The role of global land use in determining greenhouse gas mitigation costs

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Motivation

- Land is a significant source of GHG emissions
  - Deforestation: 1/3 of total carbon emissions since 1850
  - Land management and land use change: 75% of N2O, 50% of CH4
- Previous studies suggest land-based mitigation is cost-effective
  - e.g., Sohngen and Mendelsohn (2003), Rao and Riahi (2006), van Vuuren et al. (2006), Jakeman and Fisher (2006)
- Analytical challenges for land modeling
  - Land-use competition and overall market reallocations
  - Land-based mitigation competition and net emissions effects
  - Land heterogeneity and dynamics
  - Lack of key consistent global data—land, emissions, mitigation costs
- New global datasets—land, emissions, mitigation costs

➔ Opportunities for improving our understanding of the mitigation role of land

Objective:
Analyze land allocation decisions and *global* general equilibrium feedbacks in mitigation

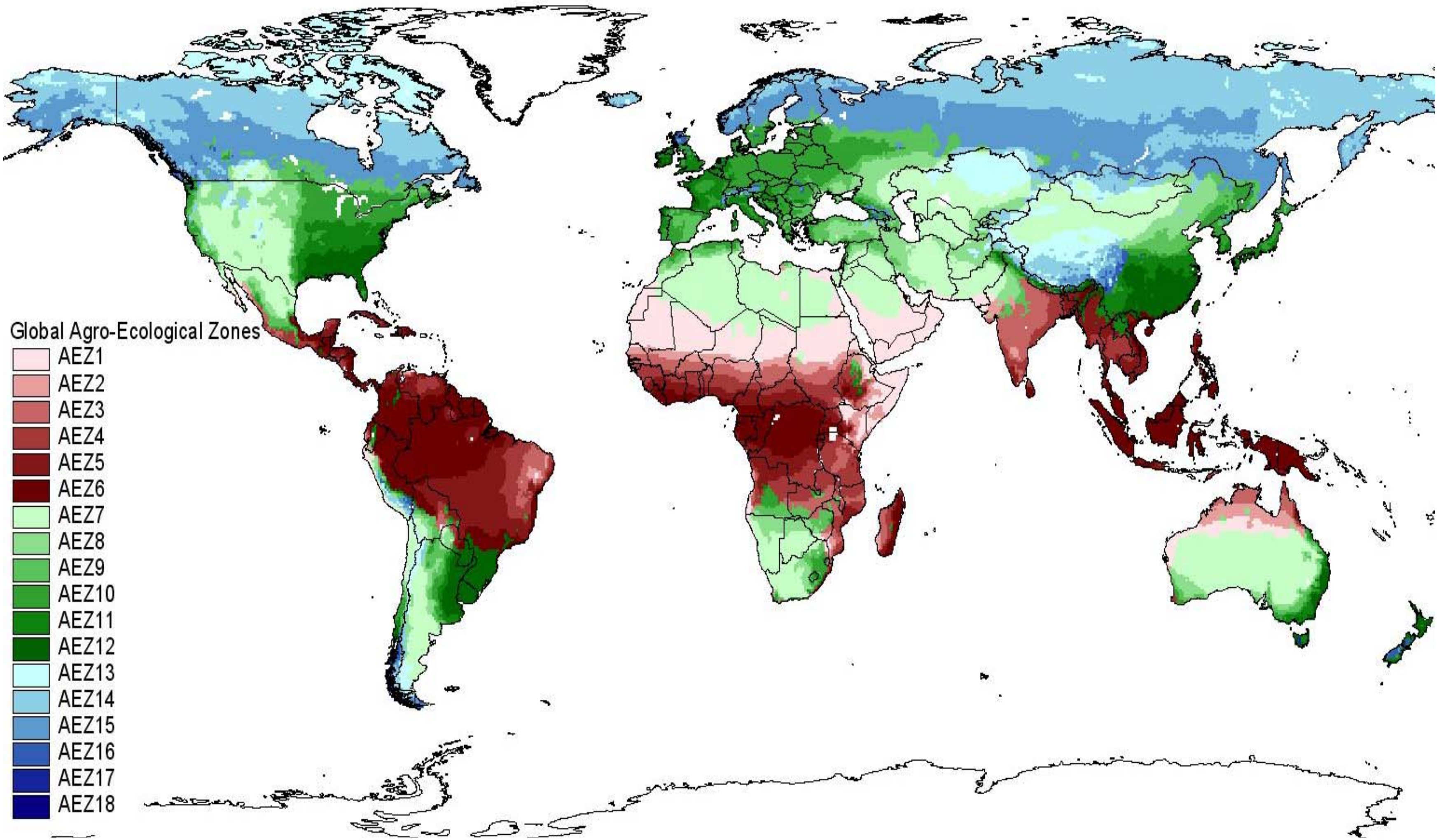
Outline

- Model structure
- Land, emissions, sequestration data
- Analysis set-up
- Results
- Conclusions & plans

