The Evolution of Integrated Assessment:
developing the next generation of use-inspired tools

"...all models are wrong, but some are useful."

—G. E. P. Box and N. R. Draper (1987)

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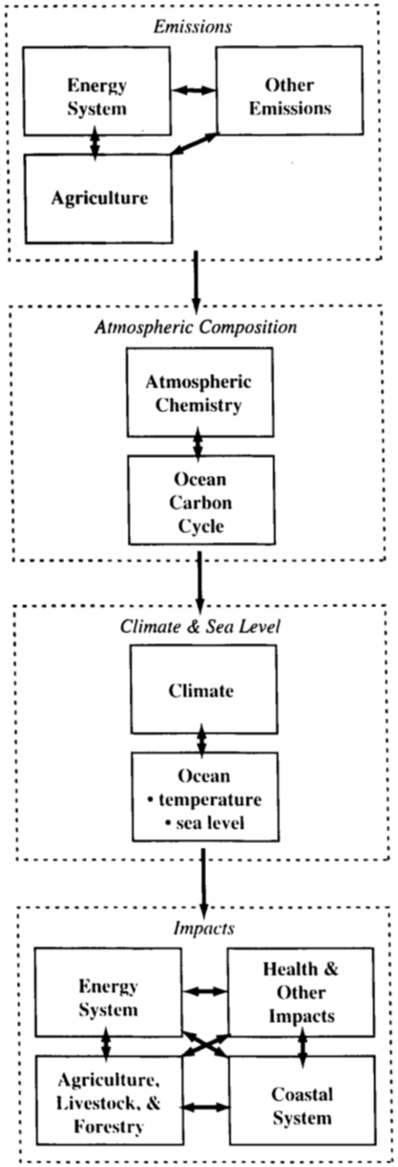
HKS PPOL '99

Brief History of Integrated Assessment

- "Integrated assessment" in the climate change context began with the pioneering work of William Nordhaus in the early 1990s.

  - He was awarded the 2018 Nobel Prize in Economic Science for this work!

- These early IA studies were focused on long-run global mitigation policy analysis, and as a result IAMs were coarse in spatial, sectoral and temporal scale.

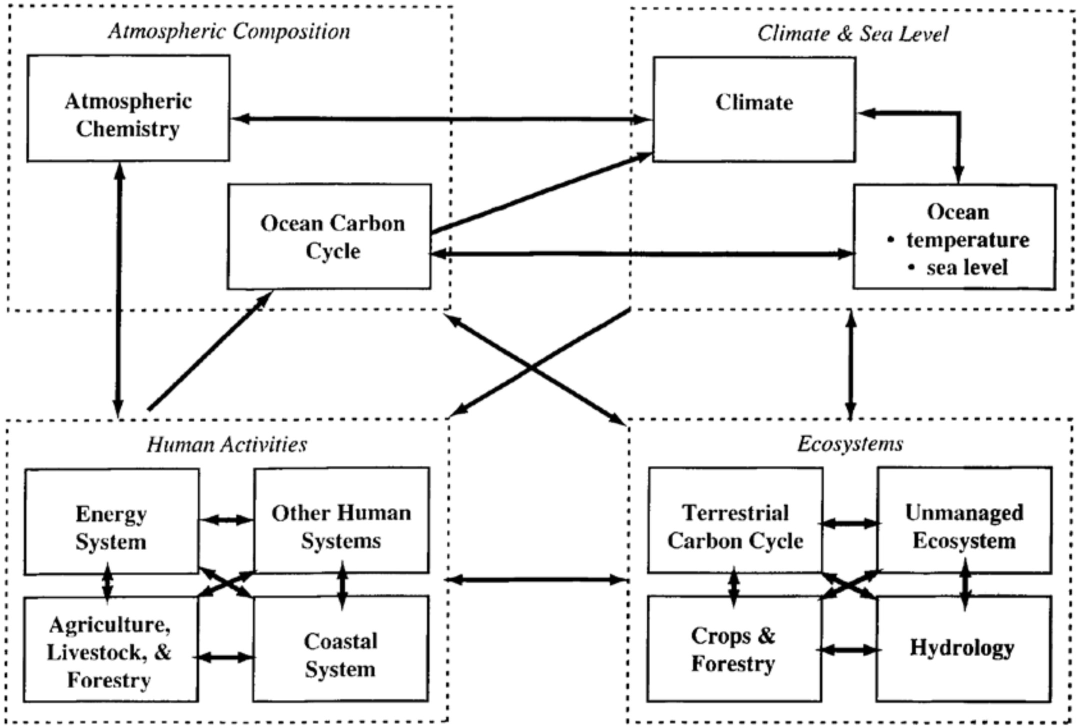


Source: IPCC SAR, 1995

Early Integrated Assessment Models

<u>"Benefit-Cost" (BC) IAMs</u>:

