# Robust decision-making on climate and energy policy

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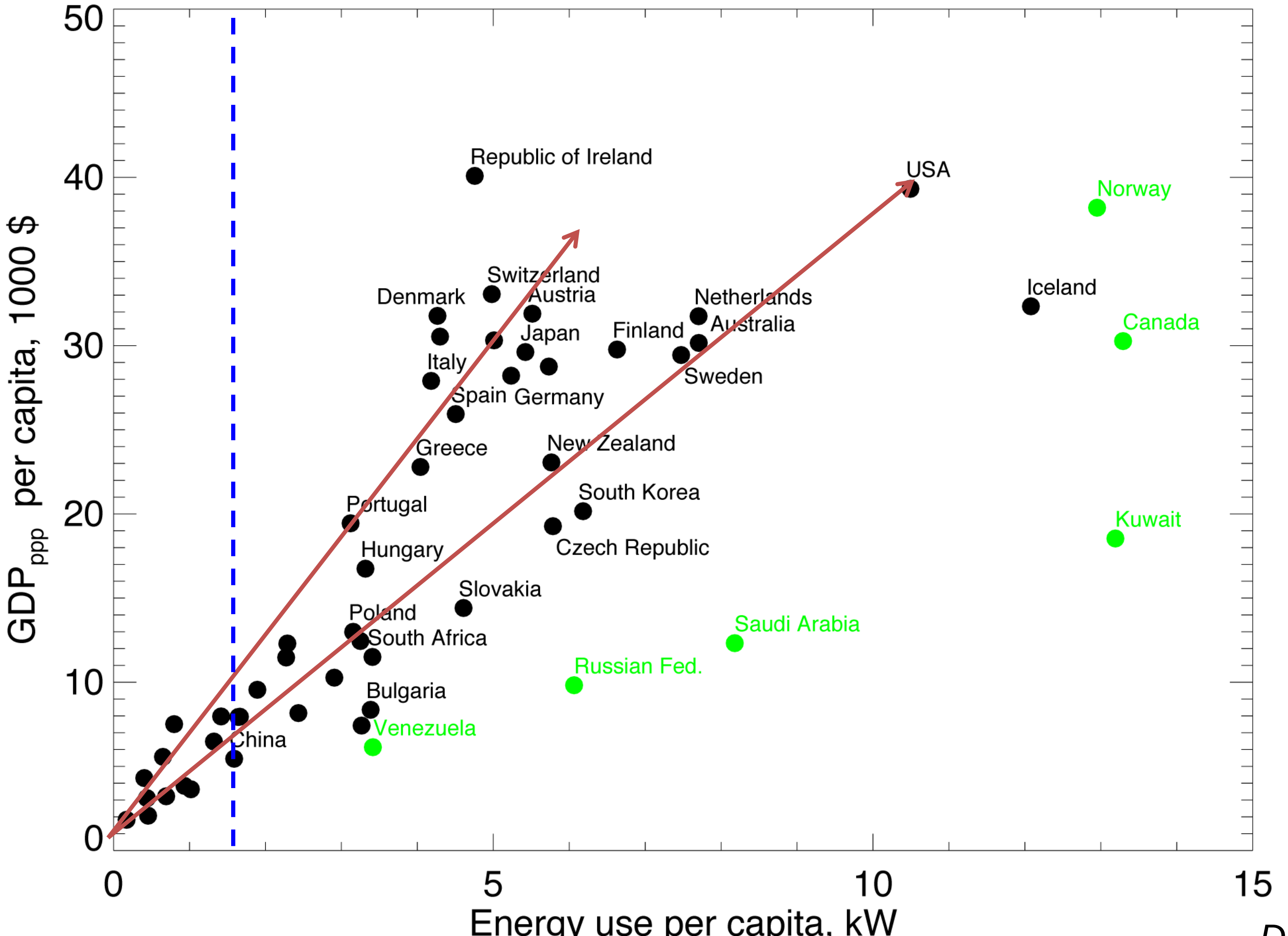
# The team

# We face an immensely challenging problem




*Data: EIA, U.N*

Green dots: major energy producers, dashed line = emissions target if fossil fueled

# Switching is difficult: energy sector is infrastructure-intensive

- Capital investment in U.S. for fossil fuel energy  > $20T
- World likely > $100T
- Turnover time ~ 50 years

# There is no question that we will move to a more sustainable energy system

*"Sustainable" = "capable of being sustained"*

*(Merriam-Webster dictionary)*

The right questions to ask include

- Should we accelerate that transition?
- Should we avoid $CO_2$ emissions while we continue burning fossil fuels?
- Should we be acting now to prepare for climate change?
- What are the tradeoffs in these decisions?
- What is the 'least-bad' means of achieving those goals?

# The tools currently available to decision makers are far from adequate

**EPA Preliminary Analysis of the Waxman-Markey Discussion Draft**

Household consumption is reduced by 0.02-0.11% in 2015 and 0.17-0.19% in 2020 and 0.37-0.39% in 2030, relative to the no policy case.

Household consumption under the WM Draft scenario still increases by 9-10% percent between 2010 and 2015 and 18-19% between 2010 and 2020.

**ADAGE** (RTI Inc.)

**IGEM** (Jorgenson Assoc.)

**IPM** (ICF Consulting)

**FASOM** (Texas A&M)

Four closed models

# The tools currently available to decision makers are far from adequate

- Models do not incorporate the most modern economics or computational methods
- Outputs do not adequately characterize uncertainty or identify its sources
- Decision makers lack tools to help them develop decision strategies that are robust to uncertainty
- Closed models and data prevent experts and public from having confidence in results

# From these and other hard questions we derive our research agenda

**Develop powerful models**

- Dynamic general equilibrium
- Modern sectoral models
- Adaptive sectoral resolution
- Geophysical emulators
- Estimation and calibration

**Confront uncertainty**

- Characterize uncertainty
- Model economic actor response to uncertainty
- Robust decision making
- Communicate uncertainty

