 25% ($65 vs. $52)

SCC meta-analysis and expert survey (Moore et al. 2024)

- Literature: Piecemiel approach to dealing with criticism and stuctural extensions
  - Vast majority make 1-2 adjustments to a standard IAM and report change in SCC

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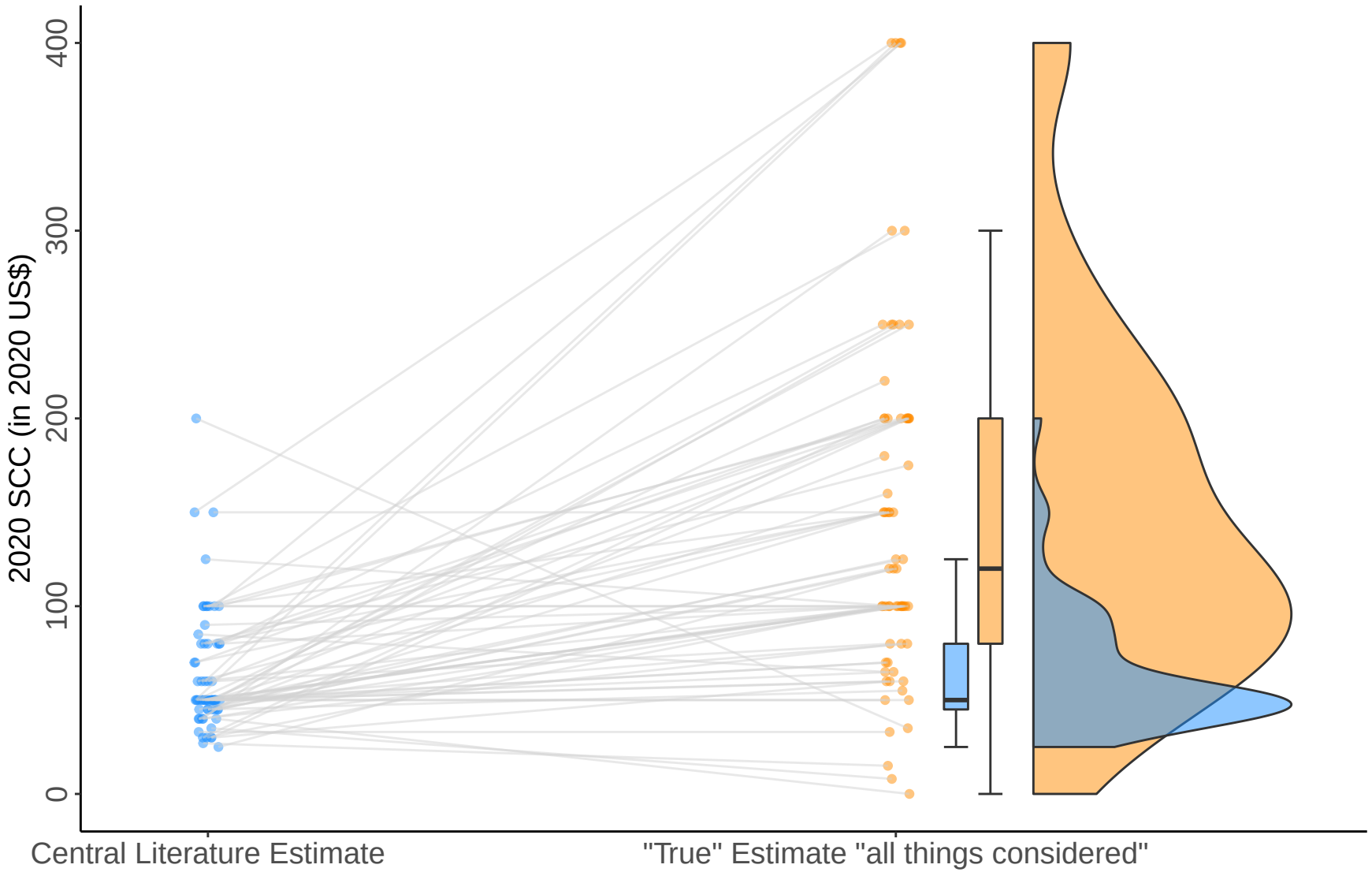
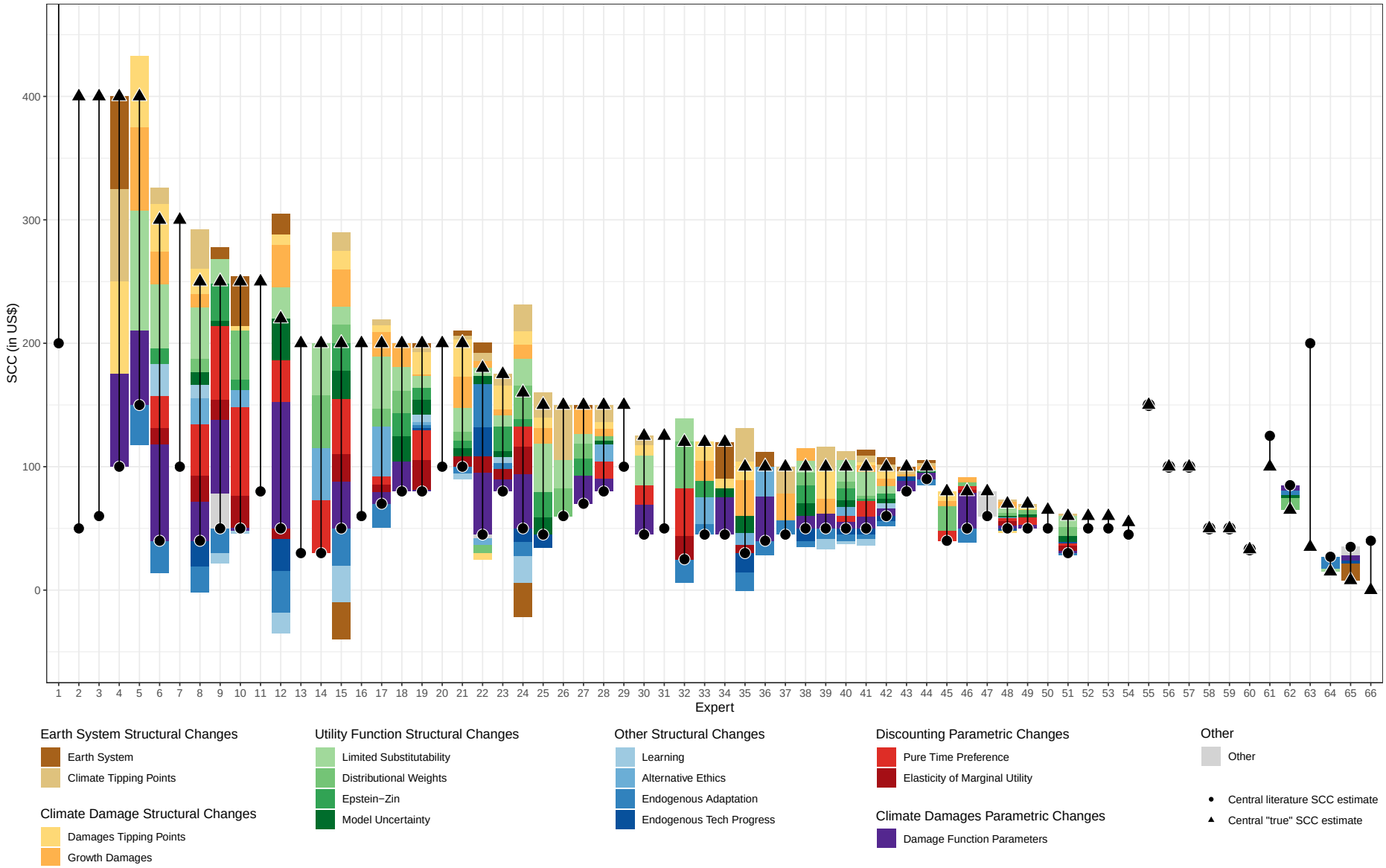
- We complement the meta-analysis with an expert survey of SCC authors.
  $\Rightarrow$ We elicit i.a. estimates of what SCC authors (N=66/176) perceive is the
  - distribution of published SCC values (**literature SCC**)
  - distribution of their "true" SCC estimates "all things considered" (**true SCC**),
  - perceptions of what drives a wedge between these two (**SCC-wedge**)