- include feedbacks between earth system model and socioeconomic model.
- Focused on determining the "optimal" level of emissions reductions
    - Also used to generate social cost of carbon estimates



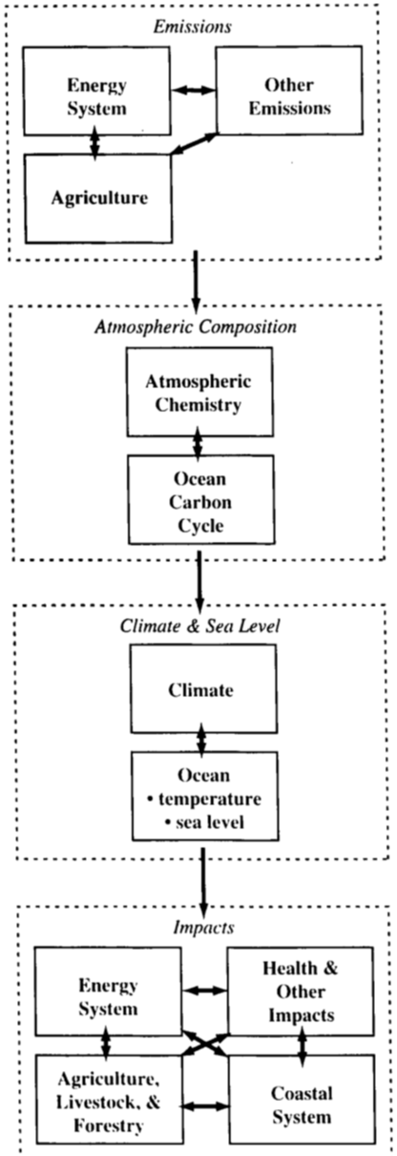
<u>"Detailed Process" (DP) IAMs</u>: have more detailed representations of the underlying socioeconomic processes but ignore climate change induced impacts on the economy

- Used to generate emissions scenarios used as inputs to earth system models.

