Phoenix

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Talk Outline

- Overview of the Phoenix Model

- MUG Scenario Results

- Decomposition of the MUG Scenarios

Phoenix

- Joint development effort between JGCRI, Boston University, and Penn State University
- Goal: construct a community-based, open-source CGE model capable of modeling both sectoral and economy-wide climate policies

- Recursive dynamic simulation of world economy
  - 24 regions, 26 sectors (5 energy commodities), 3 primary factors
  - Static sub-model calibrated on GTAP 7.1 database and IEA energy balances
  - Dynamic process on a 5-year time step for 2005-2100, capturing regional capital accumulation; cumulative fossil fuel resource depletion; carbon dioxide emissions; price-driven renewable, nuclear and hydro resource supply expansion

Energy Technology Detail

- Nine types of electric power generation: coal, oil, natural gas, biomass, nuclear, hydro, geothermal, solar, and wind
  - IEA electricity data is used to disaggregate and calibrate the single GTAP electric sector

- Four backstop energy supplies: NGCC-CCS, IGCC-CCS, coal-syngas, biofuels

- Fossil-, biofuel-, and electricity- powered household own-supplied, water, and road/other transportation subsectors

MUG Scenario Results (2050)

	Bench-mark	BAU*	2020 Recession*	High GDP Growth	High Pop. Growth	Carbon Tax
Output (10^12 2005$)	41.44	140.1 (61.85)	139.68 (58.72)	166.35	171.11	138.7
CO2 Emissions (GT CO2/yr)	27.27	60.95 (35.41)	60.77 (34.12)	69.42	69.37	31.62
Primary Energy (EJ)	463.13	910.9 (545.71)	908.55 (531.56)	1011.4	1124.3	910.9

Legend:
- Nuclear
- Biofuels
- Non-nucear Electricity
- Refined Oil
- Gas
- Oil
- Coal
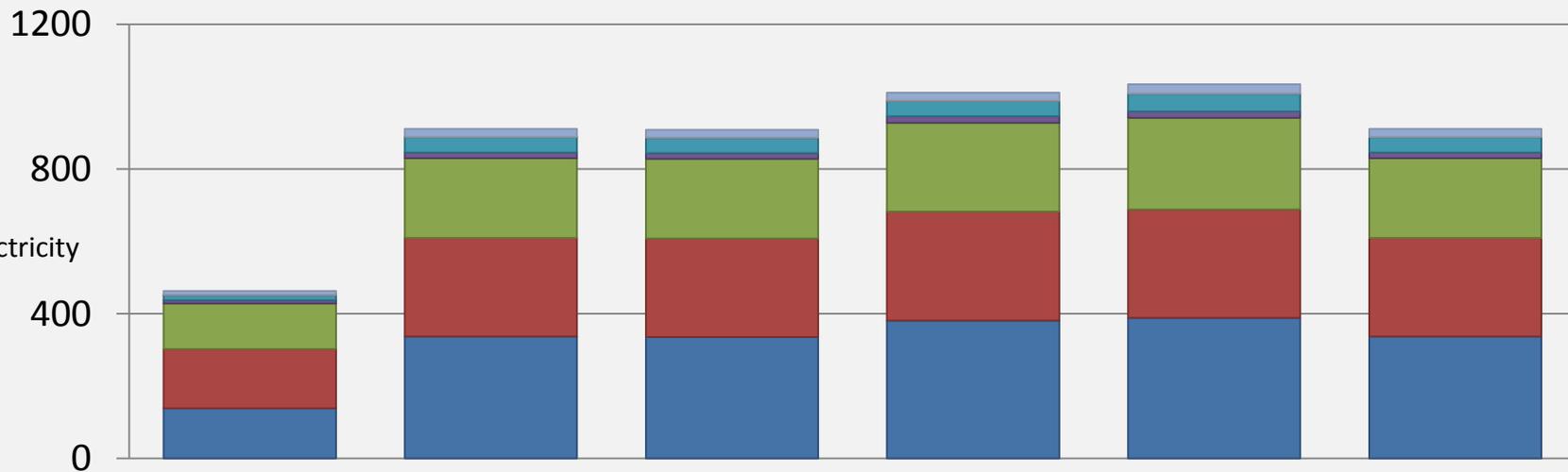
*2020 results in parenthesis.