Open CIM-EARTH framework

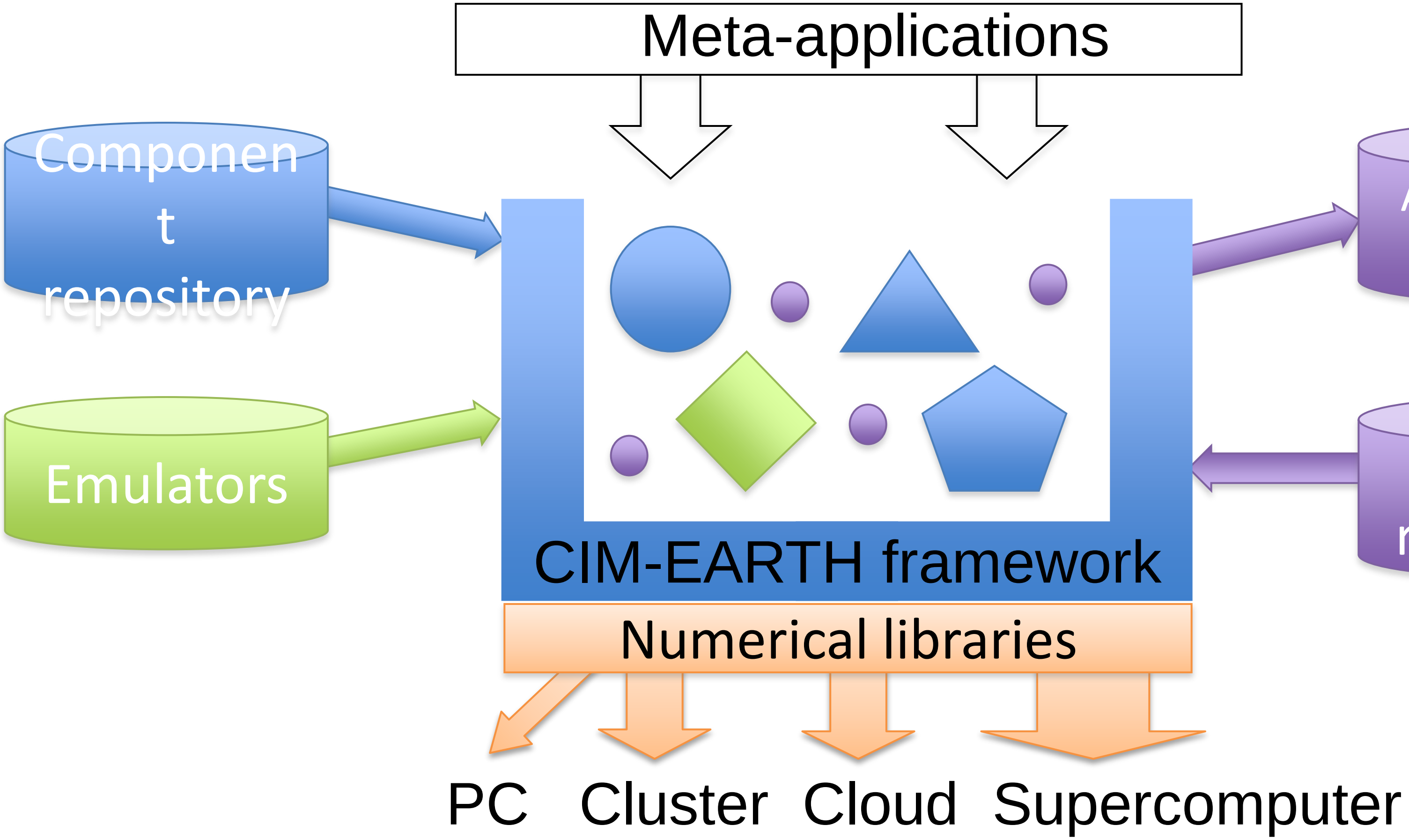
**Advance numerical methods**

- High-performance simulation methods
- Response surface methods
- Dynamic stochastic general equilibrium

# A partial list of initial projects

- Distributional impacts of climate change (Elliott, Fullerton, Loudermilk, Rao)
- Land use decisions under uncertainty (Hertel, Judd, Steinbuks)
- Stochastic dynamic models (Cai, Judd, Lontzek)
- Robust modeling and decision making for energy (Hansen, Moyer, Sanstad)
- CIM-EARTH computable general equilibrium model and modeling framework (Elliott, Foster, Munson)
- Climate model emulation (McInerney, Moyer, Stein)
- Carbon leakage (Elliott, Foster, Kortum, Munson, Weisbach)
- Characterizing parametric uncertainty (Elliott, Foster, Munson)
- Uncertainty in downscaling for impacts studies (Moyer et al.)
- Partial equilibrium land use change for biofuels (Elliott et al.)