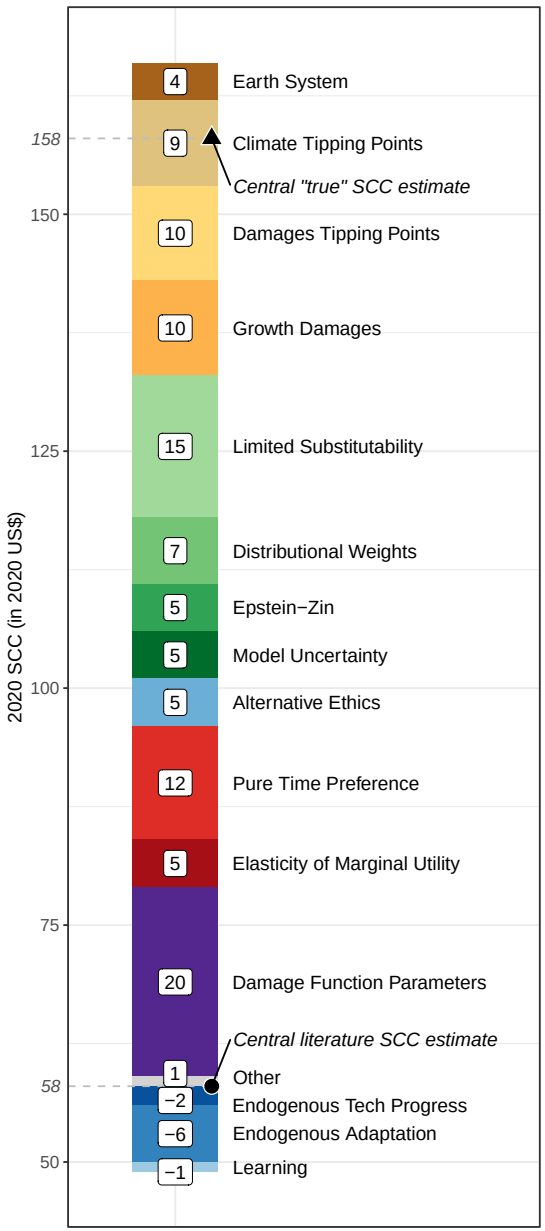
SCC is considerably biased downwards in the literature (p<0.000)