Drivers of Carbon Emissions

- Drivers of growth given by the Kaya Identity:

$$C = \sum_{r,j} c_{r,j} = \sum_{r,j} Q \frac{Q_r}{Q} \frac{q_{r,j}}{Q_r} \frac{e_{r,j}}{q_{r,j}} \frac{c_{r,j}}{e_{r,j}}$$

  – Global economic activity (Q)

  – Shift in regional composition of world output (Q_r / Q)

  – Shift in sectoral composition of regional output ($q_{r,j} / Q_r$)

  – Change in energy intensity of sectoral output ($e_{r,j} / q_{r,j}$)

  – Change in carbon composition (mix) of energy ($c_{r,j} / e_{r,j}$)

Decomposition Analysis (I)

$$C = \sum_{r,j} Q \frac{Q_r}{Q} \frac{q_{r,j}}{Q_r} \frac{e_{r,j}}{q_{r,j}} \frac{c_{r,j}}{e_{r,j}}$$

- Log-linearization expresses instantaneous growth rate of CO_2 as a weighted sum of the growth rates of the drivers of emissions

$$G_C = d\log C = \underbrace{d\log Q}_{G_{Activity}} + \underbrace{\sum_r S_r \, d\log \frac{Q_r}{Q}}_{G_{Regional}} + \underbrace{\sum_r S_r \left(\sum_j s_{j,r} \, d\log \frac{q_{j,r}}{Q_r} \right)}_{G_{Sectoral}}$$

$$+ \underbrace{\sum_r S_r \left(\sum_j s_{j,r} \, d\log \frac{e_{j,r}}{q_{j,r}} \right)}_{G_{Intensity}} + \underbrace{\sum_r S_r \left(\sum_j s_{j,r} \, d\log \frac{c_{j,r}}{e_{j,r}} \right)}_{G_{Mix}}$$

- The weights, $S_r = C_r/C$ and $s_{j,r} = c_{j,r}/C_r$, denote region r's share of global emissions and sector j's share of regional emissions

- Given data for discrete time periods, we approximate continuous growth rates and weights $\Rightarrow$ residual term on the RHS

Decomposition Analysis (II)

- With data for $t = \{0, \ldots, T\}$, cumulative effect of drivers found by <u>chaining</u> together individual growth factors to form index numbers (NB: <u>not additive</u>!)

$$D_{C,T} = \prod_{t=1}^{T} \exp(G_{C,t}) = \prod_{t=1}^{T} \exp\left(\sum_{k} G_{k,t}\right), D_{Activity,T} = \prod_{t=1}^{T} \exp(G_{Activity,t}), \ldots$$

$$\Rightarrow D_{C,T} \neq D_{Activity,T} + D_{Region,T} + D_{Sector,T} + D_{Intensity,T} + D_{Mix,T}$$

- With a particular growth rate approximation, we can split inter-period change in emissions into components associated with each factor:

$$G_{C,t} \approx 2\frac{C_t - C_{t-1}}{C_t + C_{t-1}} \Rightarrow C_t - C_{t-1} \approx \underbrace{G_{Activity,t} 0.5(C_t + C_{t-1})}_{\delta_{Activity,t}} + \cdots + \underbrace{G_{Mix,t} 0.5(C_t + C_{t-1})}_{\delta_{Mix,t}}$$

- Cumulative effect of drivers on CO_2 can now be computed <u>additively</u>!

$$\Delta_{C,t} = \sum_{t=1}^{T} \delta_{C,t}, \Delta_{k,t} = \sum_{t=1}^{T} \delta_{k,t} \Rightarrow \Delta_{C,t} \approx \Delta_{Activity,t} + \cdots + \Delta_{Mix,t}$$

BAU Scenario (2070)

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
D_{Mix}	-2%	-2%	-3%	-3%	-8%	-2%	**13%**	-3%
$D_{Intensity}$	-51%	-46%	-47%	-47%	-62%	-41%	-44%	-42%
$D_{Sectoral}$	-37%	-38%	-51%	-30%	-37%	-27%	-42%	-34%
$D_{Regional}$	63%							
$D_{Activity}$	470%	1053%	1804%	208%	2470%	90%	911%	298%
D_C	183%	277%	379%	12%	471%	**-19%**	273%	47%