# An open modeling framework

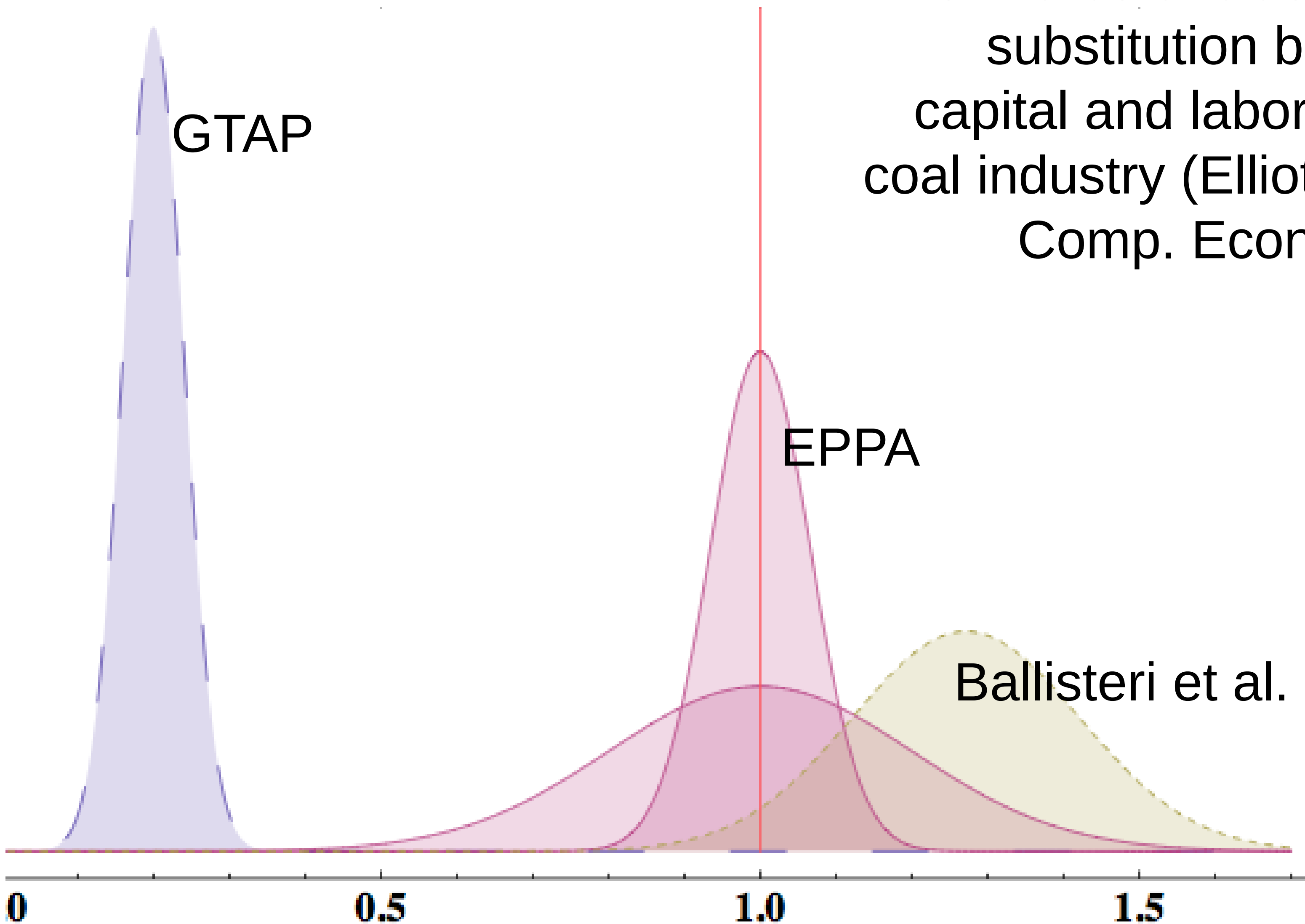


# A general equilibrium framework (Munson et al.)

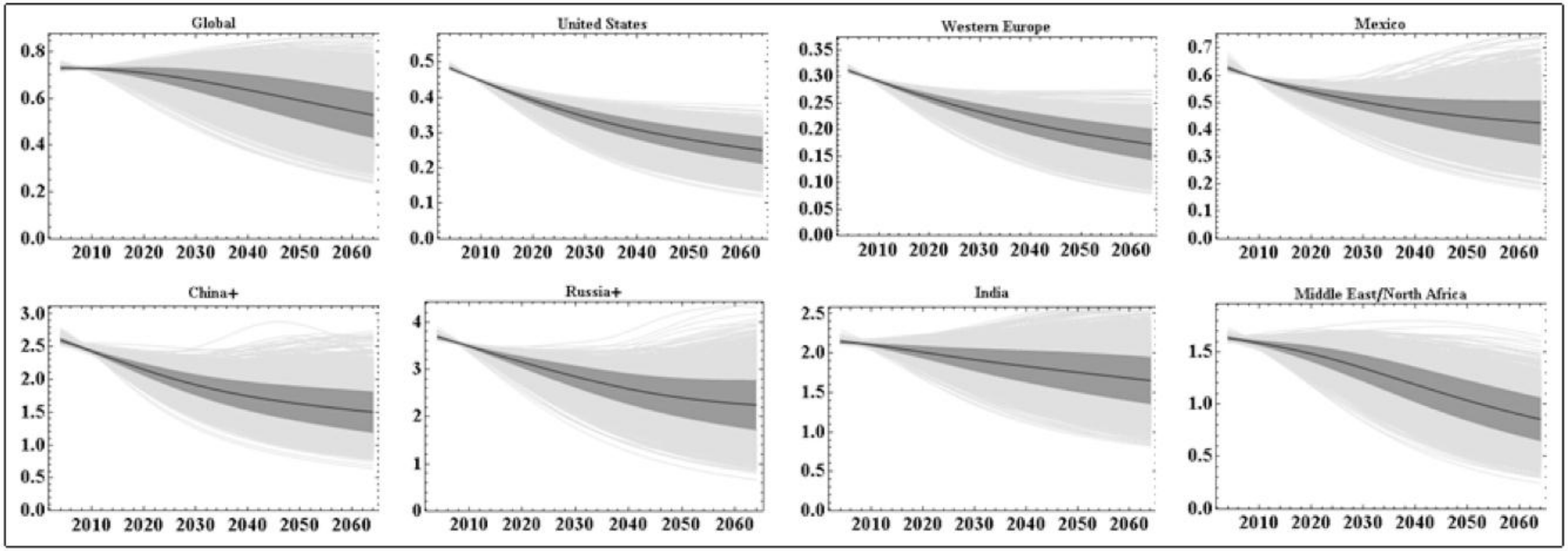
- Encodes the types of dynamic general equilibrium models being studied
  - Distributional impacts (Elliott, Fullerton, Loudermilk, Rao)
  - International trade (Kortum, Weisbach)
  - Energy technologies (Sanstad, Moyer)
- Enable easy exploration of different models
  - Sectoral and regional discretization
  - Types of dynamics: myopic, forward looking, …
  - Policy instruments
  - Treatment of uncertainty, learning, …
- Will use parallel solvers based on TAO

# Characterizing parametric uncertainty: E.g., elasticities of substitution

Estimates of elasticity of substitution between capital and labor for the coal industry (Elliott et al., Comp. Econ. 2011)