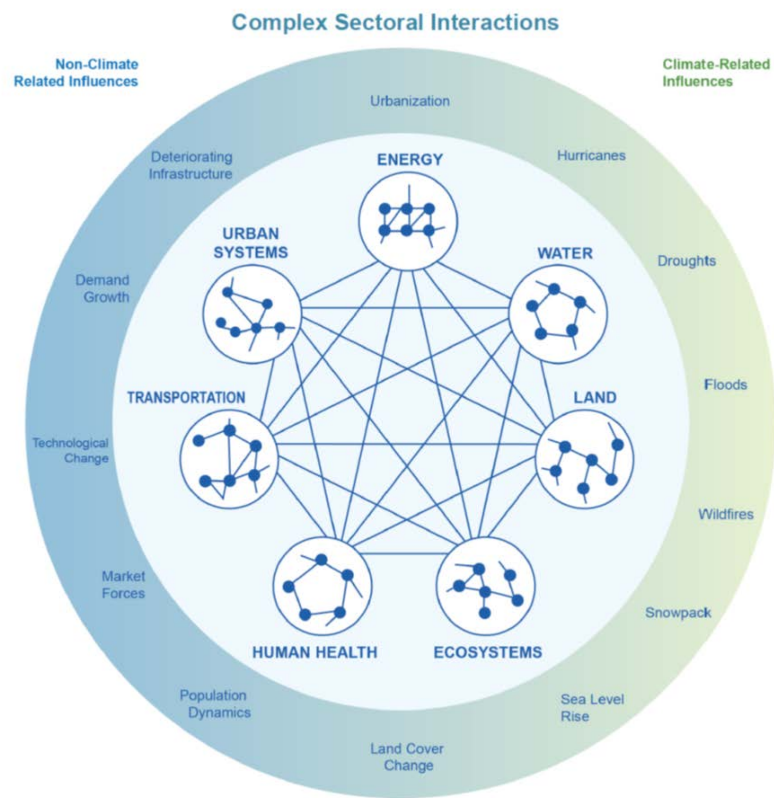
Source: IPCC SAR, 1995

The Next Generation of IAMs

- With the lack of serious international mitigation efforts, the modeling focus has moved from mitigation policy assessments to improving our understanding of impacts
- The impacts, adaptation and vulnerability (IAV) community have become interested in the use of IAMs due to their emphasis on interconnected systems.
  - Some early IAMs did capture impacts, but at a much coarser resolution and usually did not assign economic value to them
  - Past statistical and process model IAV studies focused on a specific sector and/or region but ignored spatial and sectoral interactions.
  - Disconnect between detailed empirical impact studies and IAMs



Source: IPCC SAR, 1995



Source: US National Climate Assessment, 2018

The Next Generation of IAMs

- However, the usefulness of these tools for impacts analysis is limited without improvements to account for finer spatial scale and process detail

- Improvements in data, algorithms, and computational power have led to the emergence of the "multisector dynamics" field (aka IAV IAMs).

  - New program in the Office of Science at DOE. Replaces Integrated Assessment program. Emphasis on descriptive rather than prescriptive.

  - Emphasis on "use case" framing rather than specific sectors and/or regions.

  - Focus has shifted to developing generalizable frameworks for specific *types* of problem; e.g., rather than studying ag impacts of water scarcity in isolation, study impacts from competing demands for scarce water.

  - This new emphasis requires tools that capture detailed sectoral and regional interactions

Integrated Assessment

From the Integrated Assessment Society:

"Integrated assessment (IA) can be defined as the scientific "meta-discipline" that integrates knowledge about a problem domain and makes it available for societal learning and decision making processes. Public policy issues involving long-range and long-term environmental management are where the roots of integrated assessment can be found. However, today, IA is used to frame, study and solve issues at other scales. IA has been developed for acid rain, climate change, land degradation, water and air quality management, forest and fisheries management and public health. The field of Integrated Assessment engages stakeholders and scientists, often drawing these from many disciplines."

MultiSector Dynamics

From the Department of Energy, Office of Science:

"MultiSector Dynamics seeks to advance scientific understanding of the complex interactions, interdependencies, and co-evolutionary pathways of human and natural systems, including interdependencies among sectors and infrastructures. This includes advancing relevant socio-economic, risk analysis, and complex decision theory methods to lead insights into earth system science, while emphasizing the development of interoperable data, modeling, and analysis tools for integration within flexible modeling frameworks."

Program on Coupled Human and Earth Systems (PCHES)

www.PCHES.psu.edu

A $20 million, five-year Cooperative Research Agreement with the Department of Energy's Office of Science (MultiSector Dynamics Program).

Goal: to build a next generation integrated suite of science-driven modeling and analytic capabilities, and a more expanded and connected community of practice, for analyses of the stressors related to integrated Energy-Water-Land systems dynamics and interdependent infrastructures.

Participants: ~20 investigators, ~8 post-docs, and 10+ grad students from 10 institutions and multiple disciplines (e.g., engineering, hydrology, earth system science, economics, law, statistics, agronomy)

Research Program Elements:

I. Develop Integrated EWL Modeling Frameworks
II. Develop Model/Module Integration Methods
III. Develop/Recommend Model Uncertainty Characterization, Evaluation and Inter-comparison Methods
IV. Create a Community of Practice for This Kind of Research