SCC-wedges, structural changes, and diverse mental models



What explains the SCC-wedge ($100)?



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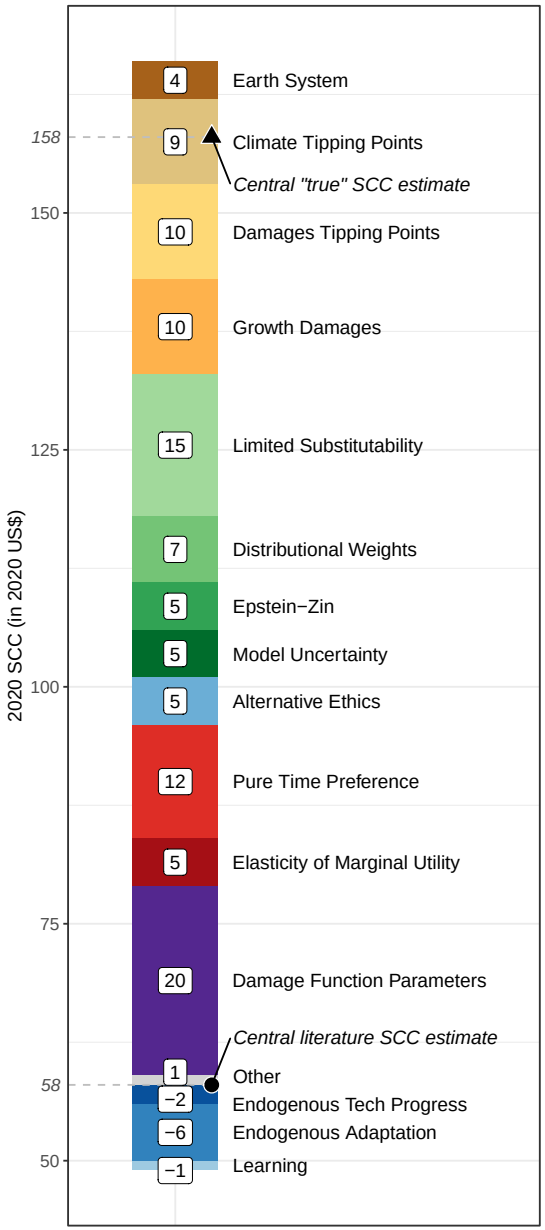


$20 Damage frunction parameters

$\Rightarrow$ e.g. Carleton et al. (2022 *QJE*)

$19 Tipping points, in the climate system or in damages

$\Rightarrow$ e.g. Dietz et al. (2021 *PNAS*)

$15 Limited substitutability

$\Rightarrow$ e.g. Drupp/Hänsel (2021 *AEJ*)

$12 Pure time preference

$\Rightarrow$ e.g. Drupp et al. (2018 *AEJ*); Nesje et al. (2022)

$10 Growth damages

$\Rightarrow$ e.g. Burke et al. (2015 *Nature*); Moore&Diaz (2015 *NCC*)