Cumulative Change in Emissions

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
Δ_{Mix}	-1401	-20	-748	-94	-458	-22	536	-244
$\Delta_{Intensity}$	-35808	-465	-10115	-2250	-4334	-576	-1910	-3831
$\Delta_{Sectoral}$	-22455	-365	-10758	-1285	-1549	-346	-1892	-2885
$\Delta_{Regional}$	22436							
$\Delta_{Activity}$	87233	1760	42757	4004	12797	701	7854	9707
Δ_C	50009	913	21139	379	6460	-241	4591	2751

High GDP Growth Scenario (2070)

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
D_{Mix}	-2%	0%	-4%	-1%	-9%	-1%	13%	-3%
$D_{Intensity}$	-53%	-47%	-50%	-48%	-63%	-43%	-46%	-43%
$D_{Sectoral}$	-42%	-42%	-58%	-34%	-40%	-31%	-45%	-37%
$D_{Regional}$	68%							
$D_{Activity}$	648%	1362%	2795%	292%	3072%	139%	1208%	382%
D_C	235%	354%	486%	33%	540%	-8%	334%	66%

Difference from the BAU Scenario

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
Mix	0%	2%	-1%	1%	0%	1%	0%	0%
Intensity	-2%	-1%	-4%	-2%	-2%	-2%	-2%	-1%
Sectoral	-5%	-4%	-6%	-3%	-3%	-4%	-4%	-4%
Regional	5%							
Activity	177%	309%	991%	84%	602%	48%	297%	84%
Total	52%	77%	106%	21%	69%	12%	61%	19%

High Population Growth Scenario (2070)

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
D_{Mix}	-2%	-1%	-4%	-3%	-9%	-2%	16%	-3%
$D_{Intensity}$	-53%	-46%	-49%	-49%	-63%	-43%	-45%	-44%
$D_{Sectoral}$	-39%	-42%	-54%	-33%	-38%	-30%	-45%	-36%
$D_{Regional}$	60%							
$D_{Activity}$	614%	1365%	2205%	296%	2848%	146%	1142%	421%
D_C	220%	355%	425%	33%	510%	-5%	337%	80%

Difference from the BAU Scenario

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
Mix	0%	1%	0%	0%	0%	0%	3%	0%
Intensity	-2%	0%	-2%	-2%	-2%	-3%	-1%	-1%
Sectoral	-3%	-4%	-2%	-3%	-1%	-3%	-3%	-3%
Regional	-3%							
Activity	144%	313%	402%	88%	377%	56%	231%	123%
Total	36%	78%	46%	21%	39%	15%	64%	33%

High Population Growth Scenario (2070)

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
D_{Mix}	-2%	-1%	-4%	-3%	-9%	-2%	16%	-3%
$D_{Intensity}$	-53%	-46%	-49%	-49%	-63%	-43%	-45%	-44%
$D_{Sectoral}$	-39%	-42%	-54%	-33%	-38%	-30%	-45%	-36%
$D_{Regional}$	60%							
$D_{Activity}$	614%	1365%	2205%	296%	2848%	146%	1142%	421%
D_C	220%	355%	425%	33%	510%	-5%	337%	80%

Difference from the *High GDP Growth* Scenario

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
Mix	0%	-1%	0%	-1%	0%	-1%	3%	-1%
Intensity	0%	0%	1%	0%	0%	0%	1%	0%
Sectoral	3%	0%	4%	1%	2%	1%	1%	1%
Regional	-9%							
Activity	-34%	4%	-589%	4%	-224%	7%	-66%	38%
Total	-15%	1%	-60%	0%	-30%	3%	3%	14%

Recession Scenario (2070)

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
D_{Mix}	-2%	-2%	-3%	-3%	-8%	-2%	13%	-3%
$D_{Intensity}$	-51%	-46%	-47%	-47%	-62%	-41%	-44%	-42%
$D_{Sectoral}$	-36%	-38%	-51%	-30%	-37%	-27%	-42%	-34%
$D_{Regional}$	63%							
$D_{Activity}$	469%	1052%	1798%	208%	2469%	90%	910%	298%
D_C	183%	277%	379%	12%	472%	-19%	273%	47%