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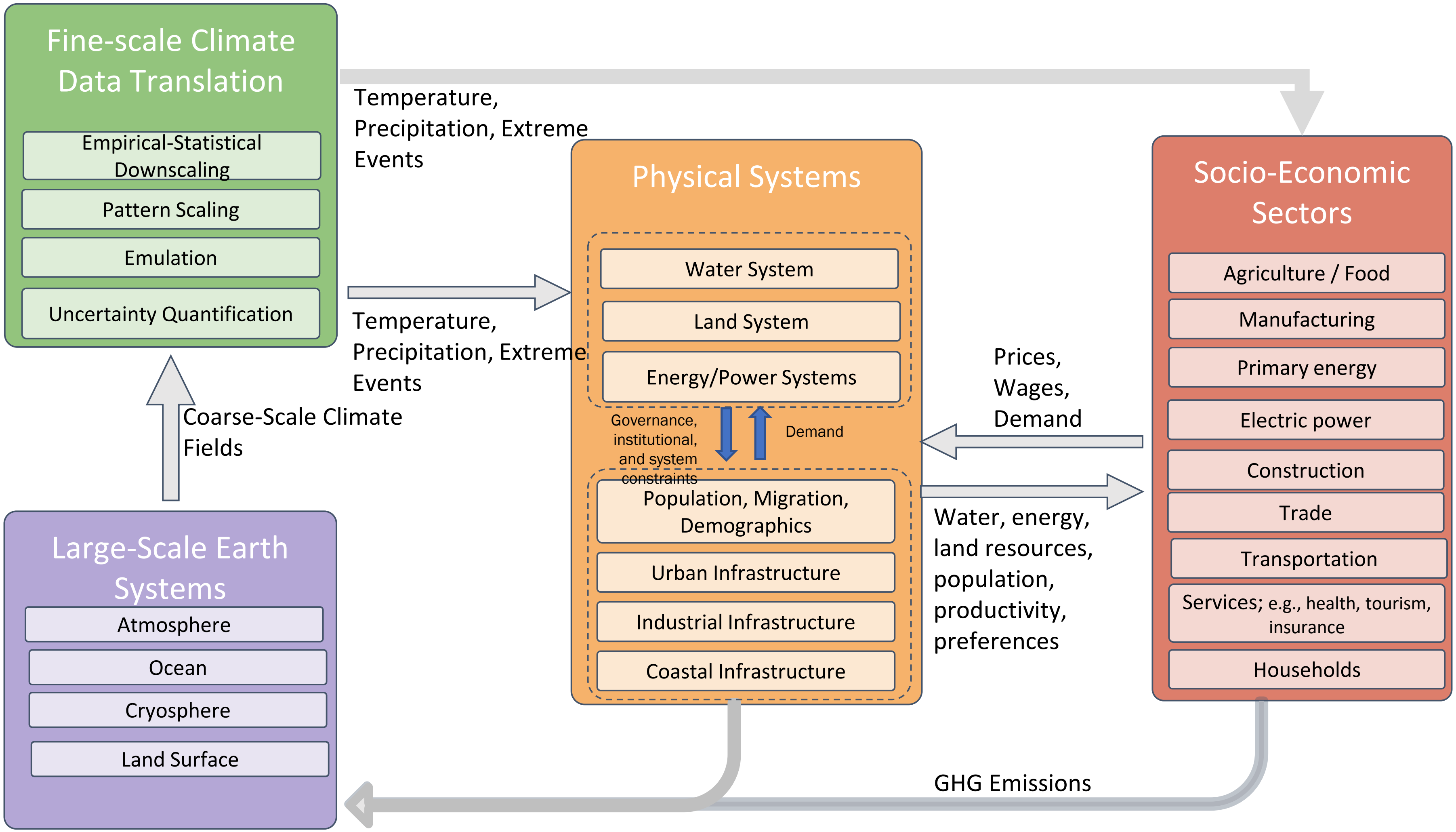
Integrated Energy-Water-Land systems dynamics and interdependent infrastructures



Building the Next Generation of IA Tools: Challenges

(1) Model Coupling Challenges

- Need new innovative computational methods to connect and translate information across modeling platforms with very different temporal, sectoral, and spatial resolutions.

(2) Translating Empirical Findings into IAMs

- Persistent problem that excellent econometric work has been done on climate change impacts that has not found its way into IAMs
- Requires econometricians and IAMers to be working collaboratively to develop empirical results that can easily translated into IAMs.

(3) Training of the next generation of MSD scholars

- Graduate students and post-doctoral scholars are the engine of our projects
- No longer possible to toss information "over the fence." Requires close interactions between faculty, graduate students and post-docs from different disciplinary backgrounds and institutions
- Need more students trained in computational economics and willing to learn other disciplinary tools
- Reward system challenges

Transparency in Climate Policy: Using Forecasting Tools to Evaluate Emission Mitigation Efforts

