NATIONAL ACADEMIES Sciences Engineering Medicine

Roundtable on Macroeconomics and Climate-related Risks and Opportunities

Macroeconomic Primers

JANUARY 2023

Session 2: Macroeconomic Primers

NATIONAL ACADEMIES Sciences Engineering Medicine

Macroeconomic Primers Panel

Macroeconomic questions, macroeconomic models, and the role of physical and transition climate risks

Jim Stock
Harvard University

THE SALATA INSTITUTE
FOR CLIMATE AND SUSTAINABILITY
at Harvard University

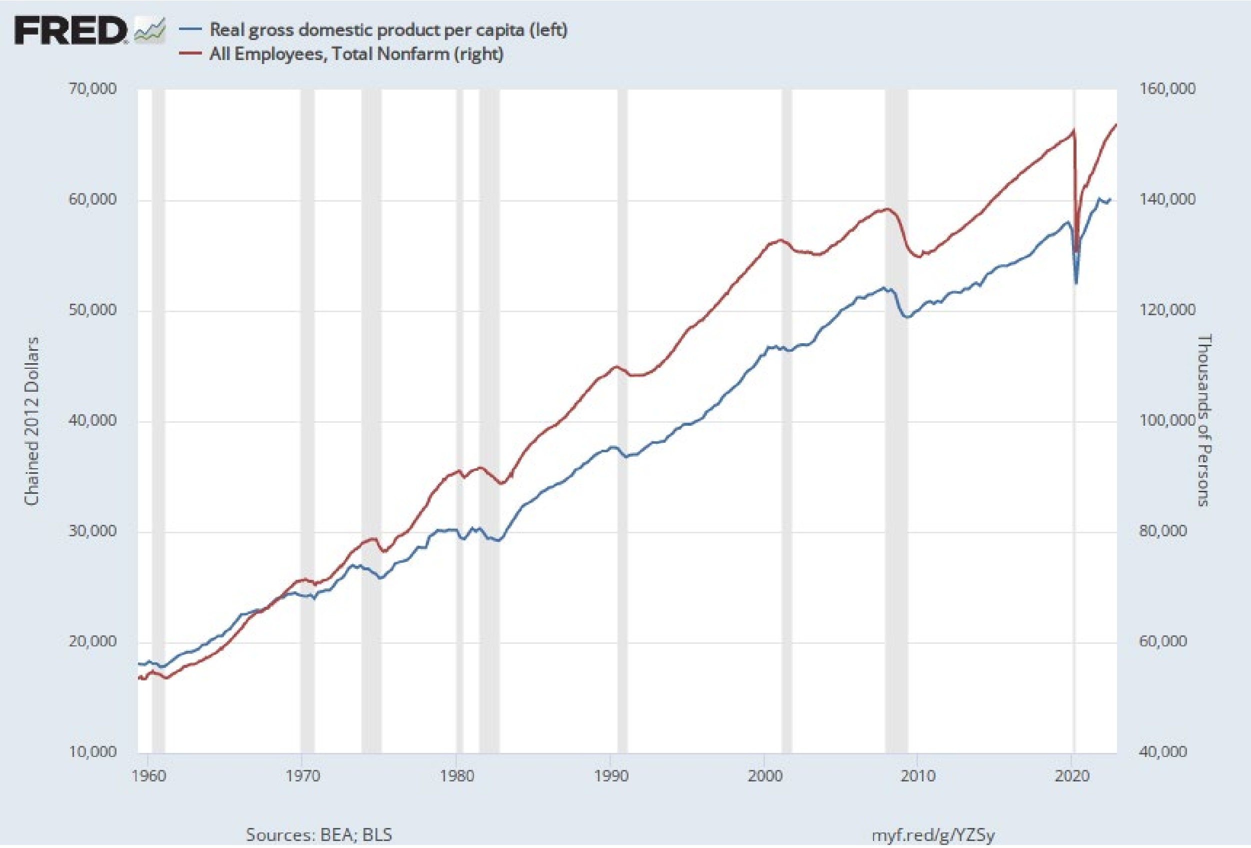
The National Academies of Sciences, Engineering, and Medicine will establish a Roundtable on Macroeconomics and Climate-related Risks and Opportunities, with a goal of improving understanding of how the physical and transition effects of climate change relate to and affect macroeconomic performance and the implications for fiscal, monetary, and financial stability policies.

The Roundtable will be a venue for federal agencies and cross-disciplinary experts in academia, industry, and non-governmental organizations to discuss challenges associated with incorporating climate change risks and opportunities into macroeconomic analysis, including: (1) how to translate the uncertain impacts of climate change and the transition to net-zero carbon emissions economies into inputs to macroeconomic analyses; and (2) how to adjust macroeconomic models and analytic approaches to accommodate the unique characteristics of climate risks and opportunities.

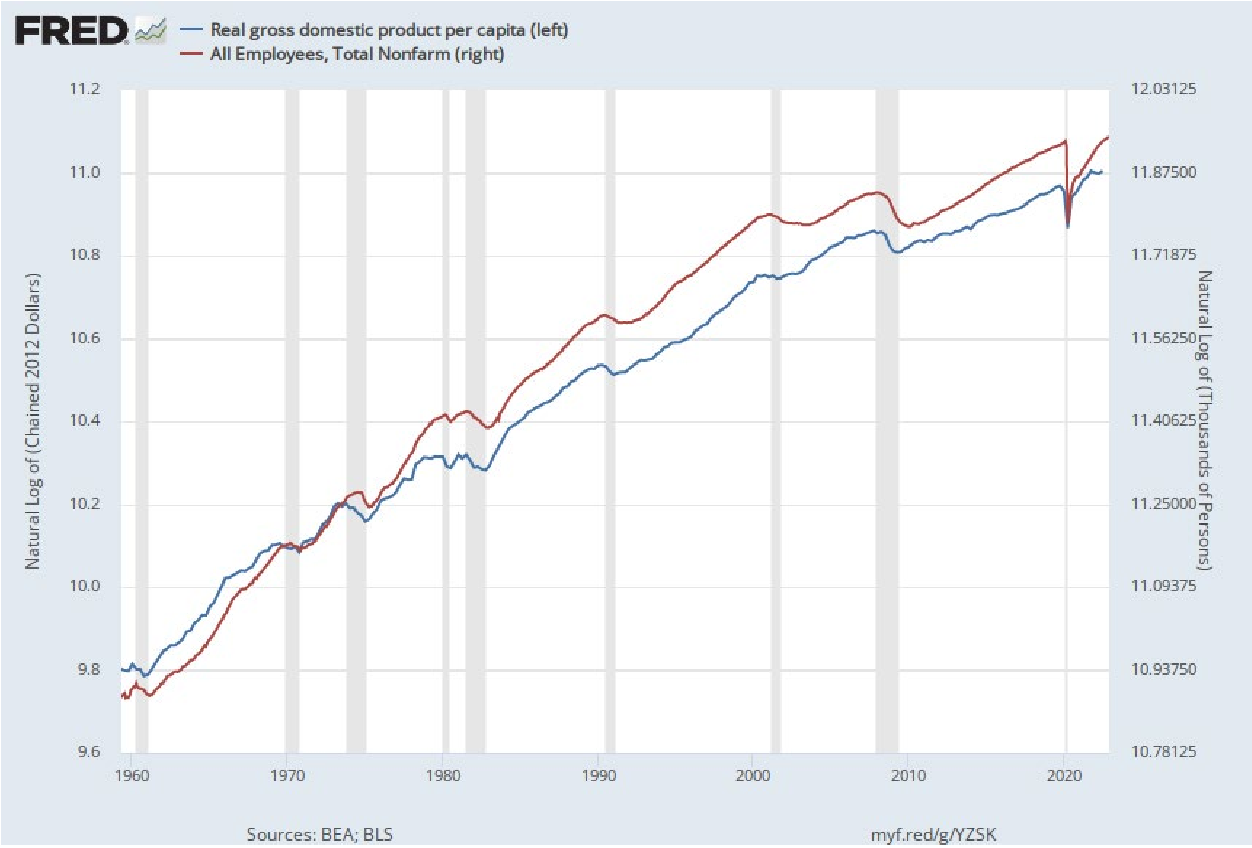
Activities of the Roundtable will help identify currently available data and analyses that can inform policy-making as the nation transitions to a net-zero carbon economy and prepares for anticipated impacts of climate change, highlight gaps in needed data and analyses, and provide a mechanism to expand relevant research efforts among both established and early career researchers. The Roundtable will focus on advancing data and methodologies that would support the development of macroeconomic analysis that inform the federal budget process in the United States, drawing upon international expertise and policies.