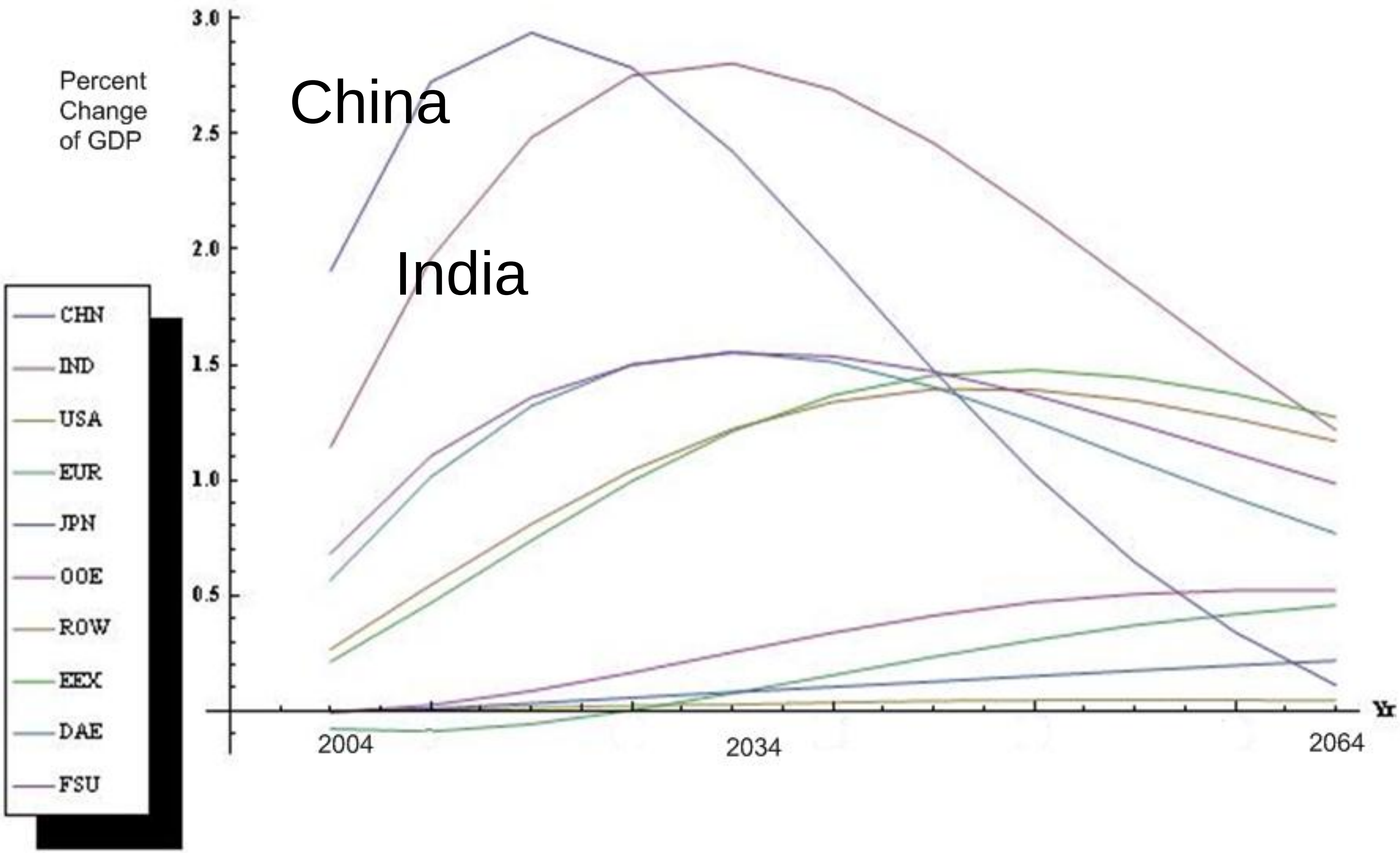


# Exploration of uncertainty in elasticities




Carbon intensity prediction for the world and 7 of 16 model regions in kg CO2 equivalent emissions per 2004 USD of gross domestic product. (70 uncertain elasticity of substitution parameters, 4,978 realizations; Elliott et al., Comp. Econ, 2011)

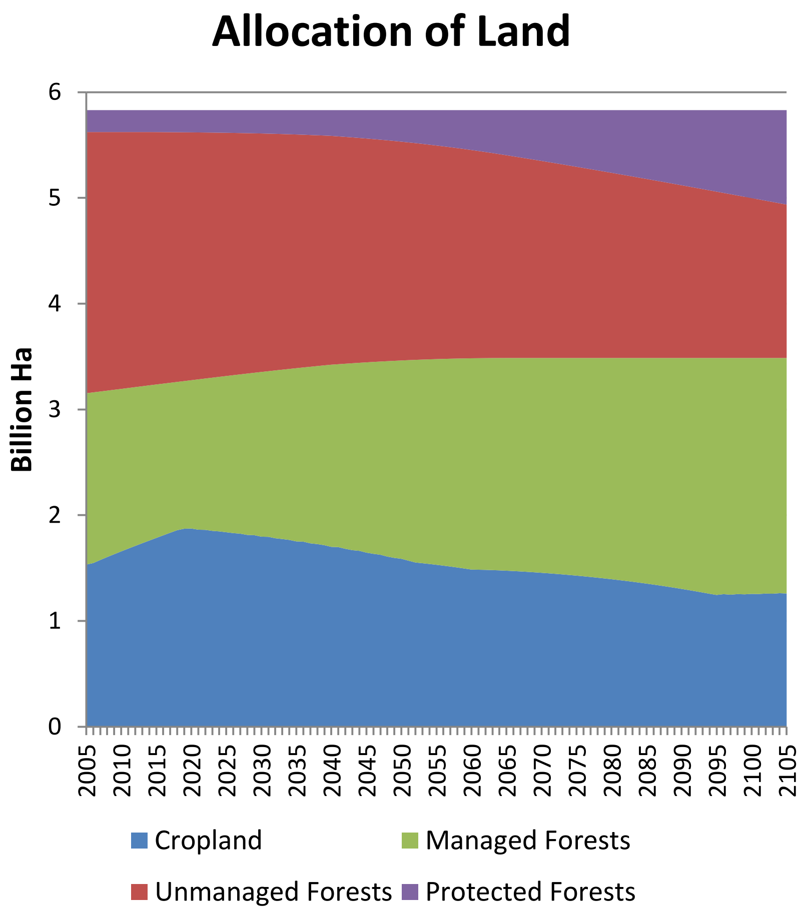
# Sensitivity to time step (1 yr vs. 5 yr)