Joseph E. Aldy
Harvard Kennedy School

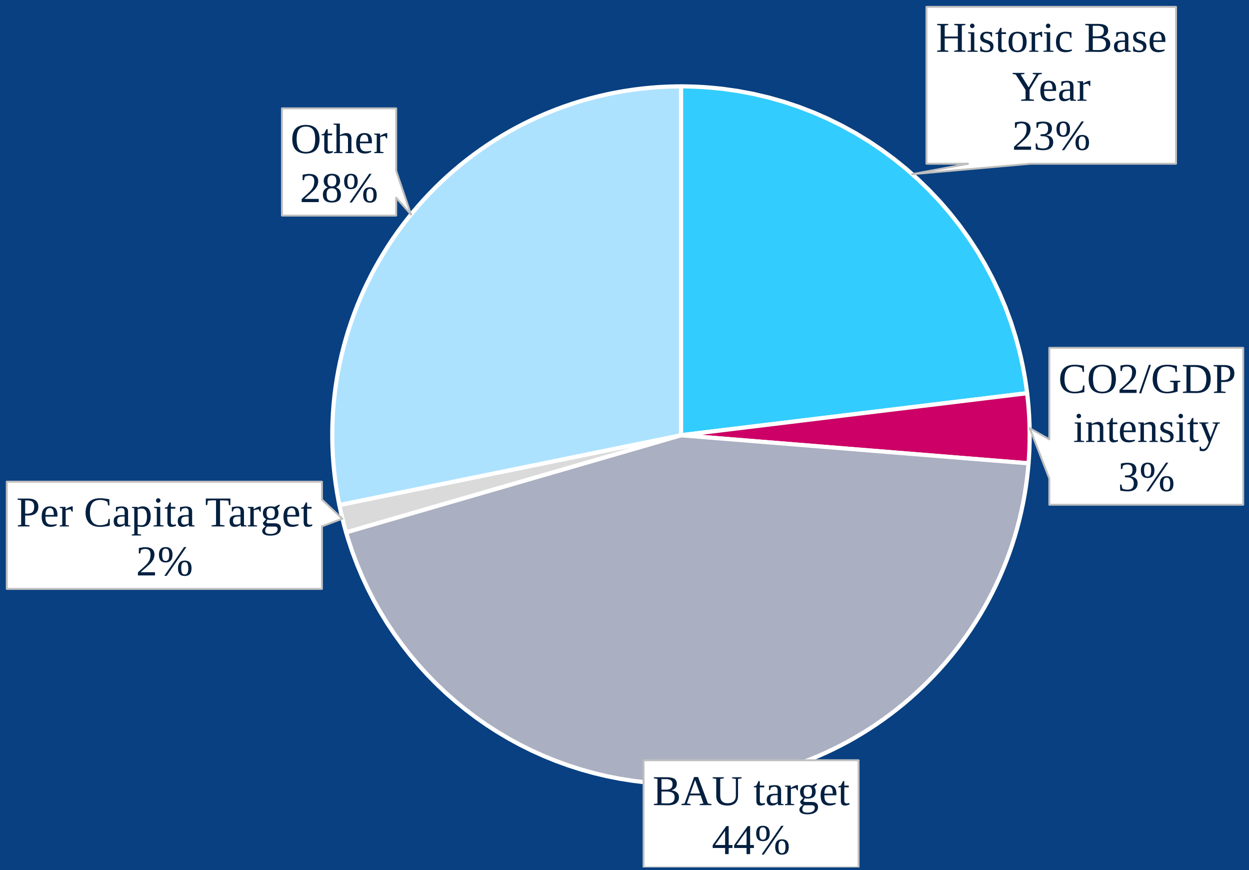
Harvard Environmental Economics Program
Research Workshop
September 19, 2019

HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

Research Questions

- How can emissions forecasting models inform our understanding of the 2015 Paris Agreement?
  - Evidence of emission mitigation effort?
  - Illustration of political economy of mitigation pledges?
  - Design of pledges that enable more (less) transparent evaluation and comparison of effort?