Real GDP and employment, 1960-present

Native units (real dollars, thou. people)



Natural log



Tasks of macroeconomists at federal agencies : Tasks -> models

Task

Misc.

SSA

CBO/JCT
OMB
CEA

FSOC (UST)

Fed

Guide deep future projections

- SCC

Analyze multidecadal fiscal policy

- Social security solvency (75 years)

Project long term economic consequences (10 years)

- Taxes, infrastructure, education,…
- Examples: IIJA, IRA

Effects of countercyclical fiscal policy

- Effects & budgetary impacts
- ARRA, American Rescue Plan, PPP,…

Ensure financial system stability

- Balance sheet effects of risk scenarios, no including climate risk

Guide monetary policy

- Interest rate & related policies to support price stability and full employment

<u>Key</u>
SSA = Social Security Administration
CBO = Congressional Budget Office
JCT = Joint Committee on Taxation
OMB = Office of Management & Budget
CEA = Council of Economic Advisors
FSOC = Financial System Oversight Council
UST = U.S. Treasury
Fed = Federal Reserve Board of Governors

Horizon

Incorporating climate risks into macro models

Macroeconomic model

Focal variables
- Labor market
  - Employment, unemployment rate
  - Real wage growth, labor force participation rate,…
- Real (i.e., inflation-adjusted) economic activity
  - GDP*
  - Income, consumption,…
  - Tax receipts, automatic outlays
- Financial markets
  - Interest rates, asset values
- Inflation rate (prices, wages)
- Policy interventions (fiscal, real side, interest rate policy,…)

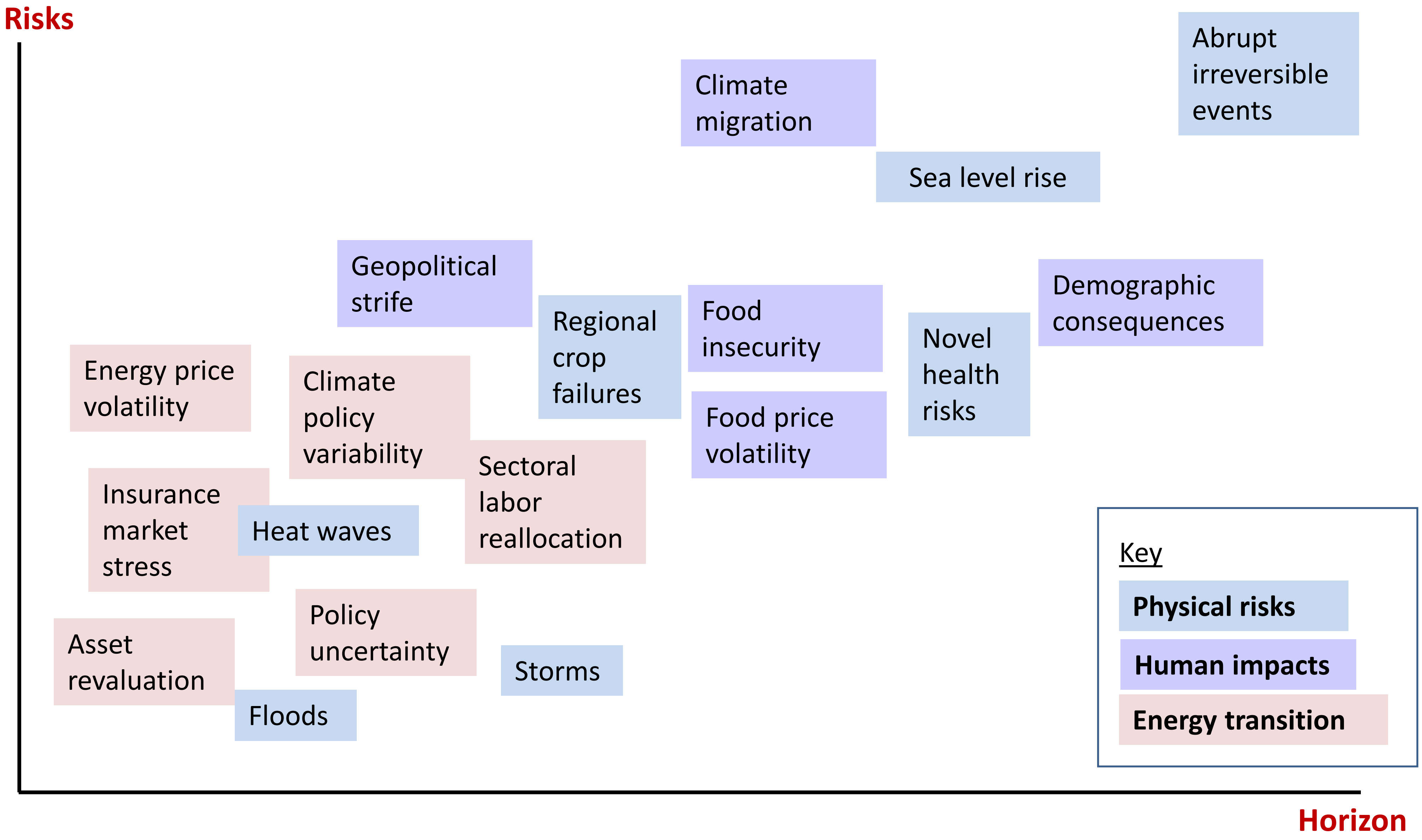
Climate risks

- Physical risks
- Transition risks

IAMs close the loop

*Why focus on GDP?
- GDP = Total market value of all domestically produced final goods & services.
- What about non-market value?
  - Natural Capital Accounts? (White House, Jan. 19, 2023)
- Depends on the task:
  - Monetary stress test/financial system stability?
  - Fiscal purposes, e.g. CBO baseline?
  - Policy assessment (welfare)

Which climate risks?



Timing and magnitudes are illustrative.

Tasks -> models: Different models for different tasks

Task

Misc.

SSA

CBO/JCT
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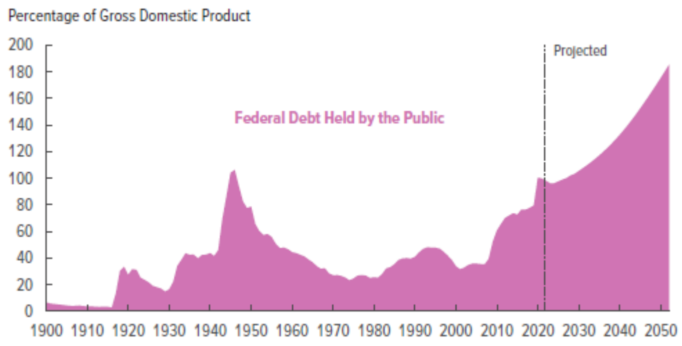
Fed