Difference from the BAU Scenario

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
Mix	0%	0%	0%	0%	0%	0%	0%	0%
Intensity	0%	0%	0%	0%	0%	0%	0%	0%
Sectoral	0%	0%	0%	0%	0%	0%	0%	0%
Regional	0%							
Activity	-1%	-1%	-6%	0%	-1%	0%	-1%	0%
Total	0%	0%	0%	0%	1%	0%	0%	0%

Recession Scenario (2020)

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
D_{Mix}	0%	-1%	0%	-1%	0%	1%	1%	-1%
$D_{Intensity}$	-15%	-13%	-13%	-12%	-14%	-13%	-14%	-16%
$D_{Sectoral}$	-9%	-9%	-15%	-6%	-13%	-6%	-10%	-10%
$D_{Regional}$	14%							
$D_{Activity}$	42%	76%	118%	25%	112%	9%	61%	41%
D_C	25%	39%	61%	3%	57%	-10%	26%	7%

Difference from the BAU Scenario

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
Mix	0%	-1%	0%	0%	0%	0%	0%	0%
Intensity	0%	0%	1%	0%	0%	1%	0%	0%
Sectoral	2%	1%	2%	2%	2%	2%	1%	2%
Regional	-1%							
Activity	-8%	-9%	-18%	-7%	-10%	-5%	-8%	-7%
Total	-5%	-5%	-8%	-4%	-4%	-3%	-4%	-3%

Carbon Tax Scenario (2070)

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
D_{Mix}	-29%	-23%	-36%	-23%	-45%	-27%	-38%	-22%
$D_{Intensity}$	-65%	-59%	-59%	-63%	-73%	-55%	-67%	-64%
$D_{Sectoral}$	-42%	-39%	-61%	-29%	-45%	-29%	-48%	-38%
$D_{Regional}$	52%							
$D_{Activity}$	462%	1049%	1755%	207%	2407%	90%	832%	295%
D_C	22%	122%	90%	-38%	104%	-56%	-2%	-31%

Difference from the BAU Scenario

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
Mix	-27%	-21%	-33%	-20%	-37%	-25%	-52%	-18%
Intensity	-15%	-13%	-13%	-17%	-12%	-14%	-24%	-22%
Sectoral	-4%	-1%	-9%	2%	-8%	-2%	-6%	-4%
Regional	-13%							
Activity	-8%	-4%	-48%	-1%	-66%	0%	-79%	-2%
Total	-161%	-154%	-288%	-49%	-368%	-36%	-275%	-78%

Carbon Tax Scenario
w/out CCS Technology (2070)

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
D_{Mix}	-18%	-21%	-15%	-21%	-24%	-26%	-19%	-18%
$D_{Intensity}$	-69%	-60%	-66%	-64%	-79%	-55%	-73%	-66%
$D_{Sectoral}$	-41%	-39%	-61%	-28%	-45%	-29%	-49%	-38%
$D_{Regional}$	51%							
$D_{Activity}$	462%	1049%	1761%	207%	2406%	90%	831%	295%
D_C	28%	123%	109%	-37%	118%	-55%	4%	-30%

Difference from the *Carbon Tax* Scenario

	World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
Mix	12%	2%	21%	2%	21%	1%	19%	4%
Intensity	-3%	-1%	-6%	-1%	-6%	0%	-5%	-1%
Sectoral	-1%	0%	-1%	0%	-1%	0%	-1%	0%
Regional	1%							
Activity	0%	0%	5%	0%	2%	0%	-1%	0%
Total	6%	0%	18%	0%	14%	0%	6%	1%

Points for Discussion

- Range of scenarios need to be expanded to be more congruent with different model types
  - Recently-completed Asian Modeling Exercise could be a useful template in this regard
- Not clear how MUG results will be analyzed; we offer our methodology as a potentially useful option
  - Scope for extending the method to radiative forcing, temperature or even impacts
  - Interesting to see how very different models (e.g., EPPA, MERGE, RICE) compare in terms of the drivers of emissions, and, crucially, *how these are related to differences in structure and/or parameterization*