Types of Emission Pledges under the 2015 Paris Agreement



Uses for Counterfactual Forecasts

- Metric for comparing countries' mitigation efforts
- Input in integrated assessment models
- Element in structure of mitigation pledges (NDCs)
- Aggregate to inform global stocktake
- Enable linking of domestic programs

Forecasting Counterfactual Emissions

- Autoregressive models: future GHG = f(past GHG)
- EKC models: emissions as a function of GDP
- Model selection by minimizing forecast error (Auffhammer and Steinhauser)
- Machine learning: use tools from computer science to further expand search for best forecast model

Data Needs

- Minimum data needs
  - Time series of GHG and/or CO_2 emissions
  - Fossil CO_2 series > 50 years for most nations
  - GHG series date back to 1990 for most nations
  - Balanced panel of 131 countries, 1990-2012

- Additional data to inform and improve precision of forecasts
  - GDP, population (World Development Indicators)
  - Any variable that could predict future emissions

Table 1. Performance of traditional econometric models

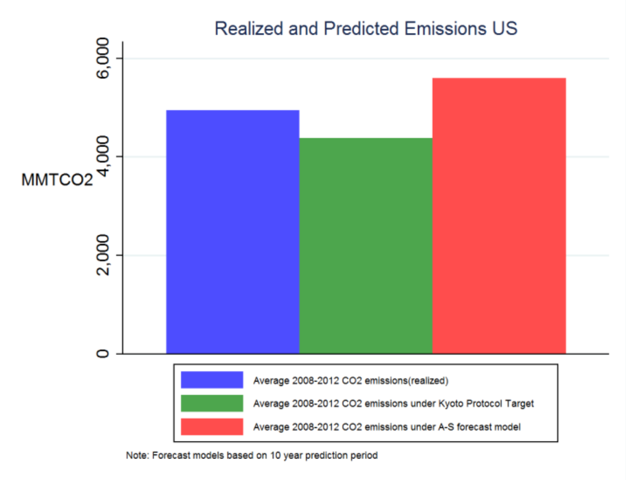
Model	AIC	BIC	R^2	R^2 adjusted	Per capita MSFE	Aggregate MSFE	# of obs.
AR	N/A	N/A	N/A	NA	5.82E-10	12,014,546	2,227
HES	-1,299	-1,201	0.967	0.965	8.30E-10	10,090,485	2,358
SSJ	-1,118	-293	0.968	0.966	8.86E-10	40,123,347	2,358
AS per capita	-3,601	-3,538	0.989	0.989	5.82E-10	3,572,170	2,227
AS aggregate	-1,177	-353	0.969	0.967	1.17E-09	1,522,865	2,358

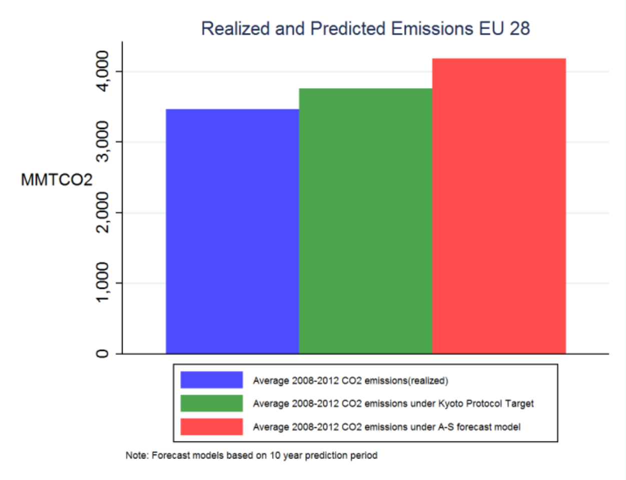
Comparing Econometric Model Selection to Machine Learning

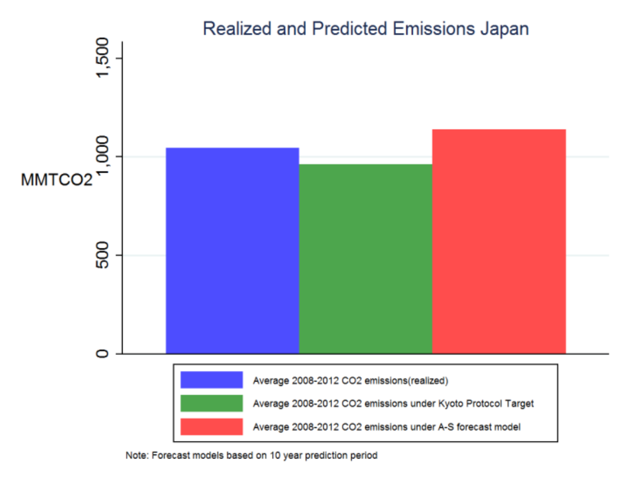
- Machine learning approach yields smaller MSFE
  - Our best ML model produces MSFE of 3.01
  - Contrast w/ best traditional econometric model of 5.82