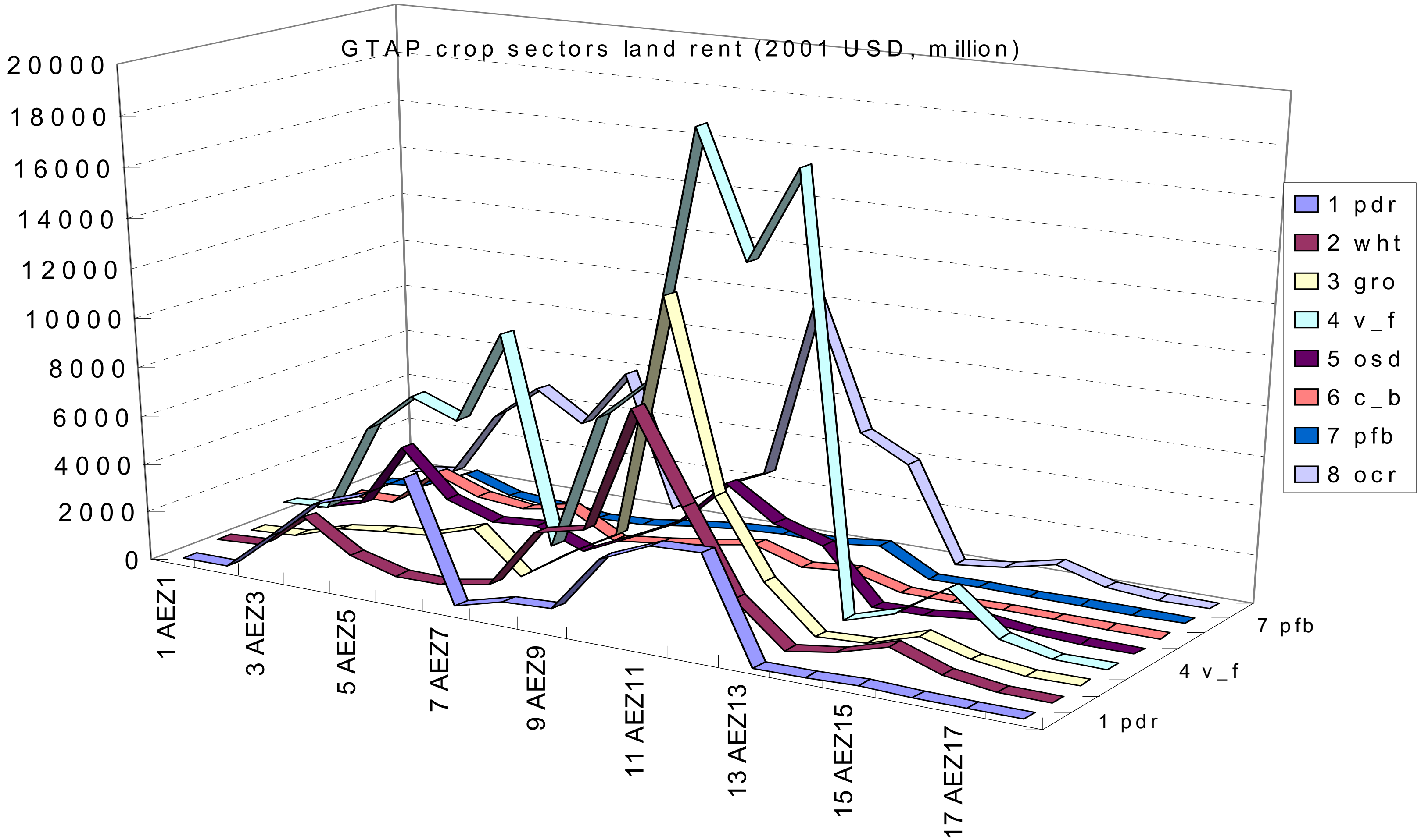
Expanded GTAP-AEZ

- Static global CGE
- Prototype applications:
  - 3 Regions: USA, China, ROW; maximum disaggr GTAP regions (nearly 100)
  - 24 Sectors – 5 land-using sectors (3 crop, ruminant livestock, forestry)
    - Max sectors = 57 of which 10 in agriculture
- Production with intra- and inter-regional land heterogeneity
  - AEZs: 18 different types of land within each region ➔ aggregated to 6 AEZs
  - Land supply and demand same as G-Dyn presentation
- GHG emissions and sequestration modifications
  - Non-CO2
    - Incorporate new detailed non-CO2 GHG emissions inventory data (N2O, CH4, F-gases)
    - Model 3 classifications of emissions – output, intermediate inputs, factor inputs
  - Forest carbon
    - Incorporate new detailed forest carbon stock data
    - Model intensive and extensive carbon management options
  - Introduce emissions pricing
  - Calibrate mitigation responses to PE model responses
- Given land emphasis, focus is on non-CO2 GHGs and forest sequestration
- Future: bring into dynamic model, add CO2 emissions and soil carbon

Land endowments – biophysical heterogeneity



Land endowments – economic heterogeneity



Detailed non-CO2 emissions & forest sequestation data

- New GTAP 2001 non-CO2 emissions data
  - Corresponds to GTAP v6 data 2001 base year and complements GTAP 2001 CO2 emissions data
  - Highly disaggregated – explicitly for more precise mapping to economic activity (output and input)
    - 226 countries
    - Currently 24 non-CO2 GHG emissions categories (N2O, CH4, F-gases) with 119 types of emissions with subcategory disaggregation
      - To be expanded further to all subcategories in new USEPA dataset (29 categories, 153 non-CO2 & Other CO2 subcategories)
    - Data developed from:
      - Annex 1: UNFCCC CRFs
      - Non-Annex 1: National Communications, ALGAS, IPCC inventory methods, EDGAR (biomass burning, Other CO2), some extrapolation from 2000 data

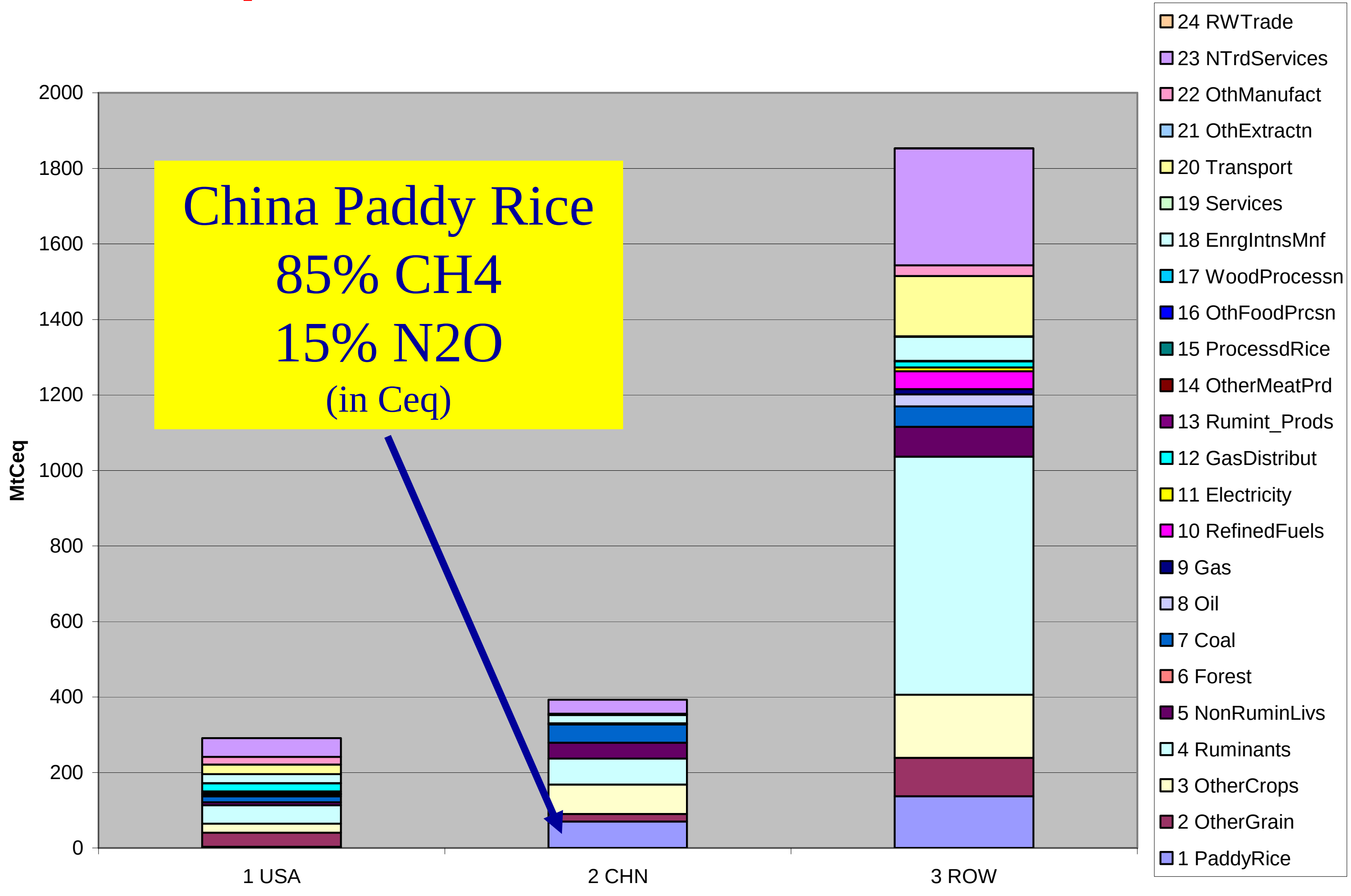
- New GTAP regional 2000 forest carbon stock data by AEZ, management type, and tree age cohort