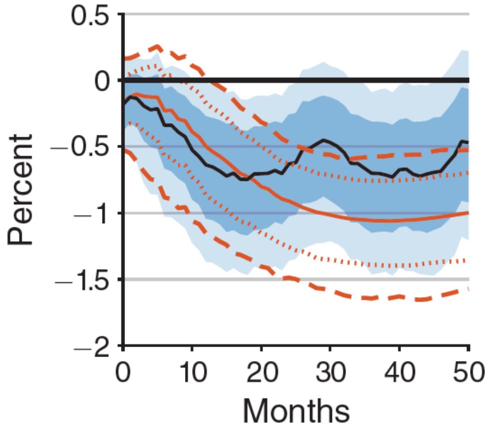
Long term growth identity

$$\Delta \ln(GDP_t) = \Delta \ln\left(\frac{GDP_t}{Hour_t}\right) + \Delta \ln\left(\frac{Hour_t}{Emp_t}\right) + \Delta \ln\left(\frac{Emp_t}{LF_t}\right) + \Delta \ln\left(\frac{LF_t}{Pop_t}\right) + \Delta \ln(Pop_t)$$



Source: CBO (*Budget & Economic Outlook, May 2022*)

Response of U.S. Industrial Production to an oil supply shock



Source: Känzig (*AER* 2021)

Horizon

Tasks -> models: Different models for different tasks

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(EIA)

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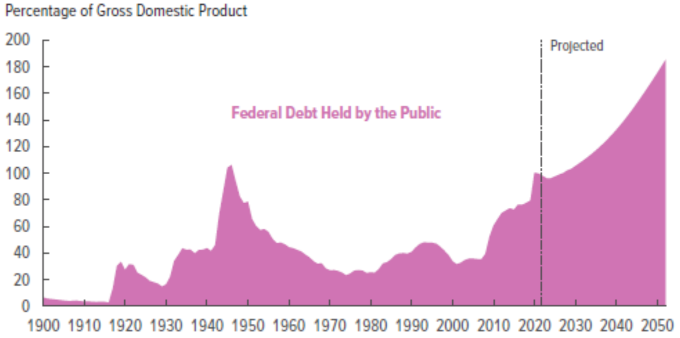
Fed

Hundreds (?) of linear simultaneous equations, estimated by OLS or IV



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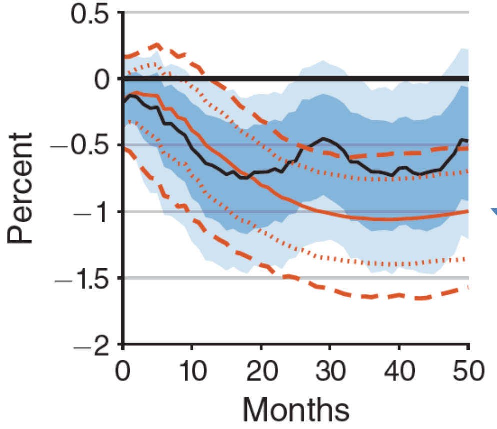
Assumptions or scenarios or stochastic modeling; demographic drivers

Response of U.S. Industrial Production to an oil supply shock



Source: Känzig (*AER* 2021)

8-variable vector autoregression with oil price shock identified using instrumental variables

Horizon

Where does climate change fit into these models?

Task

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(EIA)

FSOC (UST)

Fed

Long term growth identity

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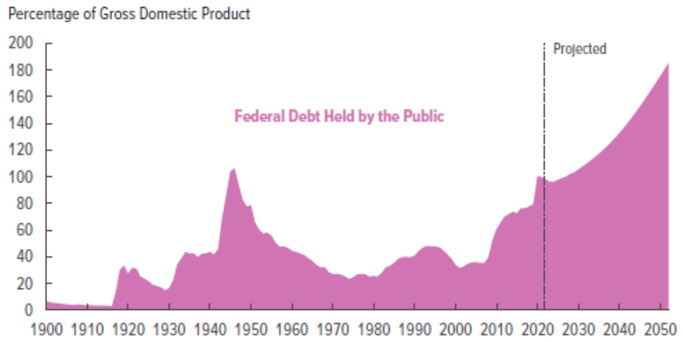
Effect of physical & transition risks on:

- Baseline for 10-year budget projections

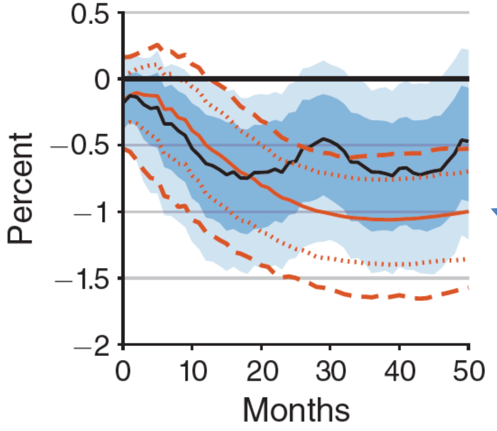


Source: CBO (*Budget & Economic Outlook, May 2022*)

Effect of physical & transition risks on:

- Productivity growth
- u*, r*
- population growth
- fiscal situation

Response of U.S. Industrial Production to an oil supply shock



Source: Känzig (*AER* 2021)

Effect of physical & transition risks on:

- Energy prices, investment, employment, unemployment rate, inflation

Horizon

Summary

- Climate affects (i) the growth baseline & (ii) the distribution of future shocks
- Transition risk is arguably more important than physical risk for horizons through 10 years

Macroeconomic Modeling and Climate Change

Lars Peter Hansen (University of Chicago)
Roundtable on Macroeconomics and Climate-related Risks and Opportunities
January 23, 2023

Modeling large scale macroeconomic systems

- ▷ "economic agents" (individuals, enterprises and other economic entities) differ from physical particles because they are "forward-looking"
- ▷ formal models incorporate the forward-looking behavior complicating the construction, solution, and use of models
- ▷ many models are "approximately linear" opening the door to numerical methods that are tractable to implement at a large scale
- ▷ many models are analyzed as approximations around balanced growth paths
- ▷ some modeling challenges are sidestepped by the considerable use of loosely structured models aimed at capturing empirical patterns and potential dynamic responses to macroeconomic shocks as reflected by historical data

No one size fits all macroeconomic model

- some models have considerable sectoral richness
- some models feature more microeconomic heterogeneity and the role of microeconomic uncertainties
- some are highly nonlinear and tailored to the study of financial crises, but they are very otherwise very highly stylized

Macro modeling versus macro-finance modeling

- in macro models aggregate (in contrast to microeconomic) uncertainty often has "second-order" implications
- in macro finance model aggregate uncertainty is necessarily a "big deal"
- long-term (to an economist) uncertainty is featured in a substantial body of research along with uncertain extreme events
- decision theory under uncertainty approaches have been more prominent in the macro-finance setting than in more standard macro settings

Valuable modeling tools from macro-finance can be imported into the modeling of macro-climate change linkages

Challenges posed by incorporating climate change considerations

- empirical challenges: pushing the economy into places it has not experienced historically
- computational challenges: approximating around balanced growth paths is off the table
- incorporating new sources of aggregate uncertainty: first-order consideration including human impacts on the environment and economic adaptation to changes in the environment
    - economic agents "inside the model" confront uncertainty
    - model builders and users "outside the model" confront uncertainty

What types of uncertainty are relevant for quantitative models?

- risk: (uncertainty within a model) each model has explicit random impulses
- ambiguity: (uncertainty across models) multiple models give rise to different implications
- misspecification: (uncertainty about models) each model is an abstraction and not intended to be a complete description of reality

Decision theory research aims to provide a way to formalize concepts such as "deep" or "radical" uncertainty sometimes referred to policy debates. Requires refinements and modifications to "uncertainty quantification."