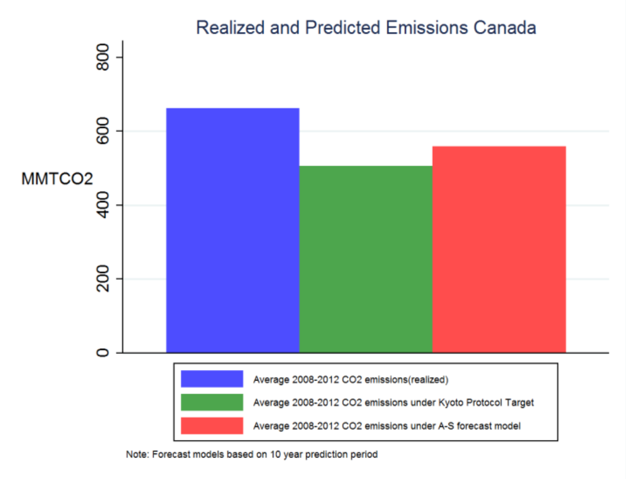
- When constraining ML to focus on predicting last 5 years in sample, MSFE ranges from 2.01-2.34

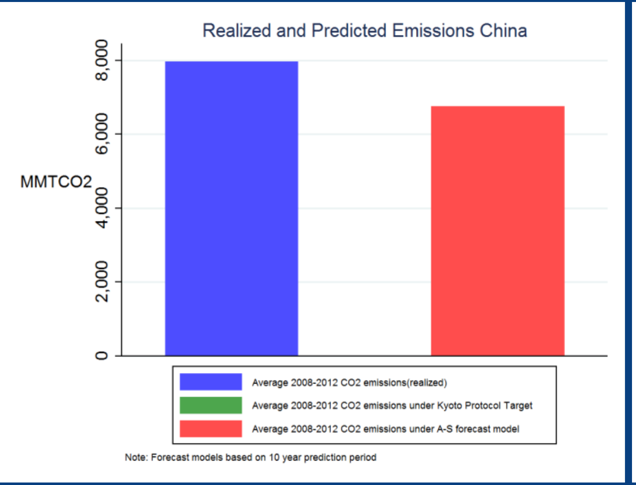
Evaluating the Kyoto Protocol: Ex Post Forecasts vs. Realized CO2, 2008-2012