Comparing Across Models:
The Importance of Internal Structure

- Our AME-style "No CCS" case is meant to highlight the importance of the technological opportunity set and its change over time for model responses (cf Nordhaus, 1973)

- Cross-model comparison will likely be facilitated by development of metrics that capture such structural differences

  - Need clever mathematical tricks for dimension reduction, and to capture qualitative differences in activities such as their abatement potentials

Additional Slides

MUG Scenario Results (2070)

	Bench-mark	BAU	2020 Recession	High GDP Growth	High Pop. Growth	Carbon Tax
Output (10^12 2005$)	41.44	236.31	236.02	308.87	295.84	232.83
CO2 Emissions (GT CO2/yr)	27.27	77.25	77.3	91.34	87.17	33.47
Primary Energy (EJ)	463.13	1170.6	1171	1340.7	1335.9	1170.6
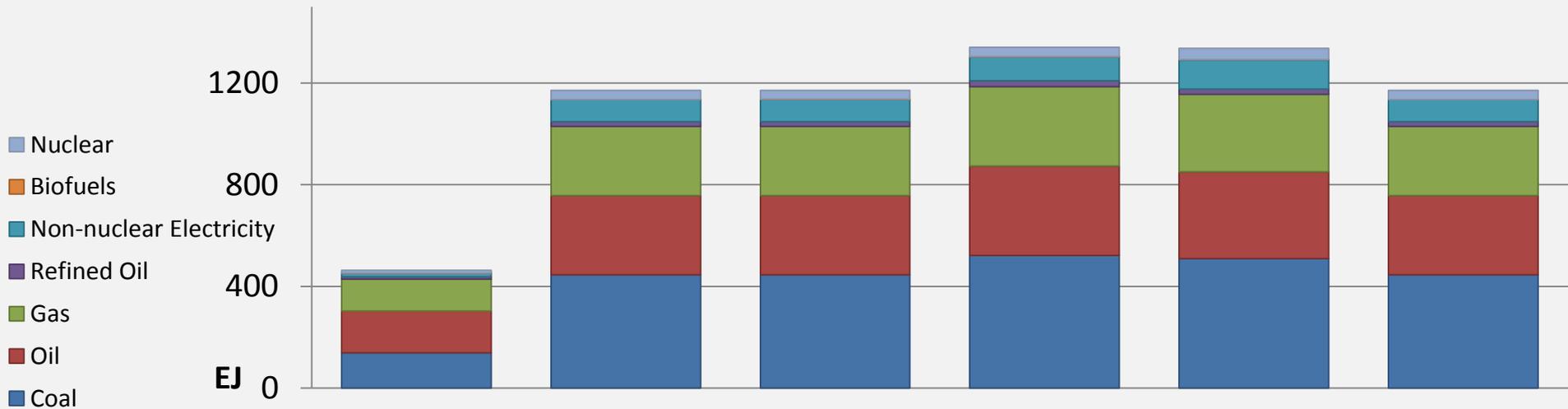
2007 Regional Results

		World	Brazil	China & Taiwan	EU15	India	Japan	Russia	USA
GDP (10^12 2005$)	BAU	236.31	7.17	42.83	36.25	16.97	8.75	6.55	47.29
	High GDP	309.87	9.09	65.12	46.15	20.95	10.98	8.47	57.32
	Tax Policy	232.79	7.14	41.75	36.13	16.54	8.73	6.04	47.00
Emissions (GT CO2/yr)	BAU	77.25	1.24	26.68	3.60	1.15	1.01	7.28	8.60
	High GDP	91.34	1.50	32.59	4.26	8.77	1.15	7.28	9.72
	Tax Policy	33.51	0.74	10.65	2.00	2.78	0.55	1.65	4.05
Primary Energy (EJ)	BAU	1170.64	25.93	331.98	70.20	92.03	17.00	108.29	139.38
	High GDP	1340.66	29.10	398.64	78.77	101.04	18.48	123.46	151.47
	Tax Policy	881.40	21.30	221.57	56.77	99.77	13.41	62.15	102.65