Primer:
Economics of Climate Change Risks

Solomon Hsiang
UC Berkeley

Roundtable on Macroeconomics and Climate-related Risks and Opportunities – Executive Meeting
National Academies of Sciences, Engineering & Medicine
January 23, 2023

Assessing climate change risks & damages

1. Models w. endogenous equilibria $\rightarrow$ optimal climate policy
    - Derive fundamental aspects of the climate change problem (e.g. risk premium)
    - Guides optimal policy stringency
    - Many = "Integrated Assessment Models" (IAMs)

Assessing climate change risks & damages

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2. Scenario-driven "applied policy" models
    - Assume the trajectory of global economy & emissions
    - Often endogenize key feedbacks
    - Can be globally comprehensive & capture many sectors
    - Enable exploration of several immediately policy-relevant outputs
    - Many = IAMs

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3. Empirical estimate of climate damages
   - Focus on identification & measurement
   - Generally local & sector-specific
   - Challenge: understanding link between weather & climate effects
   - Difficult to connect directly to policy

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Empirical	Scenario-driven		Equilibrium	
Mendelsohn, Nordhaus, Shaw (AER 1994)	*PAGE* Hope et al (EP, 1993)	*FUND* Tol (EMA, 1997)	*DICE* Nordhaus (Science 1992) Nordhaus & Boyer (2000)	*GTAP* Hertel et al

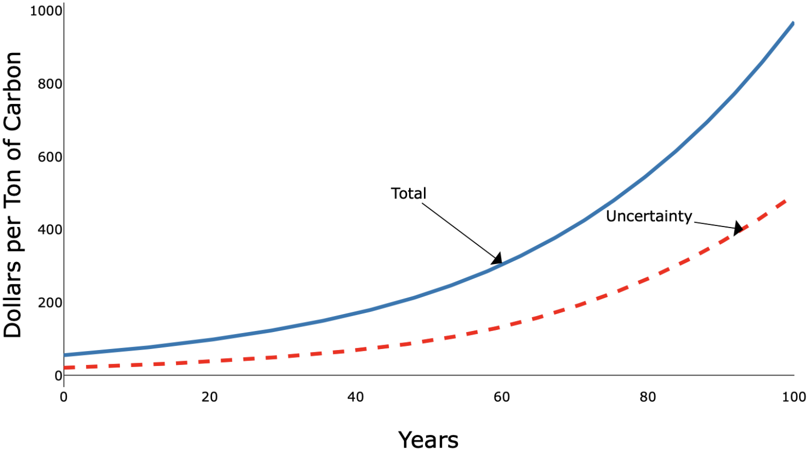
Models w. endogenous equilibria: Foundation

"An Optimal Transition Path for Controlling Greenhouse Gases"
William Nordhaus (Science, 1992)

Dynamic Integrated Climate-Economy (DICE) model

- Welfare: $W = \sum_t^T U(c_t, L_t) R_t$
- Output: $Q_t = [1 - \Lambda_t] A_t K_t^{\gamma} L_t^{1-\gamma} / [1 + \Omega_t]$
- Damages: $\Omega_t = \psi_1 T_t + \psi T_t^2$
- Emissions: $E_t = \sigma_t [1 - \mu_t] A_t K_t^{\gamma} L_t^{1-\gamma}$
- Carbon: $M_{At} = E_t + \phi_1 M_{At-1} + \phi_2 M_{UPt-1}$ (+ other carbon sinks)
- Temperature: $T_t = T_{t-1} + \Psi_1 [F_t - \Psi_2 T_{t-1} - \Psi_3 (T_{t-1} - T_{L0t-1})]$

Models w. endogenous equilibria: Price uncertainty



Barnett, Brock, Hansen (JFE, 2022)

Models w. endogenous equilibria: Spatial allocation

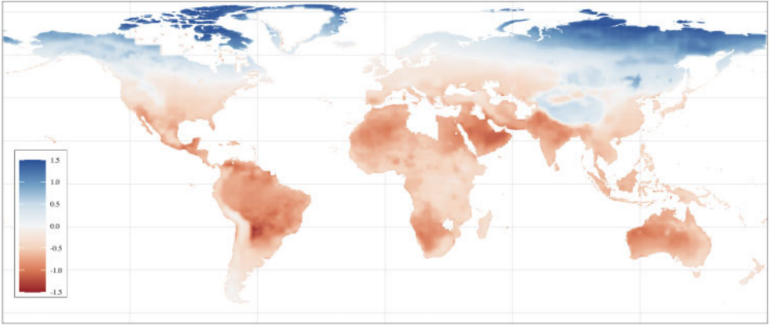


Figure 7. Effect of climate change on real output per capita in 2200
Note: The log of real output per capita under climate change minus the log of real output per capita under no climate change in period 200.

Conte, Desmet, Nagy, Rossi-Hansberg (J Econ Geo, 2021)

Equilibrium

DICE
Nordhaus (Science 1992)
Nordhaus & Boyer (2000)

Weitzman (ReStat, 2009)

Golosov et al
(ECMA, 2014)
Traeger & Lemoine
(AEJ, 2014)
Cai & Lontzek
(JPE, 2019)
Barnett, Brock & Hansen
(RFS, 2022)

Equilibrium

DICE
Nordhaus (Science 1992)
Nordhaus & Boyer (2000)

Acemoglu et al (AER, 2012)

COMET
Barrage (ReStud, 2021)

Equilibrium

DICE
Nordhaus (Science 1992)
Nordhaus & Boyer (2000)

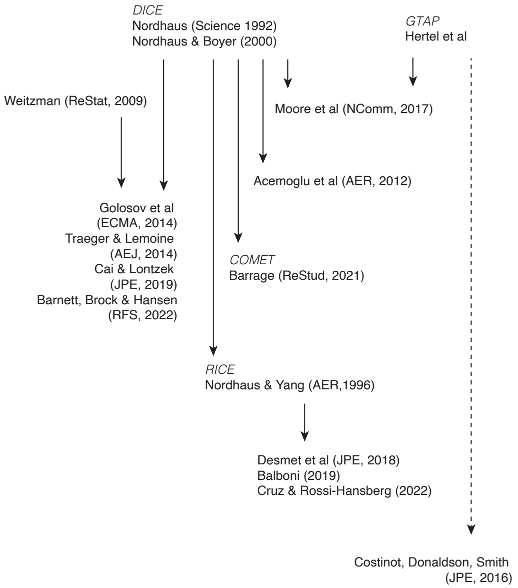
GTAP
Hertel et al

RICE
Nordhaus & Yang (AER,1996)

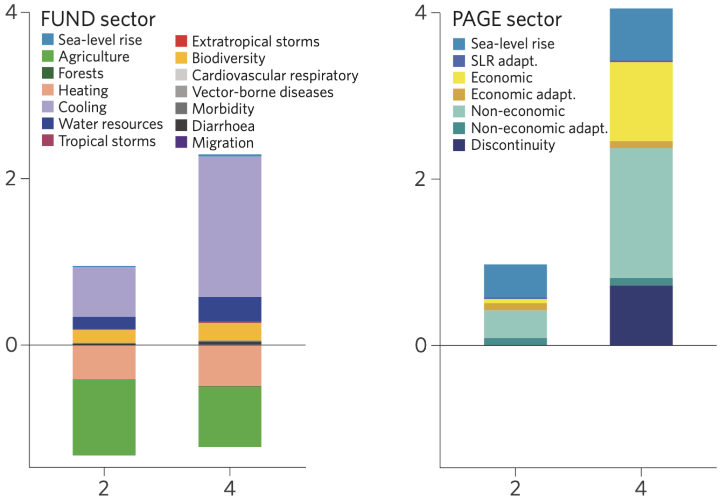
Desmet et al (JPE, 2018)
Balboni (2019)
Cruz & Rossi-Hansberg (2022)

Costinot, Donaldson, Smith
(JPE, 2016)