$7 Distributional weights

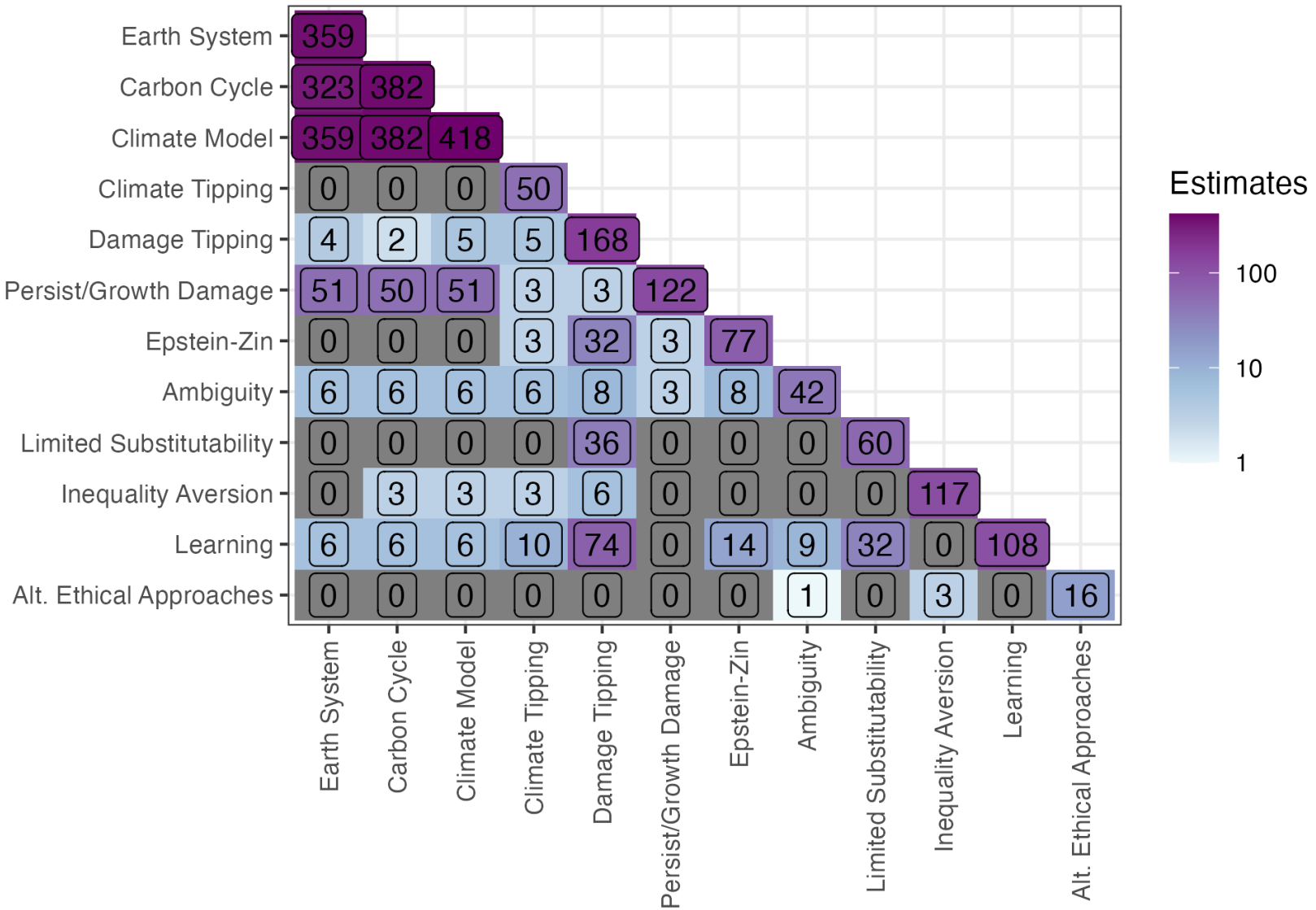
$\Rightarrow$ e.g. Anthof&Emmerling (2019 *JAERE*);

$5 Alternative ethical approaches

$\Rightarrow$ e.g. Dietz&Asheim (2012 *JEEM*)

-$6 Endogenous adaptation

Lots of modelling to be done...



Conclusions

- Climate change is a central policy challenge
- Estimating the SCC fraught with uncertainties, requires multiple methods & disciplines
- SCC has been substantially biased downwards
- ≈50% of expert's SCC-wedges relate to climate risks (damages, tipping points)
  - Followed by ethical matters (≈25%), substitutability (≈15%), uncertainty (≈10%)
  - We need to look out for these when extending our models
- Central SCC estimate tend to cluster ≈\$200 per t/CO_2 ($\rightarrow$ ≈0.5€ per l/gasoline)

$\Rightarrow$ Strong economic case for more ambitious climate policy