# Land use decisions under uncertainty (Hertel, Steinbuks, Judd, et al.)

- Dynamic, finite horizon, partial equilibrium
  - Income, population, wages, oil prices, total factor productivity, etc., exogeneous
- Focus: Optimal allocation of scarce land across time
- Six sectors / commodities
  - Agrichemical: {Fossil Fuels} → Fertilizers
  - Agriculture: {Cropland, Fertilizers} → Crops (Food)
  - Biofuels: {Crops less Food} → Liquid Fuels
  - Energy: {Fossil Fuels, Biofuels} → Energy Services
  - Forestry: {Commercial Forests} → Timber
  - Recreation: {Natural land} → Biodiversity Services
- Multiple forest vintages
- AIDADS preferences

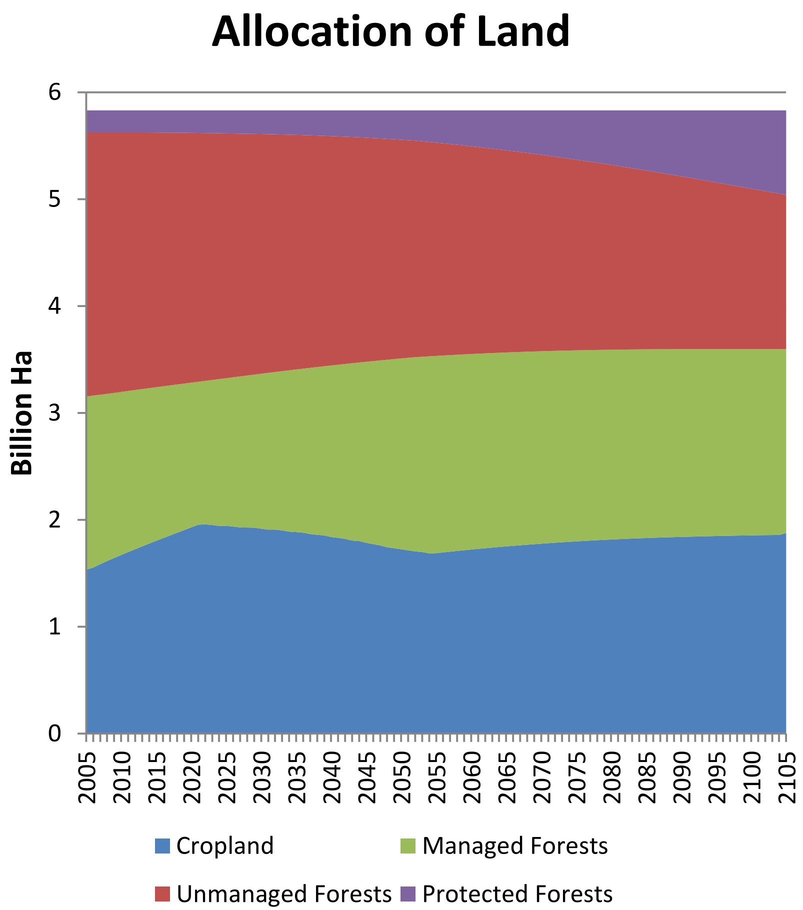
# Land use decisions [not yet under uncertainty]: (a) Model baseline