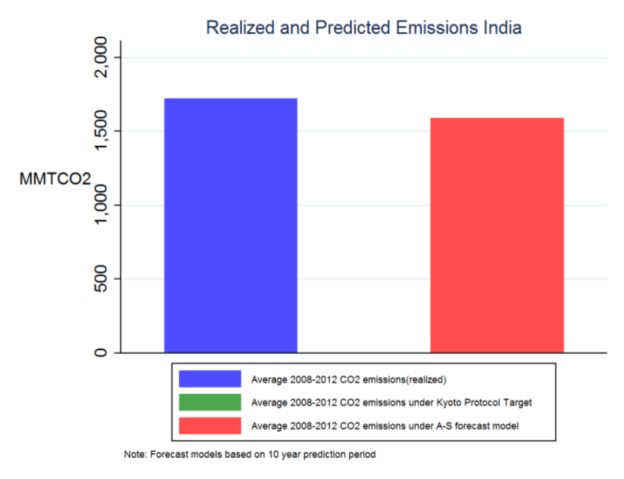




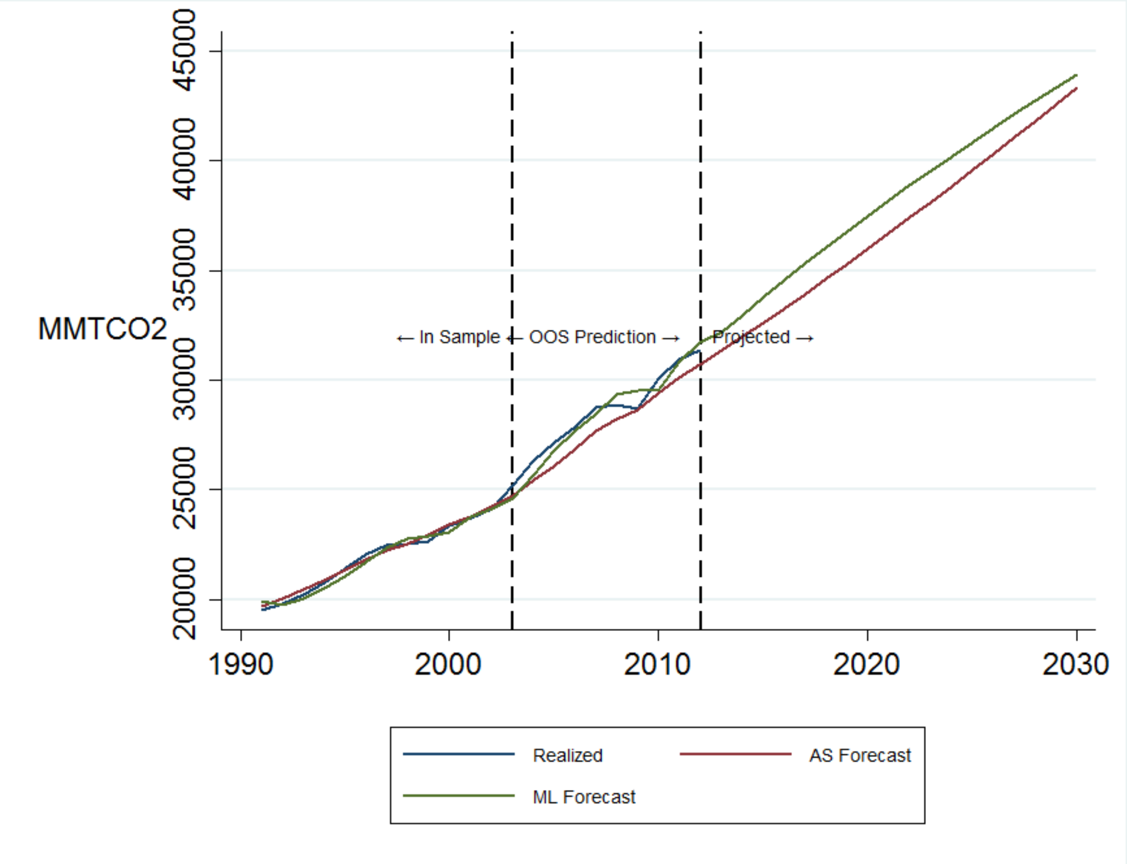








Informing the Global Stocktake: Ex Ante Analysis of Paris Agreement



Global GHG Forecast through 2030

Political Economy of Pledges: Reduction from BAU Pledges

Nation	%age vs. ML Forecast	Nation	%age vs. ML Forecast	Nation	%age vs. ML Forecast
Afghanistan	37	Ghana	-17	Namibia	-9
Angola	-10	Guatemala	8	Niger	192
Bangladesh	-41	Haiti	98	Paraguay	226
Barbados	-34	Honduras	-50	Peru	-23
Benin	-9	Indonesia	22	Sao Tome & Principe	-19
Burkina Faso	172	Jamaica	-6	Senegal	-43
Burundi	16	Jordan	-13	Seychelles	-48
Central African Republic	103	Kenya	61	South Korea	4
Chad	-46	Lebanon	41	St. Lucia	-42
Colombia	17	Madagascar	224	Thailand	21
Comoros Islands	-39	Maldives	26	Togo	158
Cote d'Ivoire	6	Mauritania	34	Trinidad and Tobago	153
Djibouti	162	Mauritius	-18	Turkey	163
Ethiopia	117	Mexico	48	Vietnam	232
Georgia	115	Morocco	95	Yemen	32

Political Economy of Pledges:
ML Forecasts vs. Biennial Report Forecasts

Nation / Region	%age vs. ML Forecast
Canada	-11
EU-28	-14
Japan	-5
New Zealand	21
Norway	26
Russia	7
Switzerland	-41
United States	-4

“Common but Differentiated”

- “BAU Forecasts” in developing country pledges:
  - 42% higher emissions than our ML forecasts
- On paper, these countries pledge to reduce emissions 21% below these BAU forecasts
  - These BAU -21% levels are 12% above our ML forecasts
- Developed countries’ forecasts are 5% below our ML forecasts

What is "Business-as-Usual?"

- Sample period?
- Control variables?
- Different data / forecasting demands of controls for ex post vs. ex ante analyses