- Soil carbon stock data also available (but not yet implemented in the model)

Non-CO2 emissions sources for land sectors

GHG/category GTAP-AEZ sector	Paddy rice	Other grain	Other crops	Ruminant livestock	Non-ruminant livestock	Forest	Ruminant animal products	Other meat products	Processed rice	Other food processing	Wood processing
Methane (CH_4)											
Enteric fermentation				x	x						
Manure management				x	x						
Rice cultivation	x										
Biomass burning	x	x	x	x							
Other industrial non-agriculture											x
Stationary and mobile combustion	x	x	x	x	x	x	x	x	x	x	x
Nitrous oxide (N_2O)											
Agricultural soils	x	x	x								
Manure management				x	x						
Pasture, range, and paddock				x	x						
Biomass burning	x	x	x	x							
Other industrial non-agriculture											x
Stationary and mobile combustion	x	x	x	x	x	x	x	x	x	x	x

Base year non-CO2 emissions profiles in the model

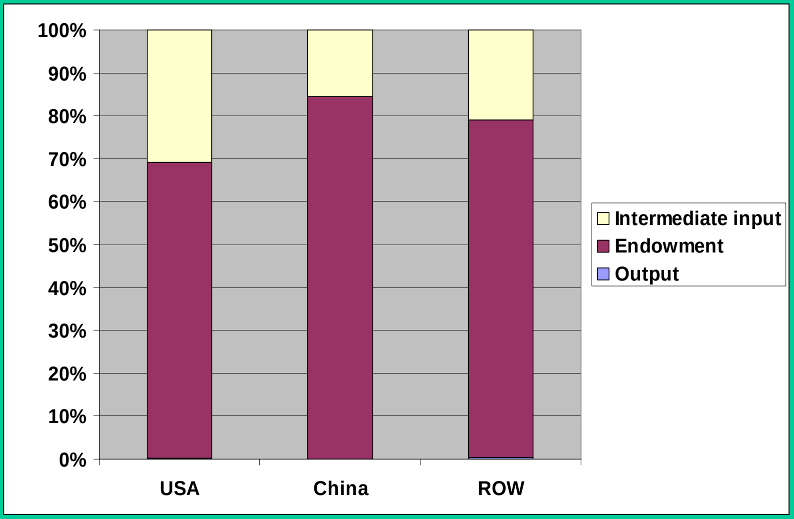


Modeling non-CO2 emissions
- 3 categories -

- **<u>Input</u>** – emissions related to input use; mitigation involves reducing input intensity
  - **<u>Intermediate input</u>** – e.g., fertilizer use in maize
  - **<u>Endowment</u>** – e.g, paddy rice land
- **<u>Output</u>** – emissions treated as distinct input to production, substitution for commercial inputs captures mitigation options:
  - Use when emissions not linked to input use
  - Calibrate CES elasticity following Hyman et al.

	Total non-CO2 GHG emissions (MtCeq)		
	USA	China	ROW
1 PaddyRice	2.971	70.160	137.364

Paddy Rice



Calibrating mitigation responses: Non-CO2 mitigation

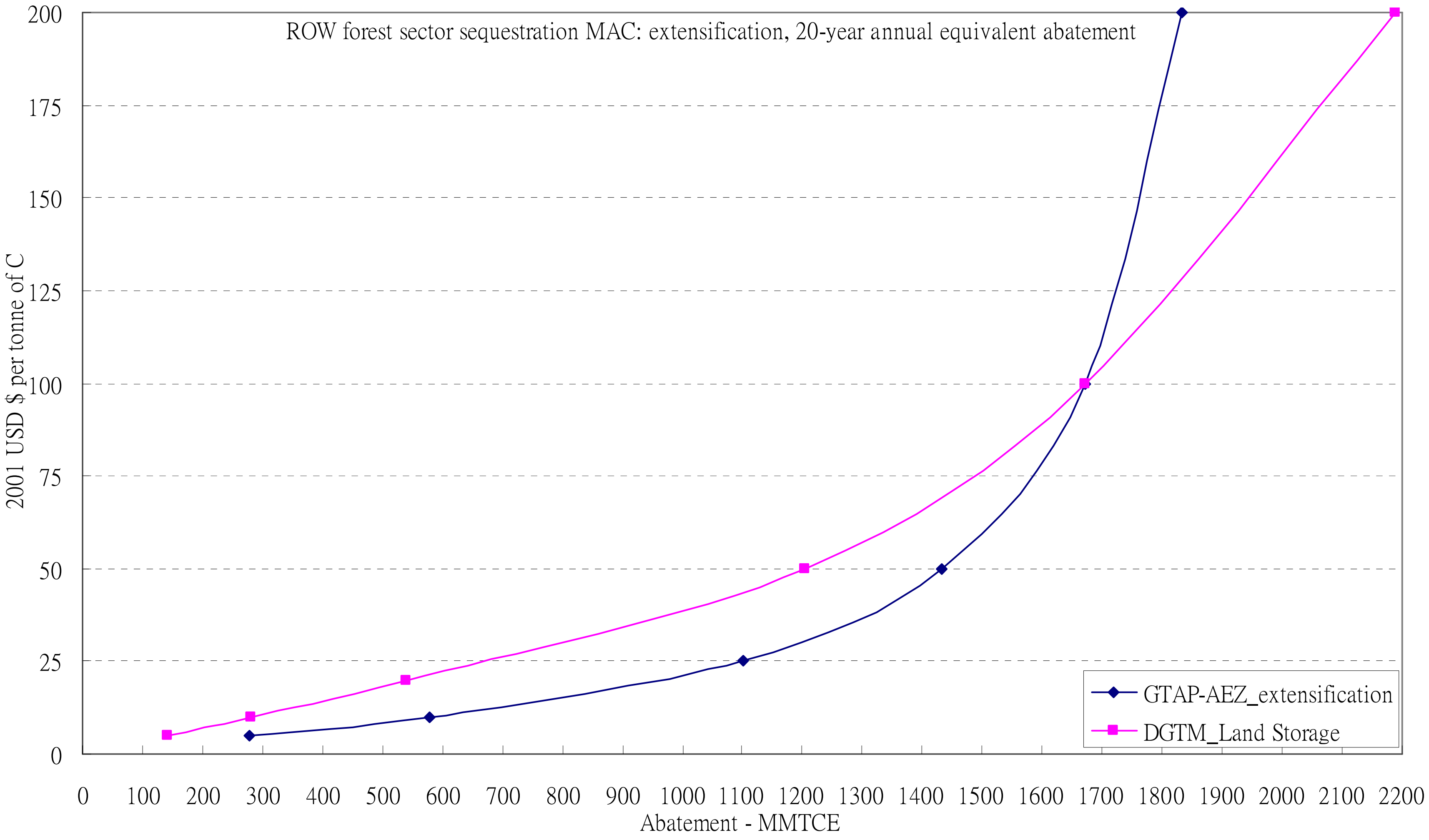
- Non-CO2 mitigation
  - New engineering mitigation cost estimates for detailed technologies—both agriculture and other sectors (USEPA, 2006)
  - Calibrate the relevant substitution elasticity <u>and</u> appropriate share of sector emissions with a partial equilibrium closure