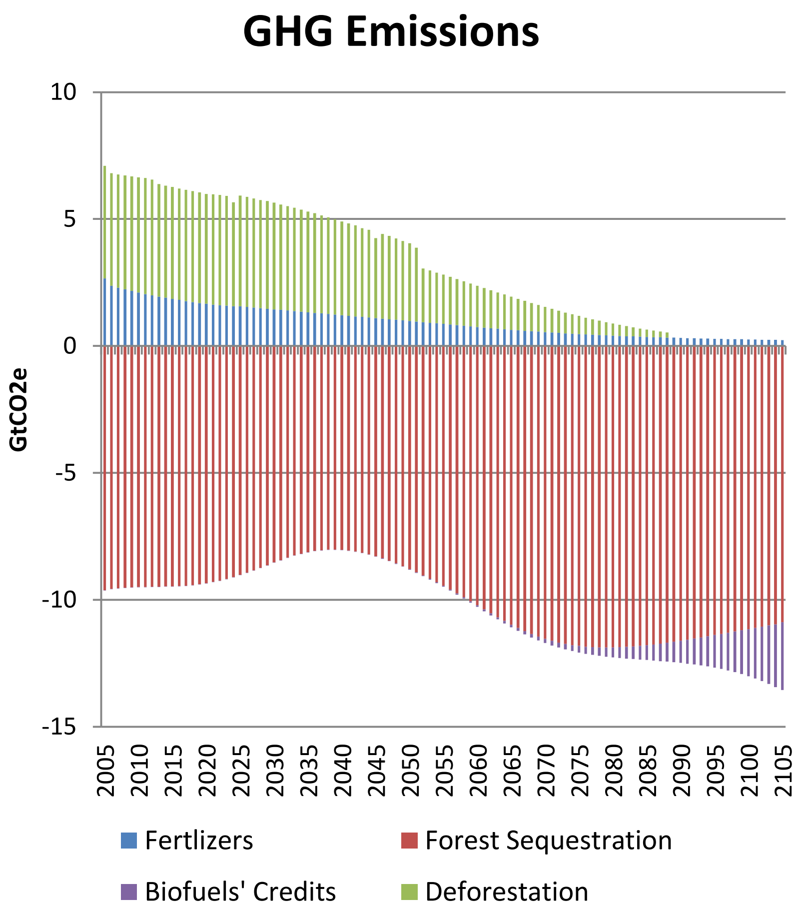




Hertel, Steinbuks

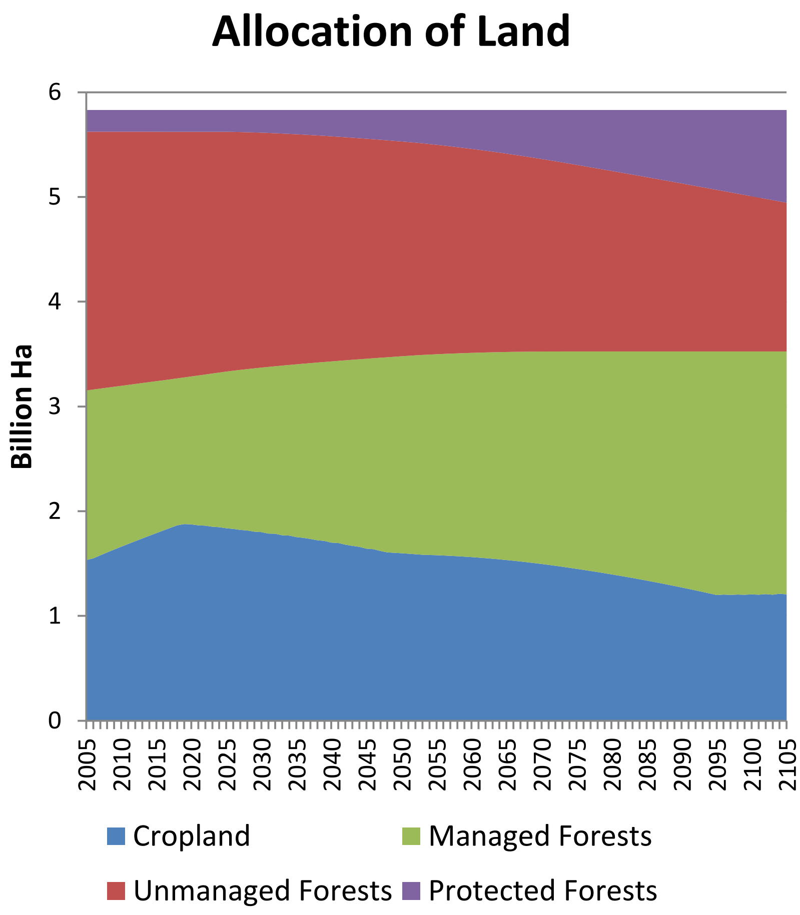
# Land use decisions [not yet under uncertainty]: (b) Anticipated increase in energy prices

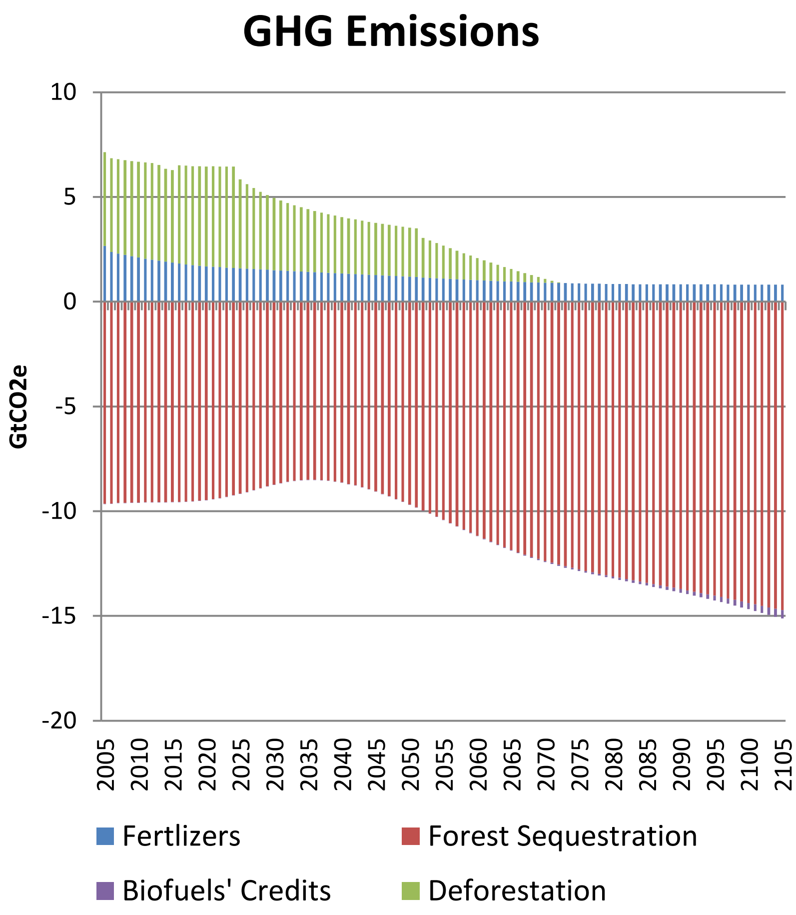



Hertel, Steinbuks

# Land use decisions [not yet under uncertainty]: (c) Anticipated land-use emissions target




Hertel, Steinbuks

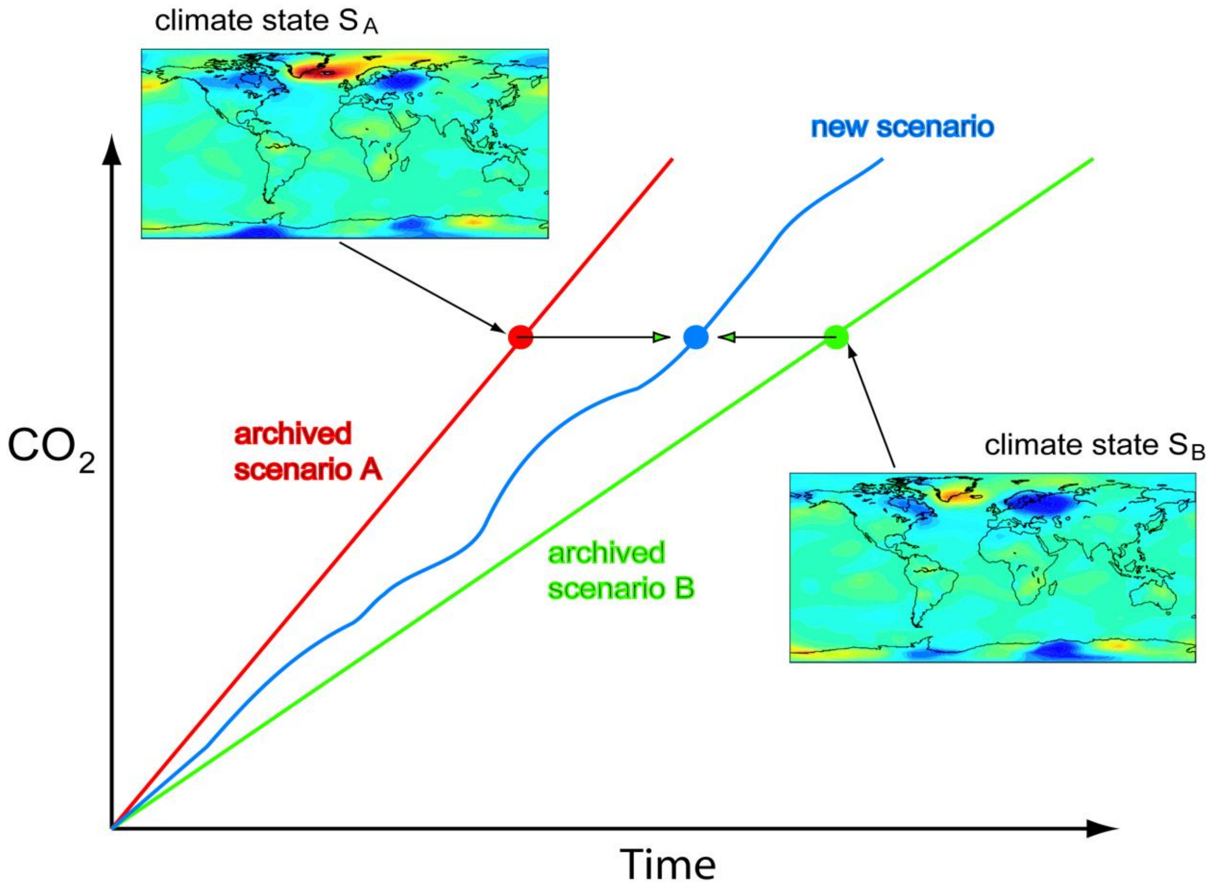
# Robust modeling and decision making for energy (Sanstad et al.)