Equilibrium



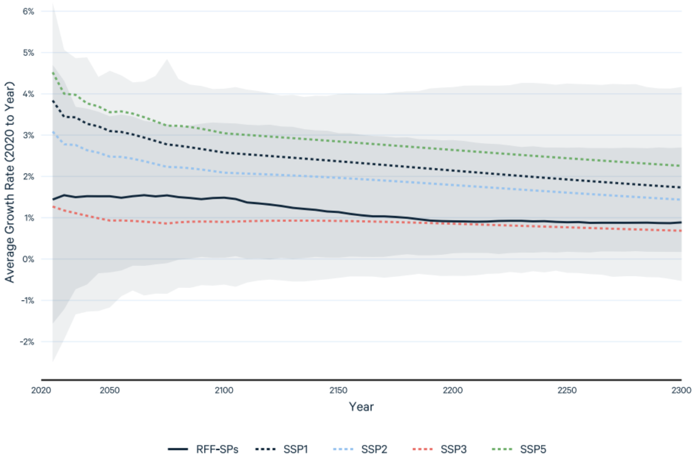
Scenario-driven "applied policy" models



Diaz and Moore, 2017

Scenario-driven “applied policy” models

Figure 6. Average Projected Growth Rates of Global GDP per Capita



Rennert et al, 2021

Scenario-driven

PAGE
Hope et al
(EP, 1993)

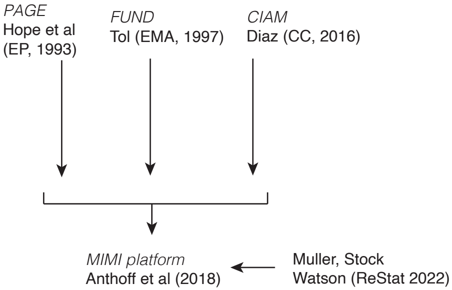
↓

Stern (2006)

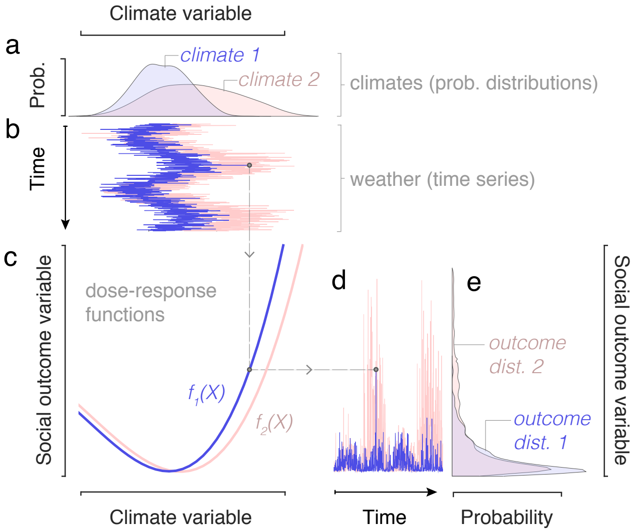
FUND
Tol (EMA, 1997)

CIAM
Diaz (CC, 2016)

Scenario-driven



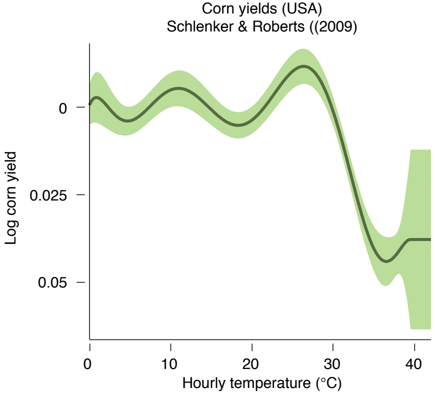
Empirical damage estimation

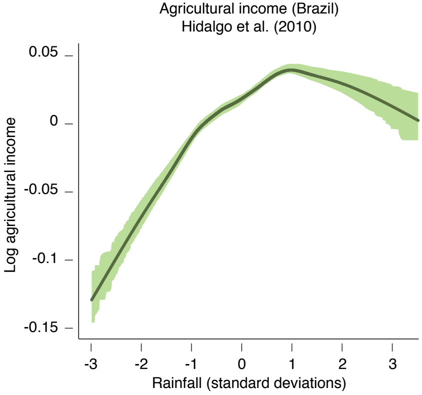


Carleton and Hsiang, 2016

Empirical damage estimates: agriculture

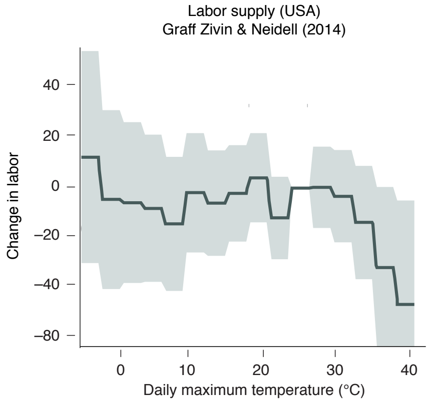
Heat and dryness lower crop yields

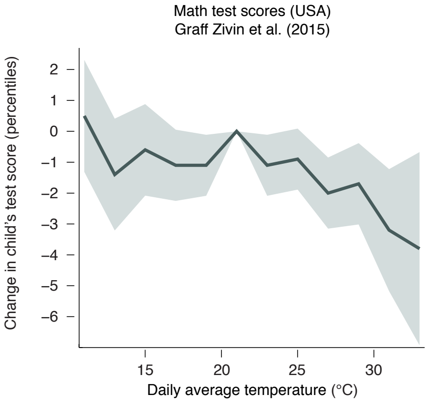




Empirical damage estimates: labor

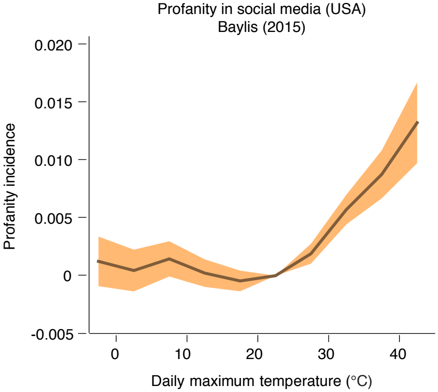
Labor supply and productivity fall at high temperatures

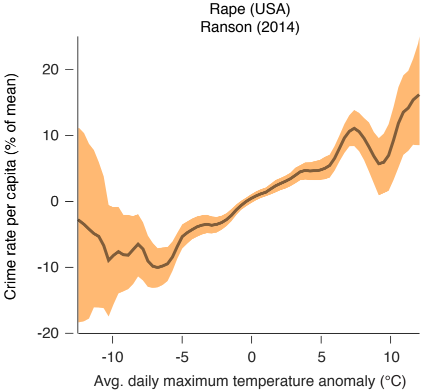




Empirical damage estimates: violence

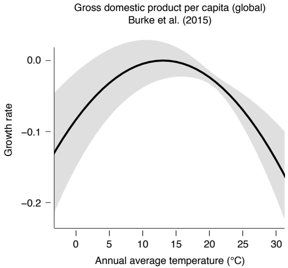
Violence and aggression increase with warming temperatures

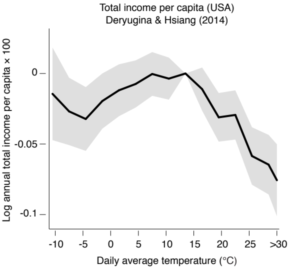


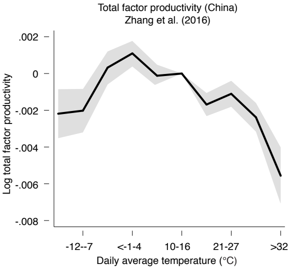


Empirical damage estimates: growth

Macroeconomic indicators are nonlinear in temperature







Empirical

Mendelsohn, Nordhaus, Shaw (AER 1994)

↓

Deschenes & Greenstone (AER, 2007)
Schlenker & Roberts (PNAS, 2009) + others

Empirical

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Deschenes & Greenstone (AER, 2007)
Schlenker & Roberts (PNAS, 2009) + others

Ranson (JEEM, 2014) + others

Hsiang & Jina (2017)

Dell, Jones, Olken (AEJ, 2011)
Burke, Hsiang, Miguel (Nature, 2015)

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Auffhammer (JEEM, 2022)