- Forest sequestration supply
  - Regional forest carbon supply curves Sohngen and Mendelsohn (2006) – afforestation and forest management
  - Calibrate forest carbon production intensification and extensification responses

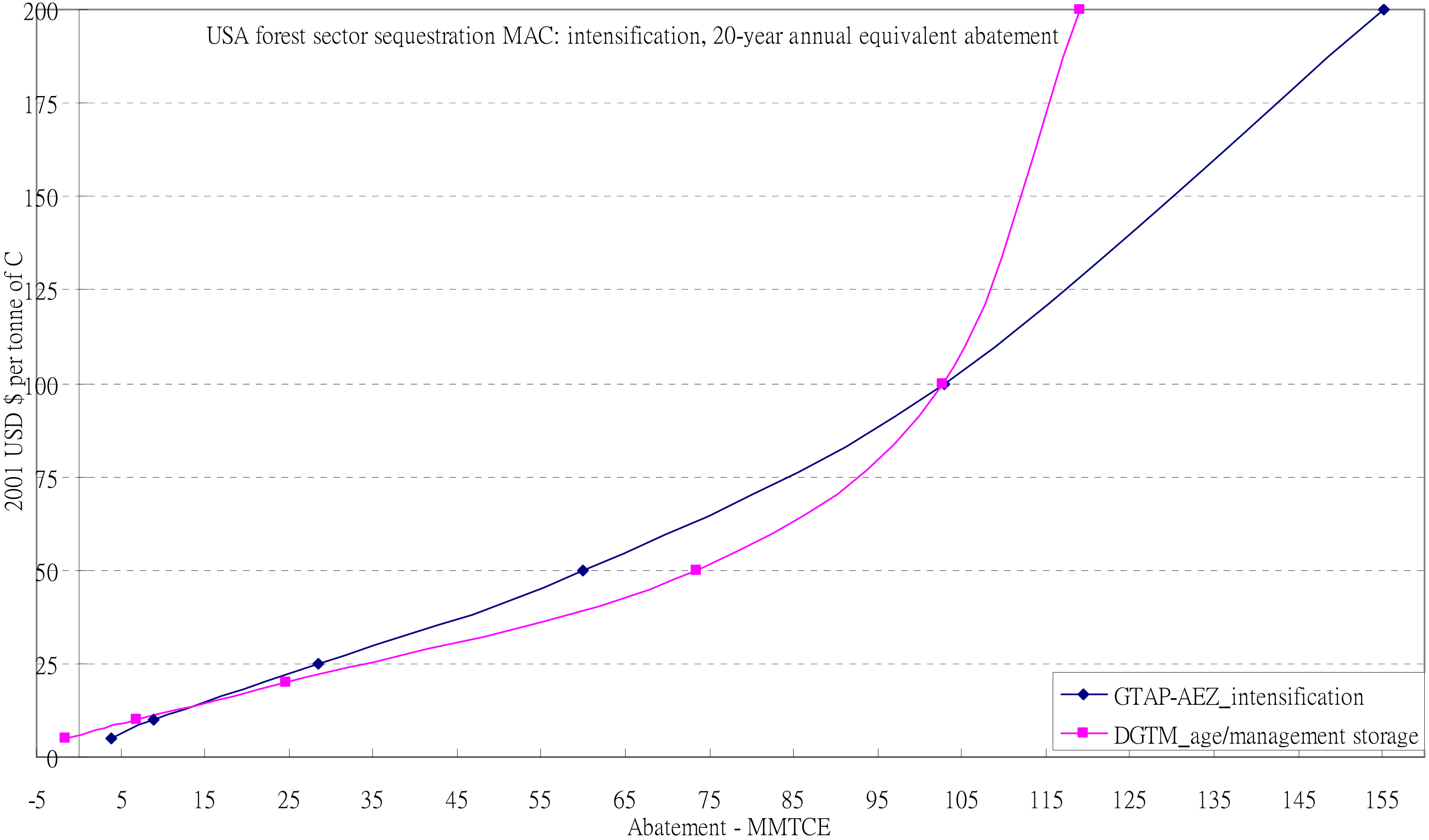
Calibrating forest sequestration responses

Carbon price	Extensive Margin	Intensive Margin	Wood Products	Access Margin**	Total
US					
5	1.672	-1.663	-0.476	0.839	0.371
10	3.509	6.802	-0.238	1.346	11.419
20	7.023	24.585	-0.084	2.866	34.390
50	17.811	73.503	-0.948	5.147	95.513
100	43.069	102.749	-0.132	9.298	154.986
200	118.287	119.006	1.667	19.931	258.893
500	270.741	286.616	0.537	25.322	583.216
CHINA					
5	0.440	3.018	-0.028	4.733	8.164
10	0.612	14.865	-0.282	9.966	25.161
20	1.210	26.899	-0.372	21.765	49.501
50	4.154	73.928	-1.532	53.501	130.051
100	12.797	98.522	-2.018	77.089	186.390
200	73.532	97.503	-1.325	77.089	246.799
500	108.663	202.142	-5.082	77.089	382.812
ROW					
5	143.218	31.572	-3.614	-19.259	151.917
10	281.670	78.626	-5.956	-2.370	351.969
20	539.266	114.936	-9.437	14.203	658.968
50	1203.164	250.691	-19.898	66.875	1500.832
100	1672.509	387.619	-29.708	80.424	2110.845
200	2189.741	366.732	-21.178	93.365	2628.660
500	2885.440	868.723	-47.496	103.227	3809.894

