Decomposing the Impact of Alternative Technology Sets on Future Carbon Emissions Growth

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Plan of Talk

1. Introduction: The Phoenix Model
2. Research questions and methodology
3. Decomposition analysis
4. Results
5. Summary and conclusions

Phoenix

- Joint development effort between JGCRI, Boston University (Ian Sue Wing), and Penn State University (Karen Fisher-Vanden)
- Goal: constructing 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 (6 in Asia), 26 sectors (5 energy commodities), 3 primary factors
  - Static submodel 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; price-driven renewable, nuclear and hydro resource supply expansion
- Energy technology detail
  - Nine types of electric power generation: coal, oil, nat. gas, biomass, nuclear, hydro, geothermal, solar, and wind
  - 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

Research Questions & Methodology

- What are the key drivers of the future growth of global CO_2 emissions simulated by IAMs?
- How do changes in these drivers reflect the margins of adjustment to the economic impacts of abatement policies to stabilize atmospheric CO_2 concentrations?
- How does the future availability of energy technologies change their relative importance?
- Methodology: Phoenix as a test case
  - Characterize relative contributions of five drivers of emissions growth using index number decomposition analysis
  - Measure how relative contributions of these factors change with:
    - The imposition of a carbon tax
    - Restrictions on the availability of technologies

Drivers of Carbon Emissions

- Reference Scenario: CO_2 emissions increase 168% from 2005 to 2075
- Drivers of growth given by the Kaya Identity:

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

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

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  - 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 composition of sectoral output ($e_{r,j}/q_{r,j}$)

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  - 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 composition of sectoral output ($e_{r,j}/q_{r,j}$)
  - Change in carbon composition of energy ($c_{r,j}/e_{r,j}$)

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

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

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

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

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

$$D_{C,T} = \prod_{t=1}^{T} \exp(G_{C,t}) = \prod_{t=1}^{T} \exp\left(\sum_{k} G_{k,t}\right), D_{Activity,T} = \prod_{t=1}^{T} \exp(G_{Activity,t}), \dots$$
$$\Rightarrow D_{C,T} \neq D_{Activity,T} + D_{Region,T} + D_{Sector,T} + D_{Intensity,T} + D_{Mix,T}$$

- 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>!

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

Model Scenarios

- Comparing decomposition results across scenarios:
  - sheds light on key model assumptions
  - provides a type of sensitivity analysis
  - Identifies the channels through which the policies affect emissions

- Scenario 1 : no policy, reference scenario
- Scenario 2c.1 : carbon tax starting at $50/ton in 2020 and steadily increasing to $753 by 2075
- Scenario 2c.2 : carbon tax with restricted use of carbon capture and storage (CCS) technology
- Scenario 2c.3 : carbon tax with restricted use of nuclear technology
- Scenario 2c.4 : carbon tax with restricted use of hydro technology

Reference case										
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	546%	1274%	2078%	231%	1205%	3064%	107%	334%	1206%	325%
Regional	59%									
Sectoral	-31%	-36%	-47%	-29%	-19%	-26%	-26%	-24%	-27%	-32%
Intensity	-57%	-48%	-59%	-42%	-68%	-73%	-30%	-27%	-62%	-49%
Mix	-11%	-17%	-2%	-20%	-18%	-15%	-23%	-11%	-8%	-11%
Total	168%	276%	359%	8%	175%	430%	-17%	113%	229%	31%
Cumulative components of change in emissions (Δ), 2005-2075, million metric tons of CO_2										
Activity	89097	1741	39691	4314	1833	10029	716	956	7772	10175
Regional	19965									
Sectoral	-17764	-323	-8643	-1248	-177	-690	-292	-194	-1091	-2748
Intensity	-40365	-462	-12197	-2018	-852	-4106	-343	-216	-2696	-4658
Mix	-5395	-129	-403	-785	-154	-482	-263	-76	-255	-865
Total	45539	828	18447	262	651	4751	-183	469	3730	1905

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- Higher carbon emissions are driven by economic growth (Q) and shifts in regional productivity (Q_r/Q)