DSCIM-sectors
Carleton et al (QJE, 2022)
Rode et al (Nature, 2021)

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Dell, Jones, Olken (AEJ, 2011)
Burke, Hsiang, Miguel (Nature, 2015)

Scenario-driven

Equilibrium

DICE
Nordhaus (Science 1992)
Nordhaus & Boyer (2000)

Moore & Diaz (NCC, 2015)
Ricke et al. (NCC, 20018)

Empirical | **Scenario-driven** | **Equilibrium**

GTAP
Hertel et al

Costinot, Donaldson, Smith
(JPE, 2016)

Nath (2021)
Dingel, Meng, Hsiang (2021)

Empirical | **Scenario-driven** | **Equilibrium**

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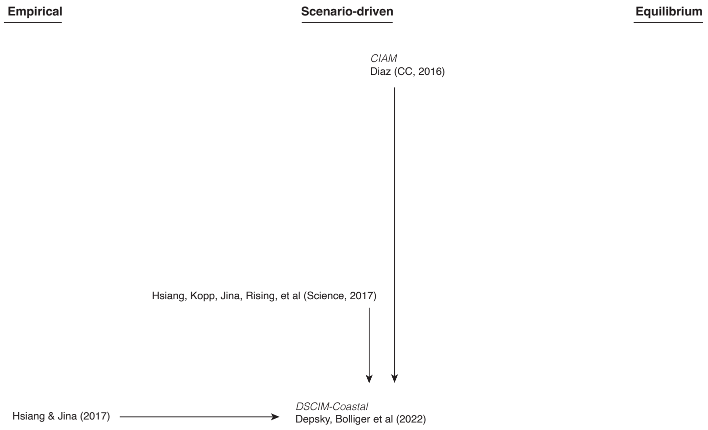
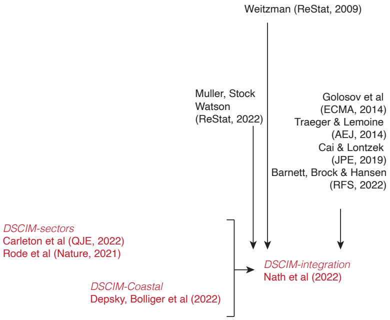
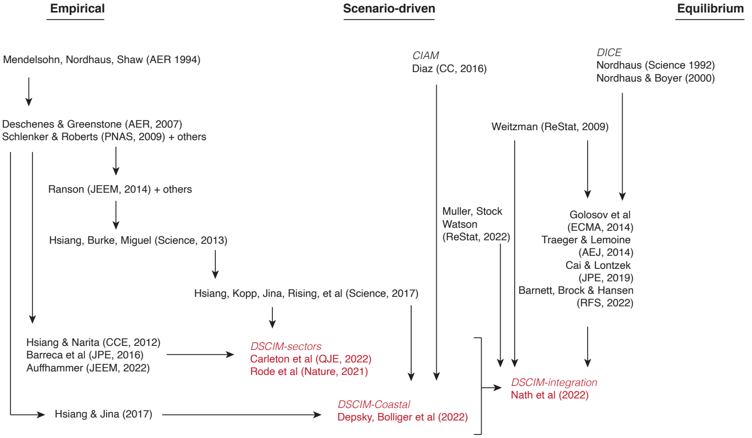

Empirical
Scenario-driven
Equilibrium
CIAM
Diaz (CC, 2016)
Hsiang, Kopp, Jina, Rising, et al (Science, 2017)
Hsiang & Jina (2017)
DSCIM-Coastal
Depsky, Bolliger et al (2022)

Empirical | **Scenario-driven** | **Equilibrium**

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Deschenes & Greenstone (AER, 2007)
Schlenker & Roberts (PNAS, 2009) + others
Weitzman (ReStat, 2009)
Ranson (JEEM, 2014) + others
Muller, Stock
Watson
(ReStat, 2022)
Golosov et al
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DSCIM-sectors
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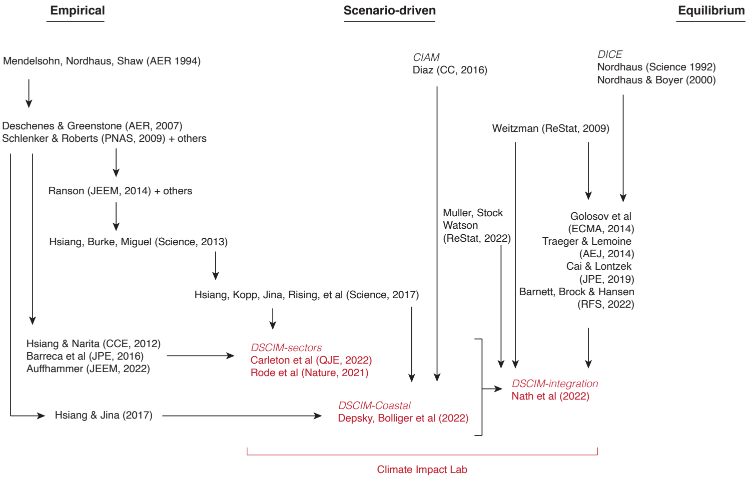
Nath et al (2022)
Hsiang & Jina (2017)
DSCIM-Coastal
Depsky, Bolliger et al (2022)



Empirical
Scenario-driven
Equilibrium
Mendelsohn, Nordhaus, Shaw (AER 1994)
CIAM
Diaz (CC, 2016)
DICE
Nordhaus (Science 1992)
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DSCIM-Coastal
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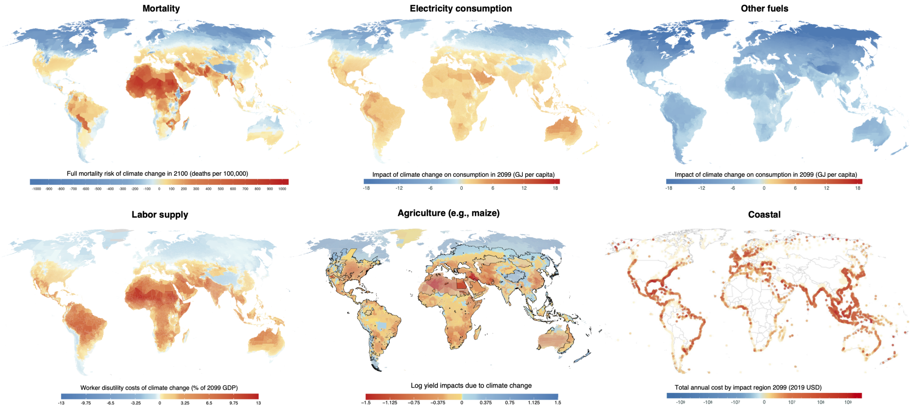
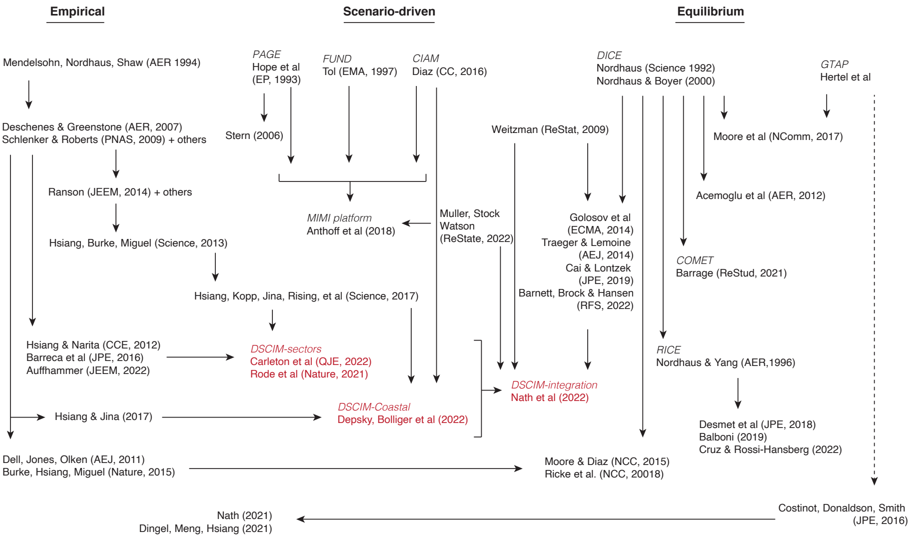
Climate Impact Lab