- Devise an alternative metric to relative entropy measure of “divergence” among models
  - Necessitated by much greater levels of complexity in energy models, and their reliance on calibration in lieu of conventional estimation for model parameterizations
- Investigate uncertainty in energy/IA model assumptions re electric power gen technologies, including carbon-reducing technical change
  - Results will include a critical assessment of key model inputs, and estimation of uncertainties
- Develop robust decision making framework given uncertainty estimates
  - Adapt theory of Hansen and Sargent in macroeconomics

# Distributional effects of environmental policy (Fullerton et al.)

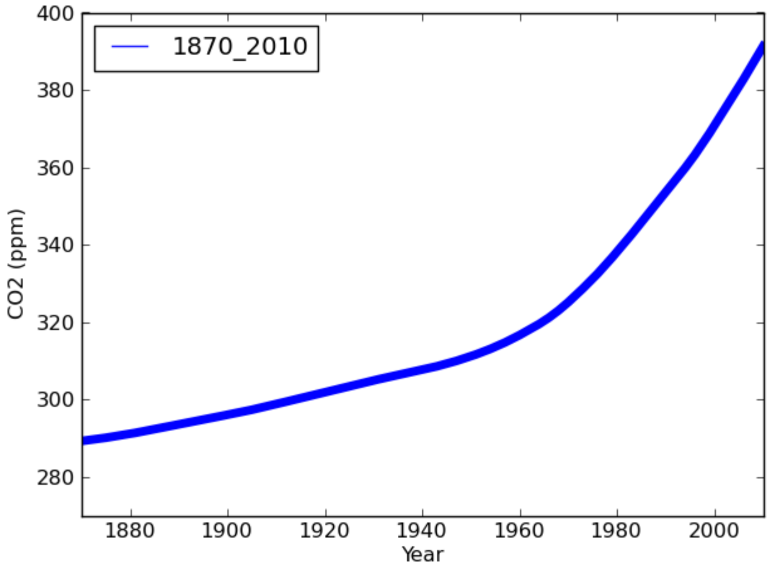
1. Changes in output prices (“uses side” of income)
2. Changes in factor prices (“sources side” of income)
3. Scarcity rents (profits to firms from restrictions on output, the handout of permits, or use of the revenue from a pollution tax or the sale of permits)
4. Transition effects (relocation, retraining, unemployment)
5. Distribution of the benefits of environmental protection
6. Land or stock price capitalization (from #1-5).

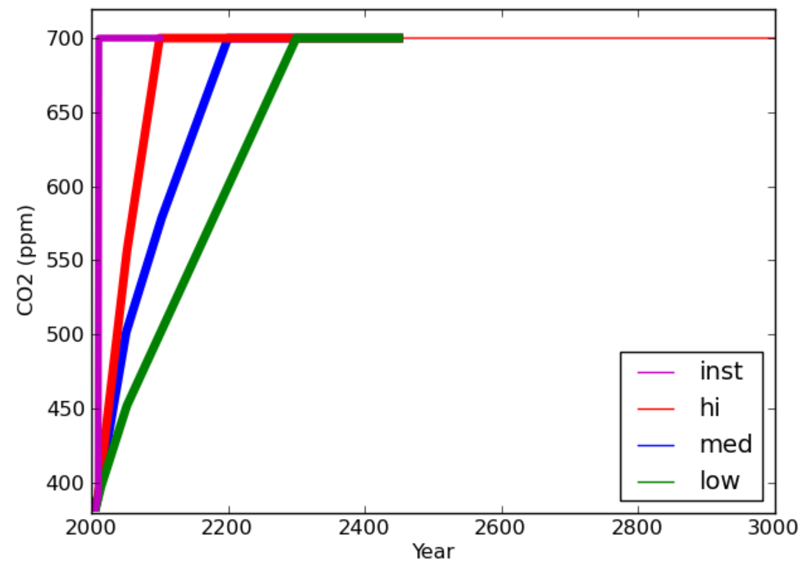
# Climate model emulation (Moyer et al.)