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- Changes in energy mix, sectoral shifts, and energy intensity apply downward pressure on emissions

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- Downward pressure from energy intensity is most prominent in China, India, Russia, and Indonesia

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- Shifts in sectoral output are particularly strong in China, where large structural changes are occurring

	Scenario 2c.1, All Energy Supply Technologies									
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Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
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Regional	43%									
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Carbon Tax, no technology restrictions

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- Under a carbon tax, economic activity is still the largest contributor but the effect is dampened relative to the reference scenario

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- Under a carbon tax, economic activity is still the largest contributor but the effect is dampened relative to the reference scenario
- This dampening effect is greatest in Russia, China, and India

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- Emissions are lower than 2005 levels in every region except Brazil and India
- However, Brazil and India's 2075 emissions under the tax are significantly lower than the reference, no tax, scenario

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Total	-218%	-241%	-390%	-77%	-199%	-423%	-57%	-150%	-292%	-102%

- The tax’s effect on energy intensity is greatest in EU, Japan, Korea, and the US
- The effect on mix is greatest in China, India, and Russia

	Scenario 2c.2, without CCS									
	World	Brazil	China	EU15	Indonesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1226%	1851%	222%	1122%	2825%	103%	326%	908%	313%
Regional	44%									
Sectoral	-48%	-49%	-67%	-34%	-35%	-44%	-34%	-39%	-44%	-43%
Intensity	-77%	-73%	-80%	-68%	-84%	-87%	-58%	-62%	-84%	-75%
Mix	-48%	-28%	-39%	-54%	-37%	-47%	-53%	-35%	-59%	-50%
Total	-47%	35%	-20%	-69%	-21%	17%	-74%	-35%	-63%	-70%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with CCS										
Activity	-1%	-1%	0%	0%	-2%	1%	0%	1%	-31%	0%
Regional	0									
Sectoral	-2%	0%	-3%	0%	-1%	-2%	0%	0%	-2%	-1%
Intensity	0%	0%	0%	0%	0%	-2%	0%	-1%	-1%	0%
Mix	5%	1%	12%	0%	5%	12%	0%	2%	3%	2%
Total	3%	0%	10%	0%	2%	10%	0%	1%	0%	1%

Carbon Tax, no CCS

	Scenario 2c.2, without CCS									
	World	Brazil	China	EU15	Indonesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1226%	1851%	222%	1122%	2825%	103%	326%	908%	313%
Regional	44%									
Sectoral	-48%	-49%	-67%	-34%	-35%	-44%	-34%	-39%	-44%	-43%
Intensity	-77%	-73%	-80%	-68%	-84%	-87%	-58%	-62%	-84%	-75%
Mix	-48%	-28%	-39%	-54%	-37%	-47%	-53%	-35%	-59%	-50%
Total	-47%	35%	-20%	-69%	-21%	17%	-74%	-35%	-63%	-70%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with CCS										
Activity	-1%	-1%	0%	0%	-2%	1%	0%	1%	-31%	0%
Regional	0									
Sectoral	-2%	0%	-3%	0%	-1%	-2%	0%	0%	-2%	-1%
Intensity	0%	0%	0%	0%	0%	-2%	0%	-1%	-1%	0%
Mix	5%	1%	12%	0%	5%	12%	0%	2%	3%	2%
Total	3%	0%	10%	0%	2%	10%	0%	1%	0%	1%

- Emissions are higher or unchanged in every region relative to their emissions under the unrestricted tax scenario

	Scenario 2c.2, without CCS									
	World	Brazil	China	EU15	Indonesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1226%	1851%	222%	1122%	2825%	103%	326%	908%	313%
Regional	44%									
Sectoral	-48%	-49%	-67%	-34%	-35%	-44%	-34%	-39%	-44%	-43%
Intensity	-77%	-73%	-80%	-68%	-84%	-87%	-58%	-62%	-84%	-75%
Mix	-48%	-28%	-39%	-54%	-37%	-47%	-53%	-35%	-59%	-50%
Total	-47%	35%	-20%	-69%	-21%	17%	-74%	-35%	-63%	-70%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with CCS										
Activity	-1%	-1%	0%	0%	-2%	1%	0%	1%	-31%	0%
Regional	0									
Sectoral	-2%	0%	-3%	0%	-1%	-2%	0%	0%	-2%	-1%
Intensity	0%	0%	0%	0%	0%	-2%	0%	-1%	-1%	0%
Mix	5%	1%	12%	0%	5%	12%	0%	2%	3%	2%
Total	3%	0%	10%	0%	2%	10%	0%	1%	0%	1%