Data-driven, probabilistic, spatially-resolved projections w. adaptation + valuing uncertainty



Carleton et al 2022, Rode et al 2021, Rode et al 2022, Hultgren et al 2022, Depsky et al 2022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Dell, Jones, Olken (AEJ, 2011)
Burke, Hsiang, Miguel (Nature, 2015)
Nath (2021)
Dingel, Meng, Hsiang (2021)
PAGE
Hope et al
(EP, 1993)
FUND
Tol (EMA, 1997)
CIAM
Diaz (CC, 2016)
Stern (2006)
MIMI platform
Anthoff et al (2018)
Muller, Stock
Watson
(ReState, 2022)
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DICE
Nordhaus (Science 1992)
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GTAP
Hertel et al
Weitzman (ReStat, 2009)
Moore et al (NComm, 2017)
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Cai & Lontzek
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Barnett, Brock & Hansen
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COMET
Barrage (ReStud, 2021)
RICE
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Desmet et al (JPE, 2018)
Balboni (2019)
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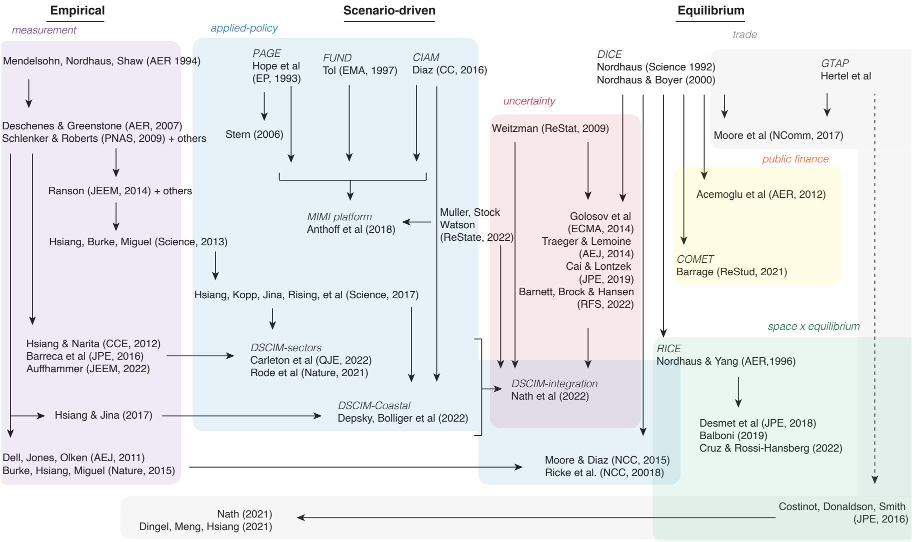
Moore & Diaz (NCC, 2015)
Ricke et al. (NCC, 20018)
Costinot, Donaldson, Smith
(JPE, 2016)



Empirical
Scenario-driven
Equilibrium
measurement
applied-policy
trade
Mendelsohn, Nordhaus, Shaw (AER 1994)
PAGE
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A FIELD GUIDE TO MACROECONOMIC MODELS

Eric Kemp-Benedict

Roundtable on Macroeconomics and Climate-related Risks and Opportunities

Executive Meeting #1

Washington, D.C., January 23rd, 2023

WHY A FIELD GUIDE?

If you have met one macroeconomic model, then…you have met one macroeconomic model.

Models differ by

- Purpose
- Structure
- Assumptions

These three characteristics will be explored through six widely-used models: DICE, ENV-Growth, TIMES-MACRO, FRB-US, REMI E3^{+}, and E3ME

NOT COVERED HERE, BUT RELEVANT

Stock-flow consistent models (see https://www.sfc-models.net), e.g.

- GEMMES: Used by the French Development Agency (AFD) to assess macroeconomic and financial impacts of climate change
- EIRIN: To assess financial risk from climate shocks
- ITFIN: A model for Italy developed by staff at Italy's Department of the Treasury

Context-specific policy models

Policy-relevant research models

PURPOSE

The structure of a particular model is strongly shaped by its purpose

DICE: Estimate the optimal path of reductions of GHG gases

ENV-Growth: Project future levels of global and country-specific GDP and income

TIMES-MACRO: Study the interconnections between economic development and energy demand

FRB-US: Forecast and the analyze macroeconomic issues, including both monetary and fiscal policy

REMI E3^{+}: Produce total economic impact analyses of energy-generating and environmental industries to inform and guide policy at local, state, and national levels

E3ME: Analyze the impacts of Energy-Environment-Economy (E3) policies

STRUCTURE

Models differ in how many **economic sectors** they include, their **spatial** detail, their **time horizon**, how many **household types** they include, the **environmental impacts** they estimate, how they treat **finance**, and so on

DICE: Long-run global growth model with one sector, coupled to a climate model

ENV-Growth: Global model made up of separate long-run one-sector national growth models; its outputs are used for climate scenarios

TIMES-MACRO: Multi-household, one-sector, one-region macroeconomic model linked to a highly detailed energy sector model; medium to long-run growth

FRB-US: Multi-sector (and multi-firm), multi-household model, with government policies (taxes, expenditure, monetary policy); a short-run business-cycle model

REMI E3^{+} and *E3ME*: Multi-sector, multi-region, multi-household models, with energy and environmental impacts; long-run, but can simulate short-run cycles

ASSUMPTIONS

Model assumptions depend on the prior knowledge of the model developers, as well as the purpose of the model

Prior knowledge comes from training, ongoing study, the modelers' own contributions to the literature, and broader developments in the field

DICE and *TIMES-MACRO*: Households optimize discounted future utility, which depends on household consumption as calculated by the model

ENV-Growth: Countries conditionally converge towards their long-run potential

FRB-US: Both households and firms optimize, but may be based on imperfect understanding of possible future trends

REMI E3^{+} and *E3ME*: Households and firms respond to current conditions, but:

- *REMI E3*$^{+}$: Consumers and firms respond to incremental (marginal) changes
- *E3ME*: Allows for path-dependency and substantial (non-marginal) changes

Unlike the others, *E3ME* is also a *demand-led model*

SUPPLY-LED VS DEMAND-LED

Sometimes a sharp distinction, sometimes a matter of emphasis

Supply-led:

- Investment is constrained by available savings

exogenous money

Demand-led:

- Investment is planned to meet anticipated demand
- Banks largely accommodate demand for loans

endogenous money

Prices are typically determined differently in these types of models:

- Supply-led: prices and wages are assumed to clear markets
- Demand-led: most prices are set to cover costs, wages are socially influenced

SOME QUESTIONS TO ASK

Purpose

What is the model's intended purpose?

What policy questions can it address?

What questions should it *not* be used to address?

Structure

Is it a one-sector or multi-sector model? What sectors does it include?

Does it include multiple households? Multiple regions?

Does it include energy or environmental accounts?

Does it include finance?