Calibration example – ROW forest extensification



Calibration example – USA forest intensification

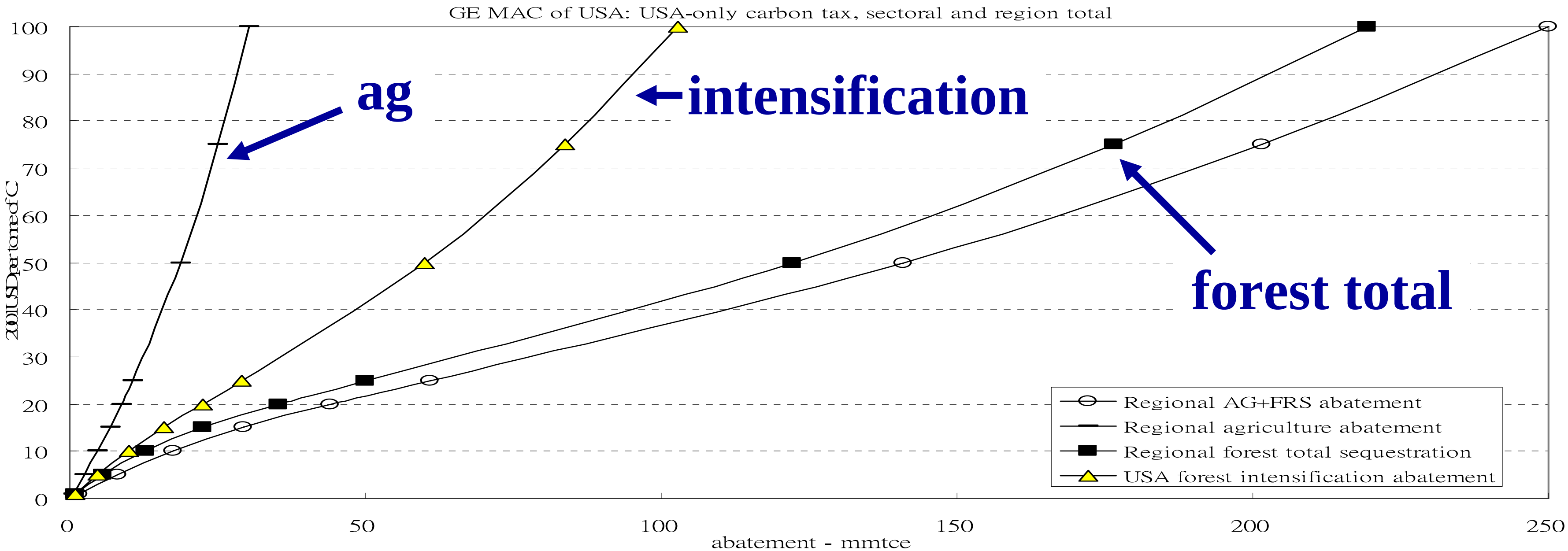


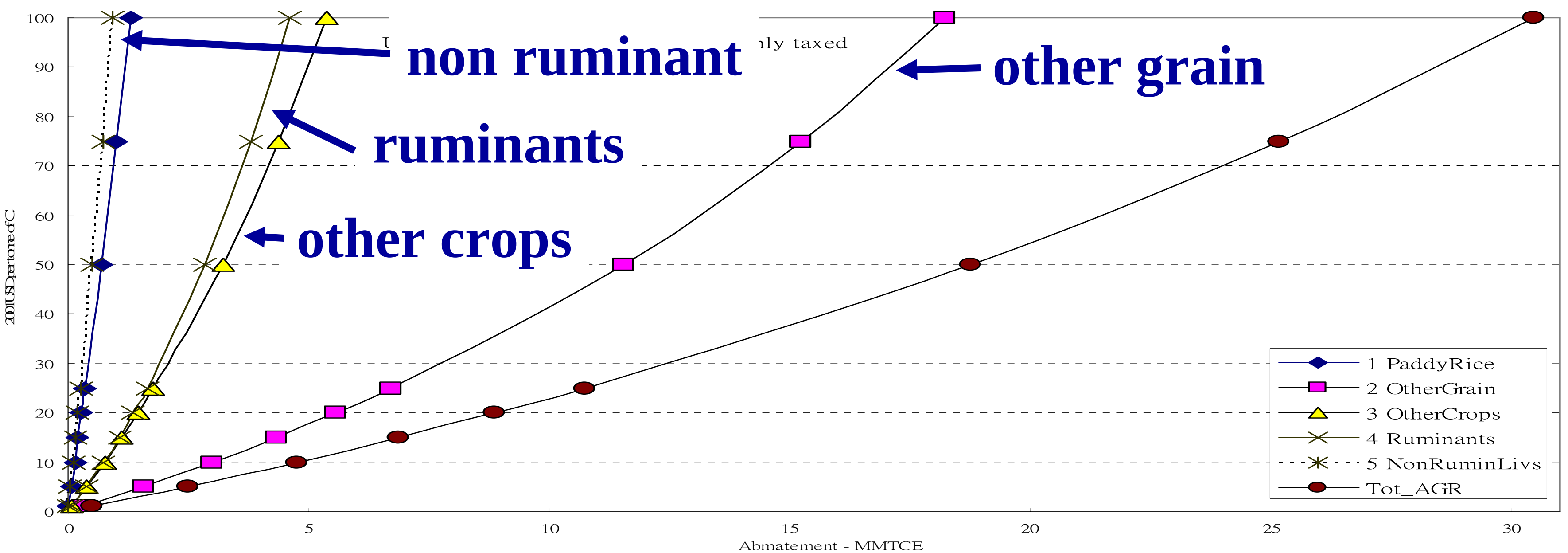
Analysis of mitigation responses

1. Intra- and inter-regional GE effects:
   A. USA carbon tax
   B. ROW carbon tax
   C. Global carbon tax

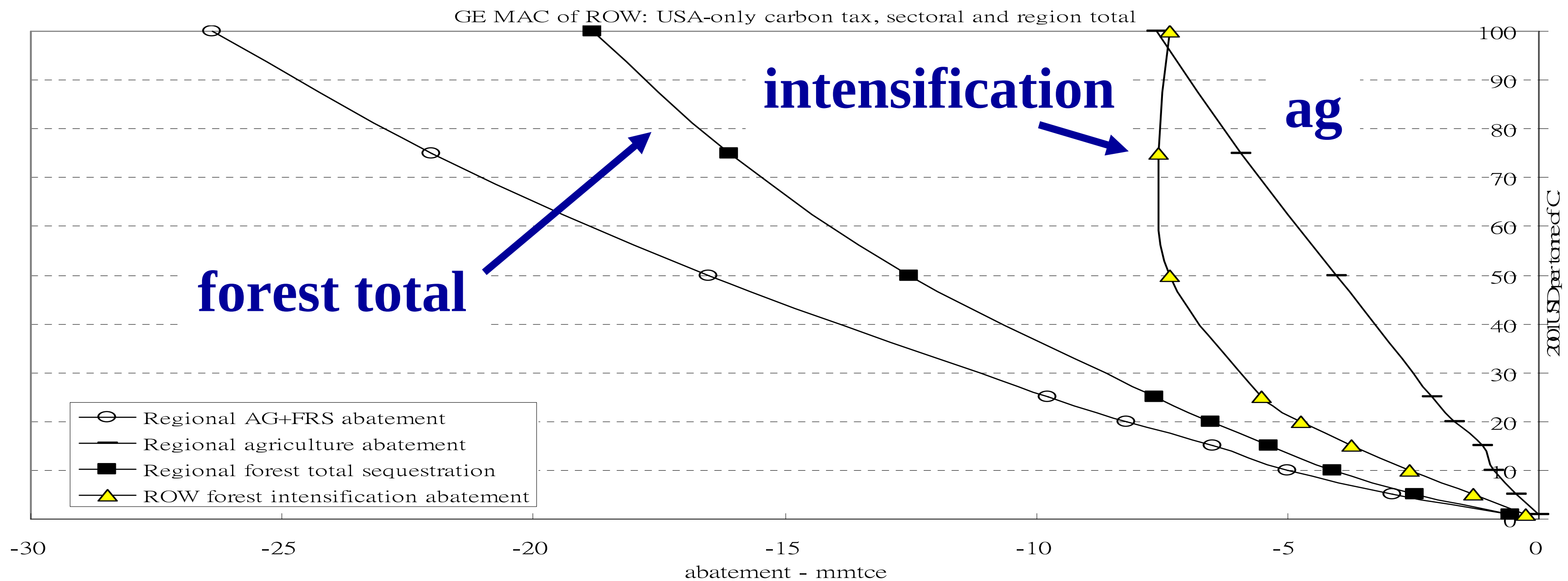
2. Individual carbon tax decomposition: GE with global carbon tax