- Emissions are higher or unchanged in every region relative to their emissions under the unrestricted tax scenario
- The increase is particularly high in China and India, both intensive users of coal

	Scenario 2c.2, without CCS									
	World	Brazil	China	EU15	Indonesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1226%	1851%	222%	1122%	2825%	103%	326%	908%	313%
Regional	44%									
Sectoral	-48%	-49%	-67%	-34%	-35%	-44%	-34%	-39%	-44%	-43%
Intensity	-77%	-73%	-80%	-68%	-84%	-87%	-58%	-62%	-84%	-75%
Mix	-48%	-28%	-39%	-54%	-37%	-47%	-53%	-35%	-59%	-50%
Total	-47%	35%	-20%	-69%	-21%	17%	-74%	-35%	-63%	-70%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with CCS										
Activity	-1%	-1%	0%	0%	-2%	1%	0%	1%	-31%	0%
Regional	0									
Sectoral	-2%	0%	-3%	0%	-1%	-2%	0%	0%	-2%	-1%
Intensity	0%	0%	0%	0%	0%	-2%	0%	-1%	-1%	0%
Mix	5%	1%	12%	0%	5%	12%	0%	2%	3%	2%
Total	3%	0%	10%	0%	2%	10%	0%	1%	0%	1%

- Russia experiences a large drop in economic growth due to its heavy dependence on natural gas with carbon capture

	Scenario 2c.2, without CCS									
	World	Brazil	China	EU15	Indonesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1226%	1851%	222%	1122%	2825%	103%	326%	908%	313%
Regional	44%									
Sectoral	-48%	-49%	-67%	-34%	-35%	-44%	-34%	-39%	-44%	-43%
Intensity	-77%	-73%	-80%	-68%	-84%	-87%	-58%	-62%	-84%	-75%
Mix	-48%	-28%	-39%	-54%	-37%	-47%	-53%	-35%	-59%	-50%
Total	-47%	35%	-20%	-69%	-21%	17%	-74%	-35%	-63%	-70%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with CCS										
Activity	-1%	-1%	0%	0%	-2%	1%	0%	1%	-31%	0%
Regional	0									
Sectoral	-2%	0%	-3%	0%	-1%	-2%	0%	0%	-2%	-1%
Intensity	0%	0%	0%	0%	0%	-2%	0%	-1%	-1%	0%
Mix	5%	1%	12%	0%	5%	12%	0%	2%	3%	2%
Total	3%	0%	10%	0%	2%	10%	0%	1%	0%	1%

- In some regions restricting CCS use results in a shift to higher efficiency improvements (Intensity) and less of dependence on shifts in energy mix

	Scenario 2c.3, without Nuclear									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	503%	1227%	1850%	222%	1123%	2824%	103%	323%	940%	312%
Regional	41%									
Sectoral	-47%	-48%	-64%	-35%	-34%	-42%	-35%	-40%	-43%	-46%
Intensity	-77%	-73%	-81%	-67%	-84%	-85%	-58%	-63%	-83%	-72%
Mix	-51%	-28%	-49%	-53%	-41%	-57%	-52%	-20%	-62%	-51%
Total	-49%	35%	-30%	-68%	-23%	7%	-73%	-26%	-62%	-69%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Nuclear										
Activity	0%	0%	-1%	0%	-1%	0%	0%	-1%	1%	-1%
Regional	0									
Sectoral	-1%	0%	0%	-1%	-1%	0%	0%	-2%	-1%	-3%
Intensity	0%	0%	-1%	0%	0%	-1%	0%	-2%	0%	3%
Mix	2%	0%	3%	1%	1%	3%	1%	17%	0%	1%
Total	1%	0%	0%	1%	0%	0%	1%	10%	0%	2%