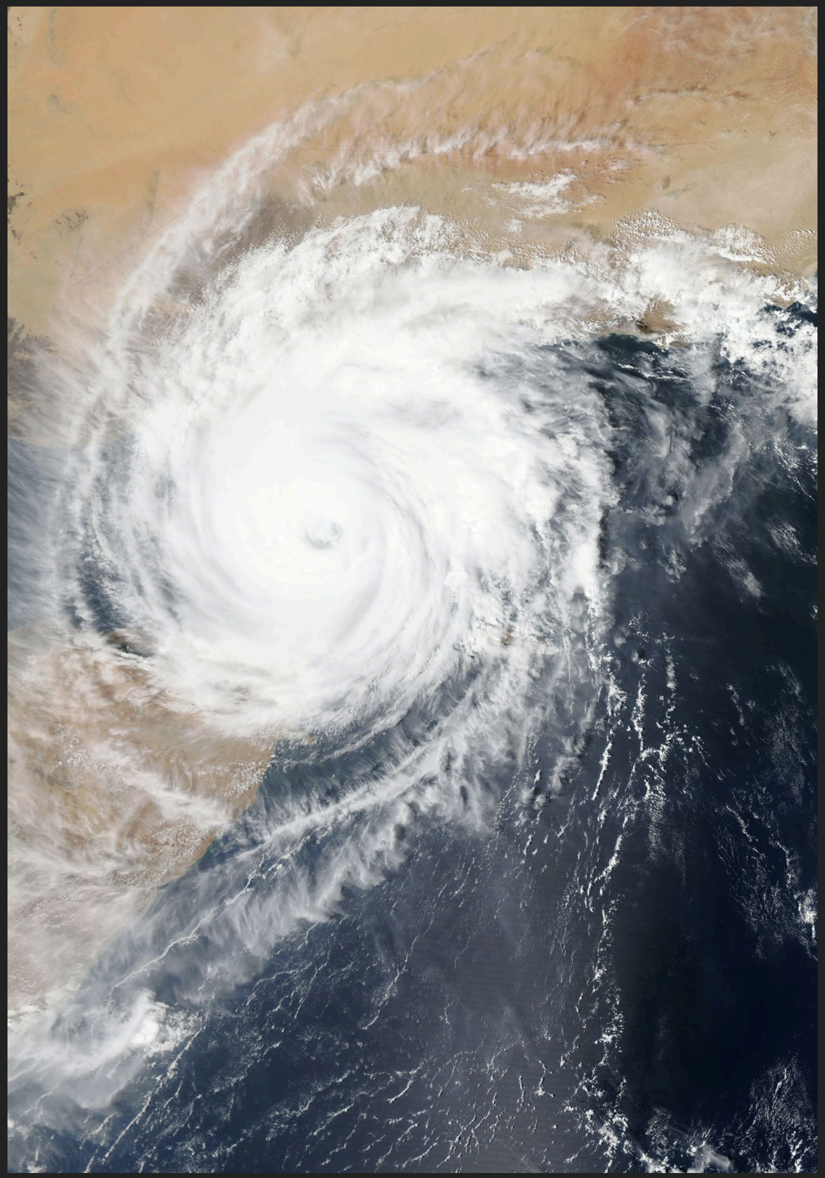
Assumptions

Does the model assume optimal behavior? Who is optimizing, and what do they optimize?

What kinds of non-optimizing behavior do you allow for (if any)?

Is the model driven mainly by aggregate demand, or aggregate supply?

Thank you!

MODELING CLIMATE RISKS IN COUPLED HUMAN-NATURAL SYSTEMS: CHALLENGES AND OPPORTUNITIES

SATHYA GOPALAKRISHNAN

AGRICULTURAL, ENVIRONMENTAL, AND DEVELOPMENT ECONOMICS

THE OHIO STATE UNIVERSITY

COUPLED HUMAN-NATURAL SYSTEMS

- The evolution of a dynamic coupled human-natural system depends on interactions or feedbacks across various components of the system, including socioeconomic and geophysical processes

TEMPORAL AND SPATIAL SCALES

- What are the timescales at which feedbacks between physical processes and economic behavior are relevant?
- How do feedbacks between human and natural dynamics cascade through time and over space?
- How can we reconcile differences in temporal and spatial resolution across system components?

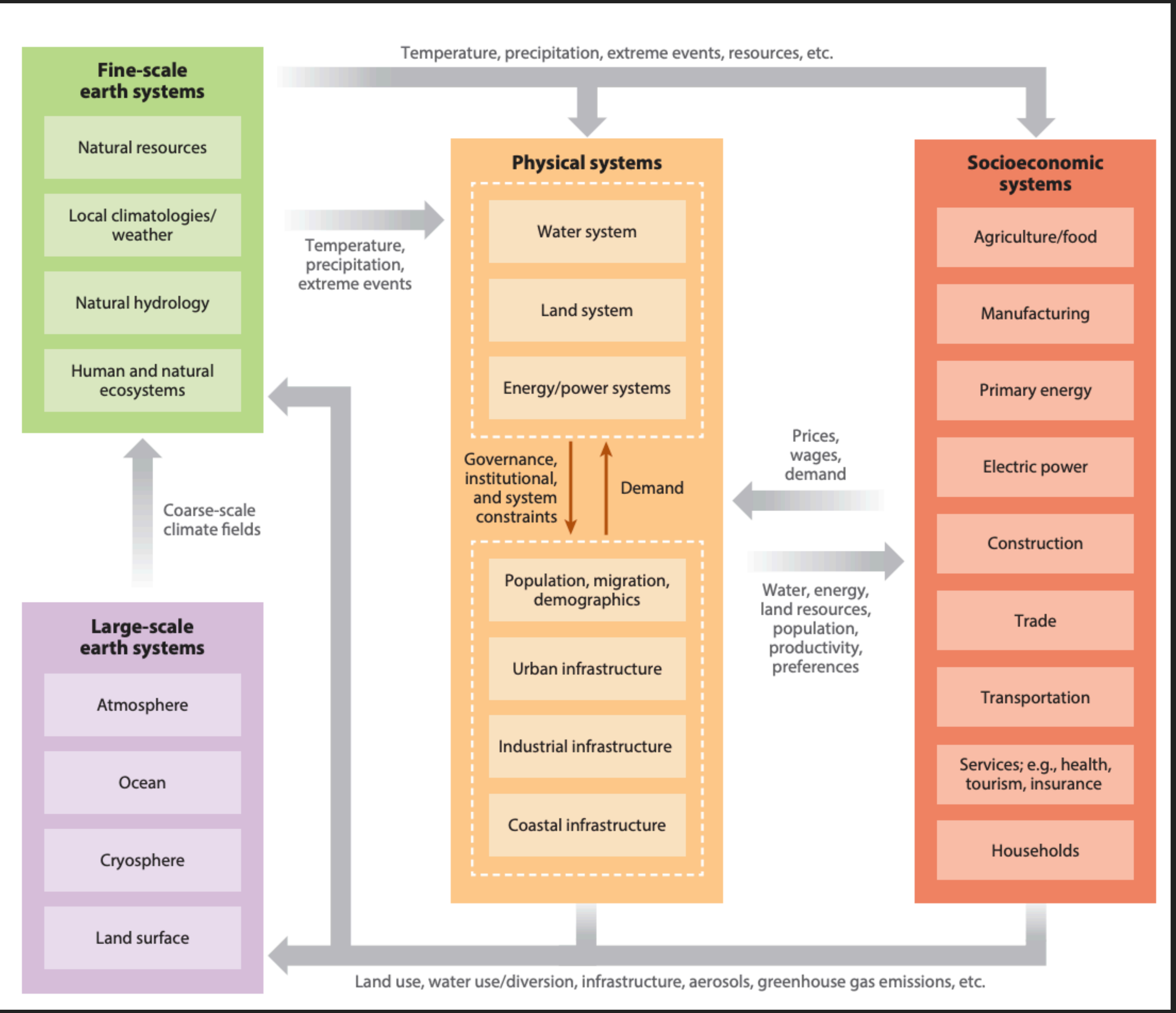


Figure from Fisher-Vanden and Weyant, 20

TRADEOFF BETWEEN COMPLETENESS AND COMPLEXITY

- Which feedbacks/interactions across sectors/regions can we empirically identify to parameterize macroeconomic models?
- How can we utilize data richness to inform large scale models?
    - Heterogeneity in the distribution and interactions of people, production, resources, and institutions
    - Accounting for natural capital stocks and flows

Thank you

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