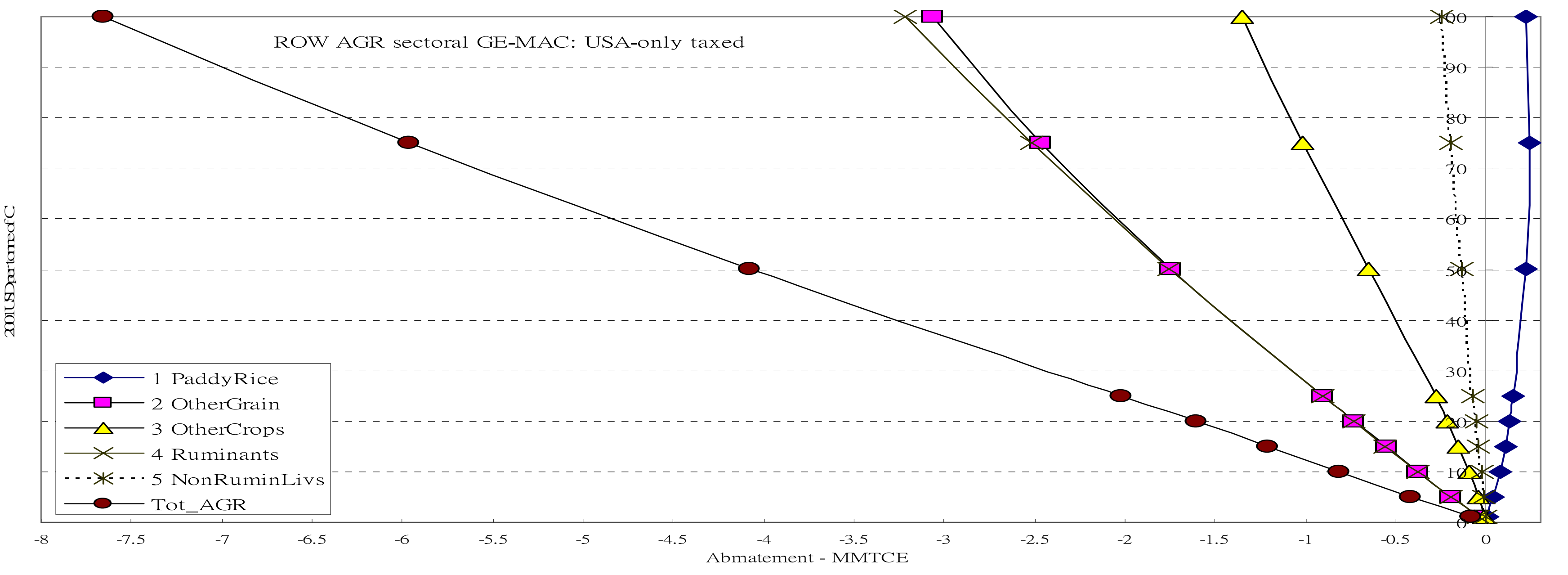
USA sectoral mitigation w/ US carbon tax