Carbon Tax, restricted nuclear case

	Scenario 2c.3, without Nuclear									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	503%	1227%	1850%	222%	1123%	2824%	103%	323%	940%	312%
Regional	41%									
Sectoral	-47%	-48%	-64%	-35%	-34%	-42%	-35%	-40%	-43%	-46%
Intensity	-77%	-73%	-81%	-67%	-84%	-85%	-58%	-63%	-83%	-72%
Mix	-51%	-28%	-49%	-53%	-41%	-57%	-52%	-20%	-62%	-51%
Total	-49%	35%	-30%	-68%	-23%	7%	-73%	-26%	-62%	-69%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Nuclear										
Activity	0%	0%	-1%	0%	-1%	0%	0%	-1%	1%	-1%
Regional	0									
Sectoral	-1%	0%	0%	-1%	-1%	0%	0%	-2%	-1%	-3%
Intensity	0%	0%	-1%	0%	0%	-1%	0%	-2%	0%	3%
Mix	2%	0%	3%	1%	1%	3%	1%	17%	0%	1%
Total	1%	0%	0%	1%	0%	0%	1%	10%	0%	2%

- Restricting nuclear leads to a shift in the energy mix towards more carbon-intensive sources

	Scenario 2c.3, without Nuclear									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	503%	1227%	1850%	222%	1123%	2824%	103%	323%	940%	312%
Regional	41%									
Sectoral	-47%	-48%	-64%	-35%	-34%	-42%	-35%	-40%	-43%	-46%
Intensity	-77%	-73%	-81%	-67%	-84%	-85%	-58%	-63%	-83%	-72%
Mix	-51%	-28%	-49%	-53%	-41%	-57%	-52%	-20%	-62%	-51%
Total	-49%	35%	-30%	-68%	-23%	7%	-73%	-26%	-62%	-69%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Nuclear										
Activity	0%	0%	-1%	0%	-1%	0%	0%	-1%	1%	-1%
Regional	0									
Sectoral	-1%	0%	0%	-1%	-1%	0%	0%	-2%	-1%	-3%
Intensity	0%	0%	-1%	0%	0%	-1%	0%	-2%	0%	3%
Mix	2%	0%	3%	1%	1%	3%	1%	17%	0%	1%
Total	1%	0%	0%	1%	0%	0%	1%	10%	0%	2%

- Restricting nuclear leads to a shift in the energy mix towards more carbon-intensive sources
- This shift is the most pronounced in Korea

	Scenario 2c.3, without Nuclear									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	503%	1227%	1850%	222%	1123%	2824%	103%	323%	940%	312%
Regional	41%									
Sectoral	-47%	-48%	-64%	-35%	-34%	-42%	-35%	-40%	-43%	-46%
Intensity	-77%	-73%	-81%	-67%	-84%	-85%	-58%	-63%	-83%	-72%
Mix	-51%	-28%	-49%	-53%	-41%	-57%	-52%	-20%	-62%	-51%
Total	-49%	35%	-30%	-68%	-23%	7%	-73%	-26%	-62%	-69%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Nuclear										
Activity	0%	0%	-1%	0%	-1%	0%	0%	-1%	1%	-1%
Regional	0									
Sectoral	-1%	0%	0%	-1%	-1%	0%	0%	-2%	-1%	-3%
Intensity	0%	0%	-1%	0%	0%	-1%	0%	-2%	0%	3%
Mix	2%	0%	3%	1%	1%	3%	1%	17%	0%	1%
Total	1%	0%	0%	1%	0%	0%	1%	10%	0%	2%

- Russia is the only region where we find an increase in emissions due to economic activity