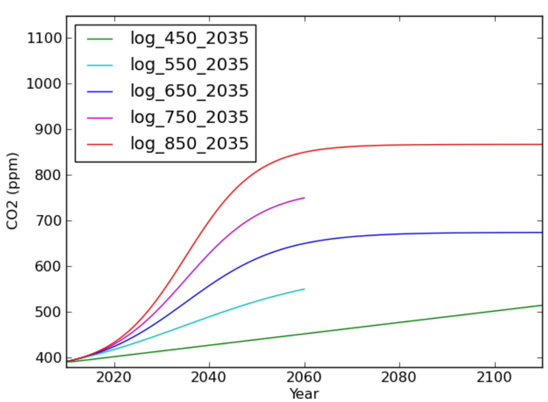


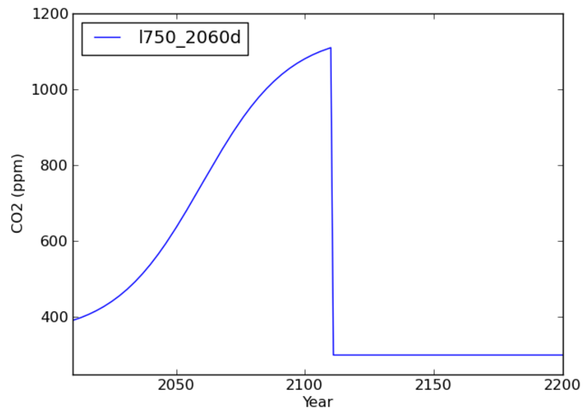

- Internal variability large
- How do we perform interpolation (history matters)

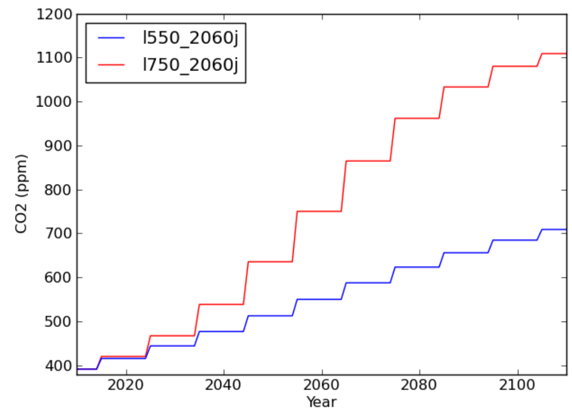
# Climate library: CCSM3, T31 atmosphere
# 10,000 years of runs so far



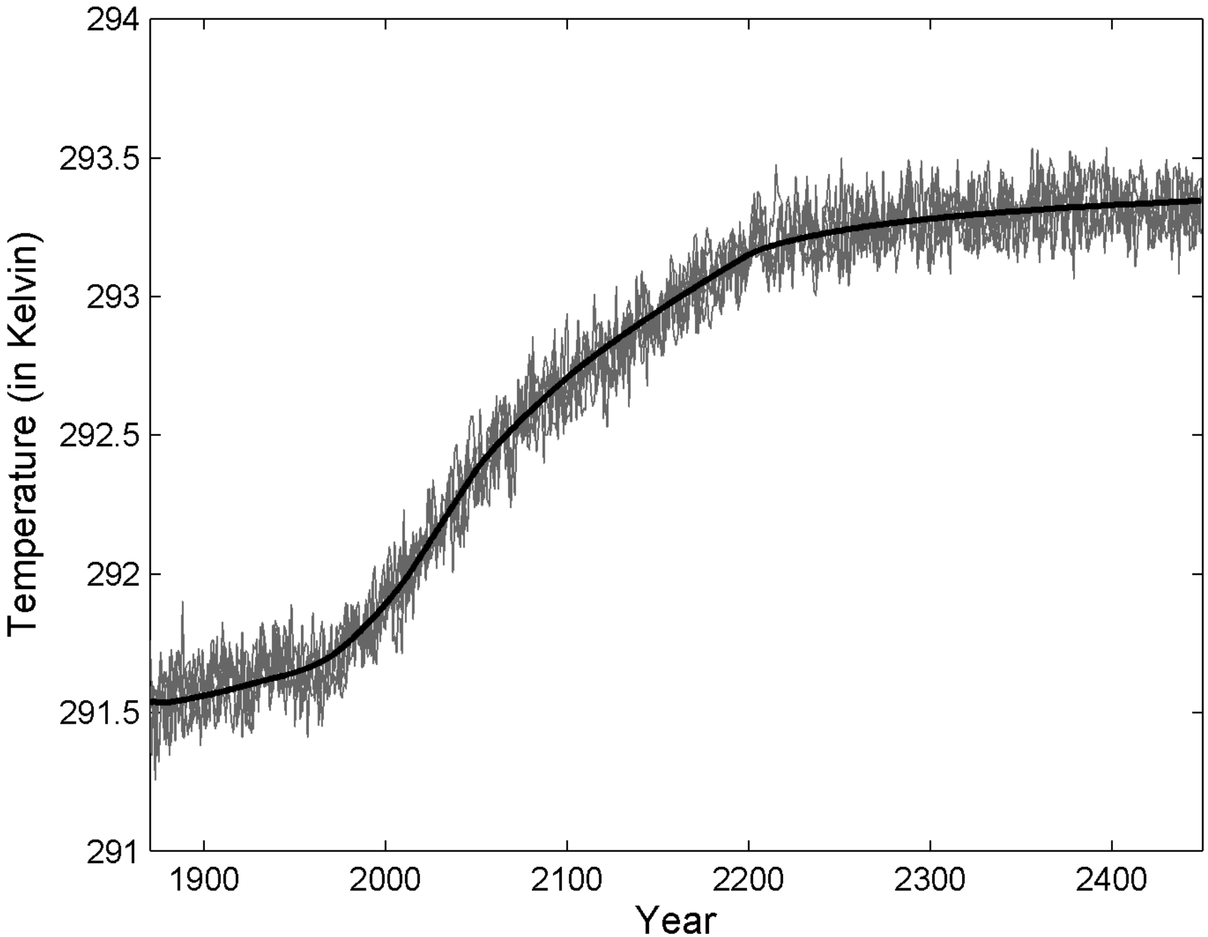



# Initial results




Example of fit for the South Pacific region and medium scenario. The solid black line is the fitted temperature based on low and high scenario, the gray lines are different realizations of the actual computer output.

# Looking forward: FACE-IT

- **What**: Framework to Advance Climate, Economic, and Impacts research with information Technology (FACE-IT)
- **Goal**: Work with GTAP, AgMIP, RDCEP, and other communities to capture commonly used data manipulation and analysis procedures and pipelines in a reusable form
- **Why**? Increasing data complexity and volume, limited sharing and reuse of code, limited reproducibility of research

# Decision makers require better tools

- Models that incorporate the most modern economics and computational methods
  - Engage economists, social scientists, computer scientists
- Outputs that adequately characterize uncertainty and identify its sources
  - More comprehensive analysis, better data, better tools
- Tools that help them develop decision strategies that are robust to uncertainty
  - Engage decision theorists, economists, and others
- Open models and data to enable experts and public to have confidence in results
  - And to enable connections within and across fields