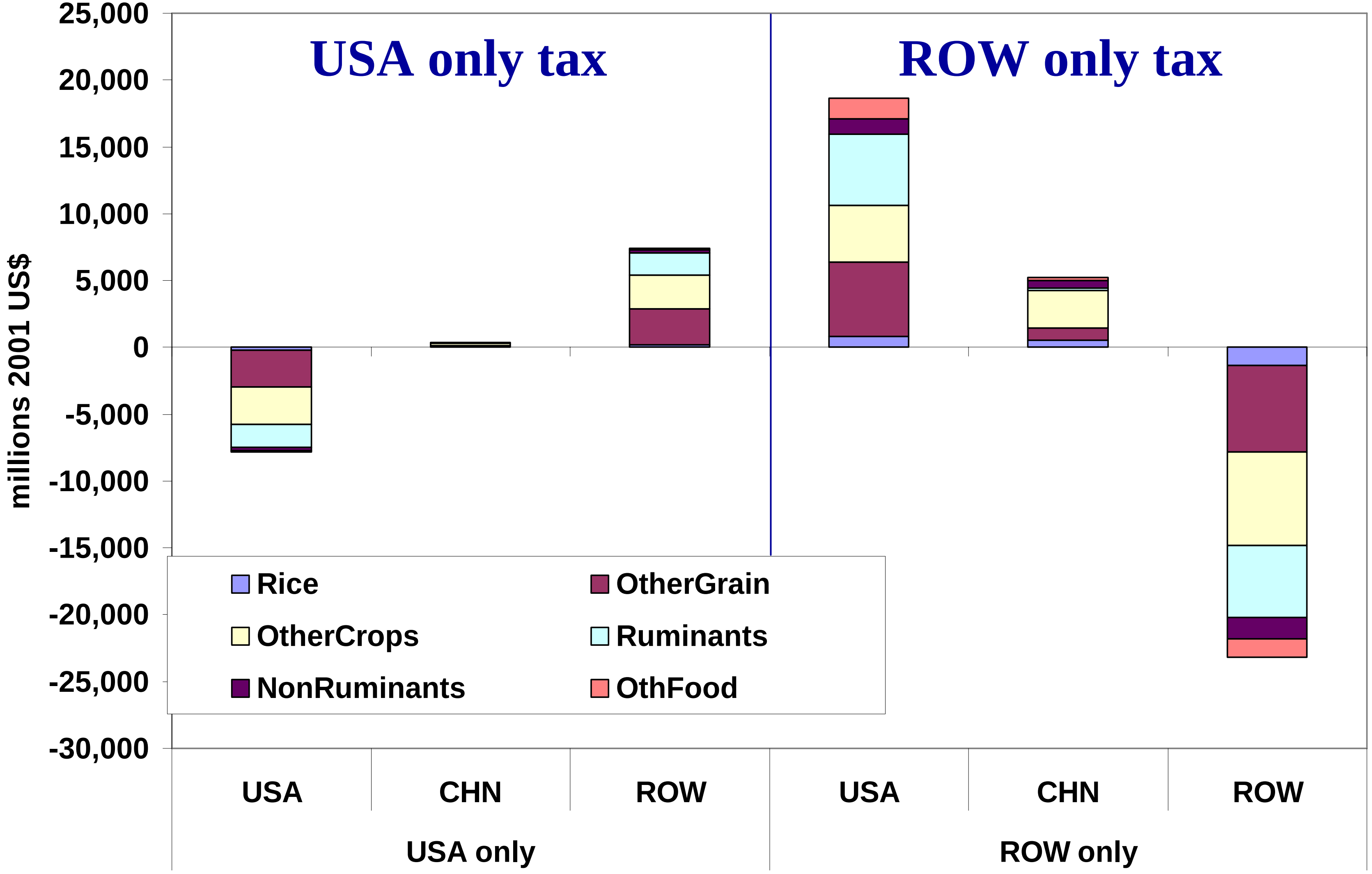


ROW sectoral mitigation w/ US carbon tax

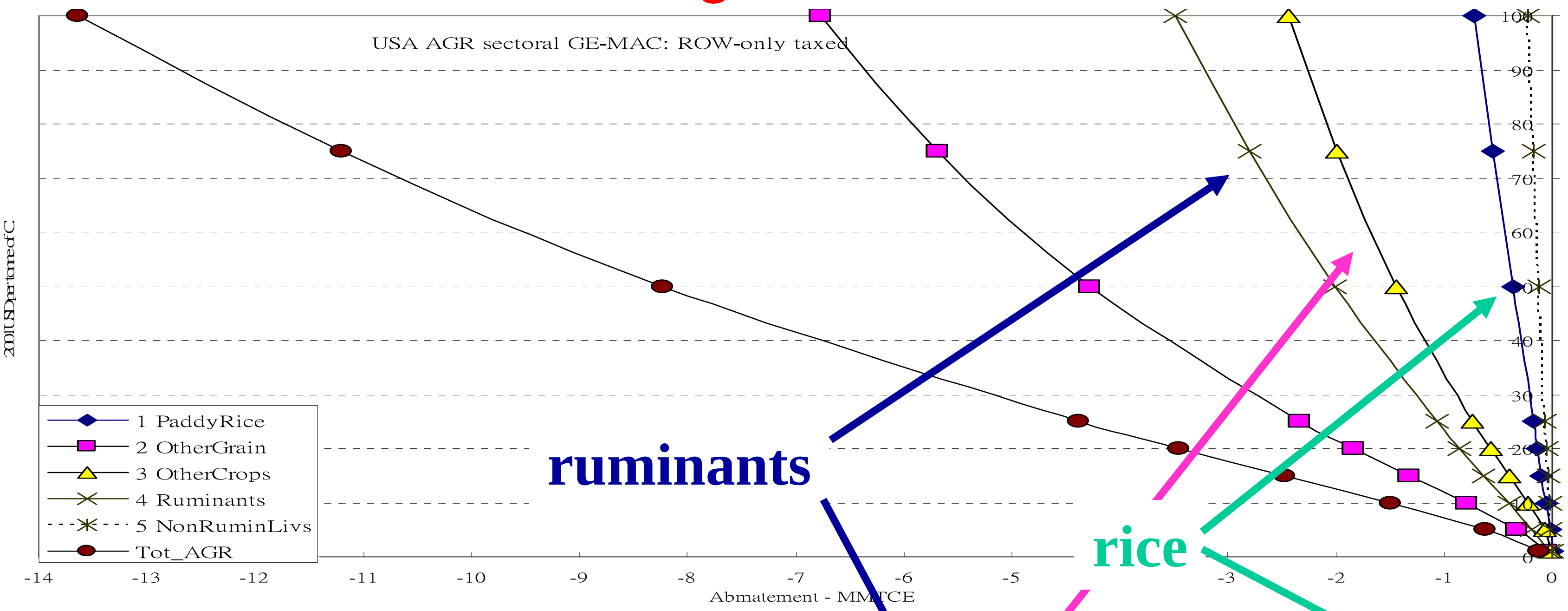




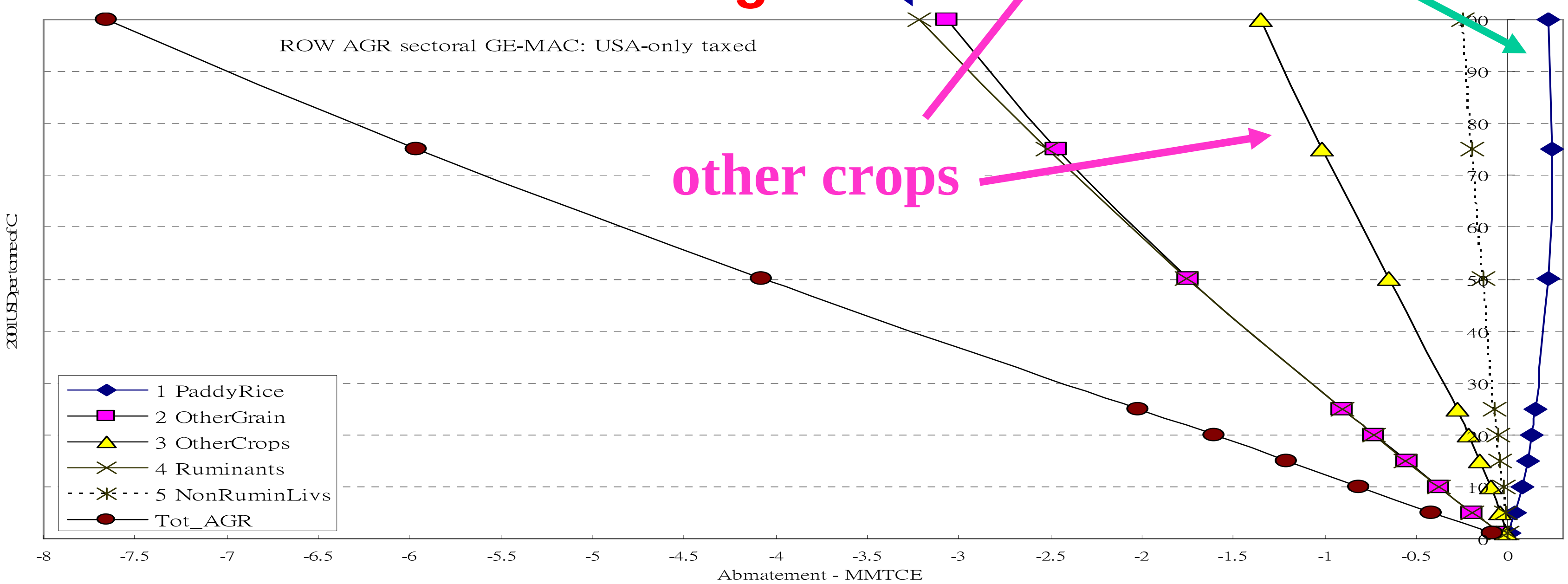
Change in regional agricultural trade balances due to unilateral carbon tax: $100/t