	Scenario 2c.4, without Hydro									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1210%	1843%	222%	1123%	2821%	103%	325%	936%	313%
Regional	44%									
Sectoral	-47%	-49%	-65%	-34%	-34%	-43%	-34%	-38%	-43%	-43%
Intensity	-77%	-73%	-78%	-67%	-84%	-84%	-58%	-61%	-83%	-75%
Mix	-53%	-26%	-52%	-55%	-42%	-58%	-53%	-37%	-63%	-52%
Total	-49%	33%	-29%	-69%	-23%	10%	-74%	-36%	-63%	-71%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Hydro										
Activity	-1%	-16%	-7%	0%	-1%	-3%	0%	0%	-3%	0%
Regional	0									
Sectoral	-1%	-1%	-1%	0%	-1%	-1%	0%	0%	-1%	0%
Intensity	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Mix	0%	2%	-1%	0%	0%	1%	0%	0%	0%	0%
Total	0%	-1%	1%	0%	0%	3%	0%	0%	0%	0%

Carbon Tax, restricted hydro case

	Scenario 2c.4, without Hydro									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1210%	1843%	222%	1123%	2821%	103%	325%	936%	313%
Regional	44%									
Sectoral	-47%	-49%	-65%	-34%	-34%	-43%	-34%	-38%	-43%	-43%
Intensity	-77%	-73%	-78%	-67%	-84%	-84%	-58%	-61%	-83%	-75%
Mix	-53%	-26%	-52%	-55%	-42%	-58%	-53%	-37%	-63%	-52%
Total	-49%	33%	-29%	-69%	-23%	10%	-74%	-36%	-63%	-71%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Hydro										
Activity	-1%	-16%	-7%	0%	-1%	-3%	0%	0%	-3%	0%
Regional	0									
Sectoral	-1%	-1%	-1%	0%	-1%	-1%	0%	0%	-1%	0%
Intensity	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Mix	0%	2%	-1%	0%	0%	1%	0%	0%	0%	0%
Total	0%	-1%	1%	0%	0%	3%	0%	0%	0%	0%

- Results are very similar to the unrestricted technology case

	Scenario 2c.4, without Hydro									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1210%	1843%	222%	1123%	2821%	103%	325%	936%	313%
Regional	44%									
Sectoral	-47%	-49%	-65%	-34%	-34%	-43%	-34%	-38%	-43%	-43%
Intensity	-77%	-73%	-78%	-67%	-84%	-84%	-58%	-61%	-83%	-75%
Mix	-53%	-26%	-52%	-55%	-42%	-58%	-53%	-37%	-63%	-52%
Total	-49%	33%	-29%	-69%	-23%	10%	-74%	-36%	-63%	-71%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Hydro										
Activity	-1%	-16%	-7%	0%	-1%	-3%	0%	0%	-3%	0%
Regional	0									
Sectoral	-1%	-1%	-1%	0%	-1%	-1%	0%	0%	-1%	0%
Intensity	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Mix	0%	2%	-1%	0%	0%	1%	0%	0%	0%	0%
Total	0%	-1%	1%	0%	0%	3%	0%	0%	0%	0%

- Results are very similar to the unrestricted technology case
- Only China and India experience an increase in total emissions

	Scenario 2c.4, without Hydro									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1210%	1843%	222%	1123%	2821%	103%	325%	936%	313%
Regional	44%									
Sectoral	-47%	-49%	-65%	-34%	-34%	-43%	-34%	-38%	-43%	-43%
Intensity	-77%	-73%	-78%	-67%	-84%	-84%	-58%	-61%	-83%	-75%
Mix	-53%	-26%	-52%	-55%	-42%	-58%	-53%	-37%	-63%	-52%
Total	-49%	33%	-29%	-69%	-23%	10%	-74%	-36%	-63%	-71%
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Hydro										
Activity	-1%	-16%	-7%	0%	-1%	-3%	0%	0%	-3%	0%
Regional	0									
Sectoral	-1%	-1%	-1%	0%	-1%	-1%	0%	0%	-1%	0%
Intensity	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Mix	0%	2%	-1%	0%	0%	1%	0%	0%	0%	0%
Total	0%	-1%	1%	0%	0%	3%	0%	0%	0%	0%

- Results are very similar to the unrestricted technology case
- Only China and India experience an increase in total emissions
- Brazil’s emissions fall slightly, and it experiences a large drop in economic activity since its only option is to reduce emissions when hydro is restricted

Conclusions (I)

- Economic growth and shifts in the regional composition of output are the largest contributors to increases in future emissions
- Imposing a tax has lowers the upward pressure due to economic activity and decreases the carbon intensity of energy
- Restricting CCS shifts the MAC curves up and increases the carbon intensity of energy
- Phasing out nuclear energy causes a slight increase in emissions due to higher MACs
- Slowing the growth of hydropower has little impact on future emissions

Conclusions (II)

- Need some brainstorming here!
- Use opportunity to draw inferences about applicability of the method to other IAMs of various kinds
  - 5 drivers we identify are kind of a common denominator
  - Speculate on summing over technologies rather than sectors in application bottom-up energy system models?
  - Would need some work to straighten out the details, but in principle doable
- Research is ongoing to extend the present analysis. Focus is on linking the origins of the changes in emissions to the macroeconomic cost of abatement.

Additional Slides

	Scenario 2c.1, All Energy Supply Technologies									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	503%	1227%	1850%	222%	1124%	2824%	103%	325%	939%	313%
Regional	43%									
Sectoral	-46%	-48%	-64%	-34%	-34%	-42%	-34%	-38%	-42%	-43%
Intensity	-77%	-73%	-80%	-67%	-84%	-84%	-58%	-61%	-83%	-75%
Mix	-53%	-28%	-52%	-55%	-42%	-59%	-53%	-37%	-63%	-52%
Total	-50%	35%	-31%	-69%	-24%	7%	-74%	-36%	-62%	-71%
Cumulative components of change in emissions (Δ), 2005-2075, million metric tons of CO_2										
Activity	34167	960	13748	2325	871	3379	375	552	2197	5244
Regional	7482									
Sectoral	-12457	-248	-4878	-879	-143	-559	-259	-173	-574	-2126
Intensity	-29032	-482	-7534	-2097	-634	-1886	-443	-357	-1828	-5092
Mix	-13997	-126	-3088	-1658	-181	-894	-489	-173	-853	-2482
Total	-13836	104	-1751	-2309	-87	40	-816	-151	-1059	-4456
Cumulative components of change in emissions (Δ), % difference from Reference Case										
Activity	-43%	-47%	-228%	-9%	-81%	-240%	-4%	-9%	-267%	-11%
Regional	-16%									
Sectoral	-15%	-12%	-17%	-5%	-15%	-16%	-9%	-14%	-15%	-11%
Intensity	-20%	-24%	-21%	-25%	-16%	-11%	-28%	-34%	-21%	-26%
Mix	-42%	-12%	-49%	-35%	-24%	-44%	-30%	-26%	-54%	-40%
Total	-218%	-241%	-390%	-77%	-199%	-423%	-57%	-150%	-292%	-102%

	Scenario 2c.2, without CCS									
	World	Brazil	China	EU15	Indonesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1226%	1851%	222%	1122%	2825%	103%	326%	908%	313%
Regional	44%									
Sectoral	-48%	-49%	-67%	-34%	-35%	-44%	-34%	-39%	-44%	-43%
Intensity	-77%	-73%	-80%	-68%	-84%	-87%	-58%	-62%	-84%	-75%
Mix	-48%	-28%	-39%	-54%	-37%	-47%	-53%	-35%	-59%	-50%
Total	-47%	35%	-20%	-69%	-21%	17%	-74%	-35%	-63%	-70%
Cumulative components of change in emissions (Δ), 2005-2075, million metric tons of CO_2										
Activity	34799	960	14310	2329	879	3461	375	555	2204	5274
Regional	7658									
Sectoral	-13238	-250	-5406	-886	-151	-606	-260	-176	-604	-2165
Intensity	-29781	-485	-7791	-2113	-650	-2052	-444	-364	-1875	-5133
Mix	-12459	-122	-2323	-1638	-157	-662	-487	-163	-790	-2386
Total	-13022	104	-1210	-2308	-78	141	-816	-148	-1064	-4410
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with CCS										
Activity	-1%	-1%	0%	0%	-2%	1%	0%	1%	-31%	0%
Regional	0									
Sectoral	-2%	0%	-3%	0%	-1%	-2%	0%	0%	-2%	-1%
Intensity	0%	0%	0%	0%	0%	-2%	0%	-1%	-1%	0%
Mix	5%	1%	12%	0%	5%	12%	0%	2%	3%	2%
Total	3%	0%	10%	0%	2%	10%	0%	1%	0%	1%

	Scenario 2c.3, without Nuclear									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	503%	1227%	1850%	222%	1123%	2824%	103%	323%	940%	312%
Regional	41%									
Sectoral	-47%	-48%	-64%	-35%	-34%	-42%	-35%	-40%	-43%	-46%
Intensity	-77%	-73%	-81%	-67%	-84%	-85%	-58%	-63%	-83%	-72%
Mix	-51%	-28%	-49%	-53%	-41%	-57%	-52%	-20%	-62%	-51%
Total	-49%	35%	-30%	-68%	-23%	7%	-73%	-26%	-62%	-69%
Cumulative components of change in emissions (Δ), 2005-2075, million metric tons of CO_2										
Activity	34994	960	13785	2414	876	3379	389	594	2227	5555
Regional	7308									
Sectoral	-13048	-248	-4904	-949	-148	-559	-272	-204	-599	-2452
Intensity	-29599	-483	-7784	-2193	-637	-1942	-457	-408	-1854	-5104
Mix	-13225	-125	-2834	-1560	-176	-838	-468	-90	-828	-2321
Total	-13569	104	-1737	-2288	-86	40	-807	-108	-1054	-4322
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Nuclear										
Activity	0%	0%	-1%	0%	-1%	0%	0%	-1%	1%	-1%
Regional	0									
Sectoral	-1%	0%	0%	-1%	-1%	0%	0%	-2%	-1%	-3%
Intensity	0%	0%	-1%	0%	0%	-1%	0%	-2%	0%	3%
Mix	2%	0%	3%	1%	1%	3%	1%	17%	0%	1%
Total	1%	0%	0%	1%	0%	0%	1%	10%	0%	2%

	Scenario 2c.4, without Hydro									
	World	Brazil	China	EU15	Indo-nesia	India	Japan	Korea	Russia	USA
Cumulative % change in factors influencing the growth of CO_2 emissions (D), 2005-2075										
Activity	502%	1210%	1843%	222%	1123%	2821%	103%	325%	936%	313%
Regional	44%									
Sectoral	-47%	-49%	-65%	-34%	-34%	-43%	-34%	-38%	-43%	-43%
Intensity	-77%	-73%	-78%	-67%	-84%	-84%	-58%	-61%	-83%	-75%
Mix	-53%	-26%	-52%	-55%	-42%	-58%	-53%	-37%	-63%	-52%
Total	-49%	33%	-29%	-69%	-23%	10%	-74%	-36%	-63%	-71%
Cumulative components of change in emissions (Δ), 2005-2075, million metric tons of CO_2										
Activity	34534	957	14067	2330	876	3455	376	552	2218	5264
Regional	7651									
Sectoral	-12886	-255	-5107	-882	-148	-592	-260	-173	-598	-2150
Intensity	-28988	-487	-7393	-2107	-631	-1889	-444	-358	-1838	-5103
Mix	-14032	-115	-3238	-1652	-183	-902	-488	-173	-840	-2468
Total	-13721	100	-1671	-2311	-86	71	-816	-151	-1058	-4456
Cumulative components of change in emissions (Δ), % difference from Scenario 2c with Hydro										
Activity	-1%	-16%	-7%	0%	-1%	-3%	0%	0%	-3%	0%
Regional	0									
Sectoral	-1%	-1%	-1%	0%	-1%	-1%	0%	0%	-1%	0%
Intensity	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Mix	0%	2%	-1%	0%	0%	1%	0%	0%	0%	0%
Total	0%	-1%	1%	0%	0%	3%	0%	0%	0%	0%