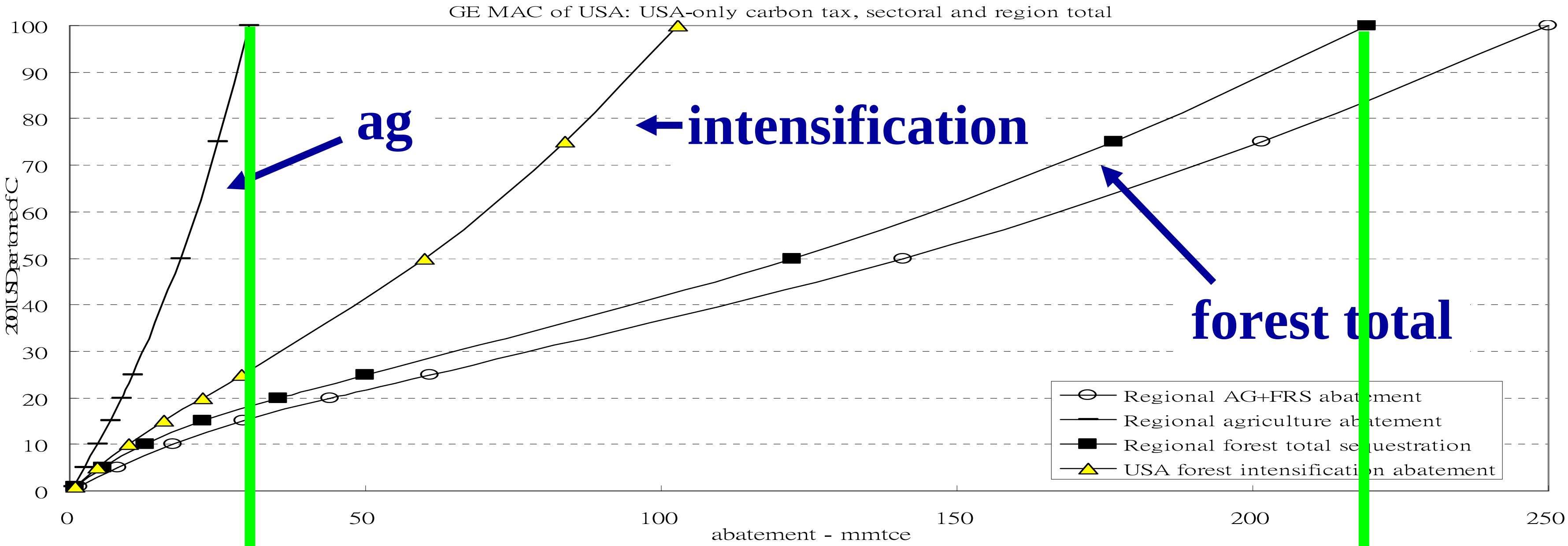
USA sectoral mitigation w/ ROW carbon tax



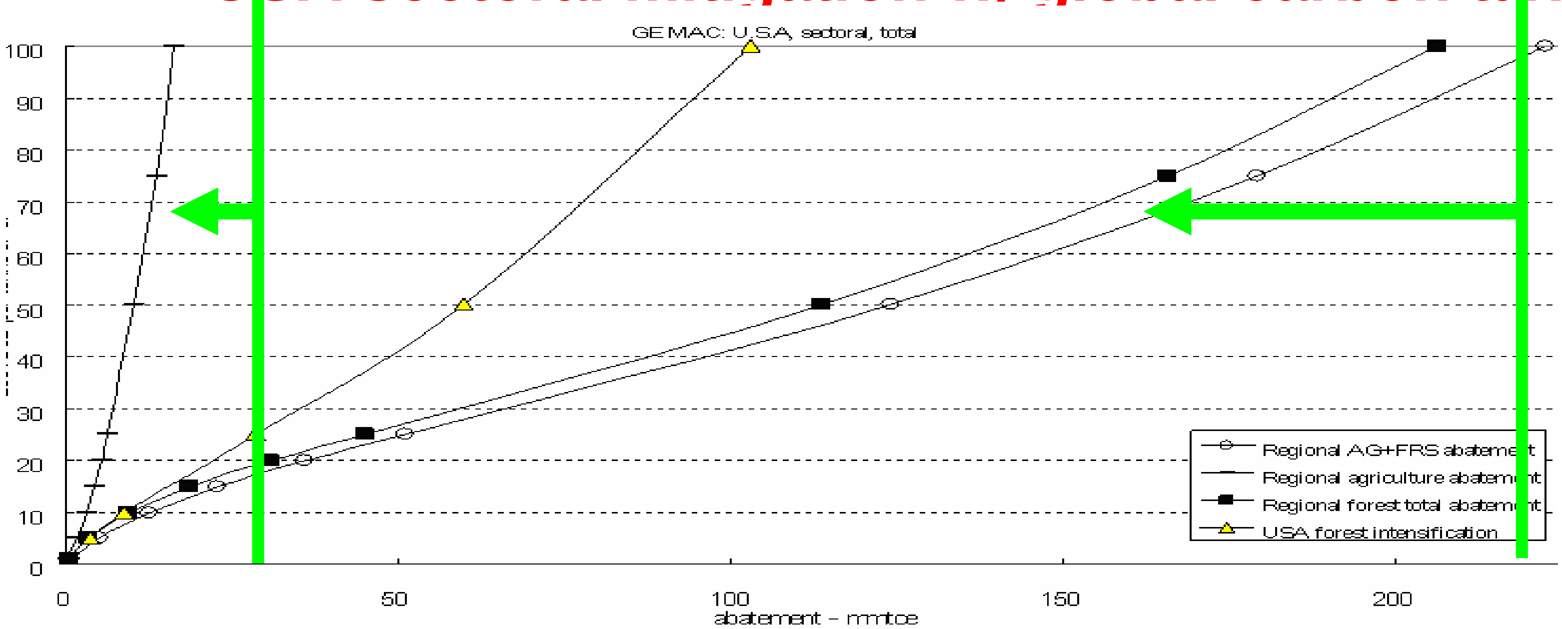
ROW sectoral mitigation w/ US carbon tax



USA sectoral mitigation w/ US carbon tax



USA sectoral mitigation w/ global carbon tax



Mitigation affects intra-regional land competition

Percentage change in USA land rents and land use by sector following a $100/tonne USA carbon tax

	Percentage change in land rents				
	Forest	Paddy Rice	Other Grain	Other Crops	Ruminants
AEZ1	1225.7	-21.39	10.13	14.08	17.59
AEZ2	1224.09	-19.4	9.93	13.88	17.38
AEZ3	1223.97	-19.18	9.91	13.86	17.36
AEZ4	1225.44	-20.85	10.07	14.02	17.53
AEZ5	1228.88	-25.59	10.41	14.36	17.91
AEZ6	1235.81	-38.88	11.19	15.16	18.71

	Percentage change in land use, weighted by AEZ land rent share				
	Forest	Paddy Rice	Other Grain	Other Crops	Ruminants
AEZ1	2.23	-0.06	-0.98	-0.32	-0.84
AEZ2	0.1	-0.04	-0.79	0.31	0.42
AEZ3	0.11	-0.09	-0.77	0.54	0.21
AEZ4	2.38	-0.05	-1.85	-0.39	-0.05
AEZ5	6.96	-0.73	-3.95	-1.57	-0.42
AEZ6	12.61	-1.05	-3.05	-7.22	-0.37

1. For a given use, similar land rent responses across AEZs
2. Changes in land rents reflect the net effect of mitigation costs and land competition (i.e., changes in land prices and changes in acreage) – mitigation cost/subsidy dominates in rice and forestry, land competition dominates in other ag sectors
3. How carbon price applied matters—taxing land (rice) vs. taxing non-land inputs (other grain)
4. Land reallocation occurring – within and across sectors!

The role of individual carbon taxes in global responses ($100/tC global tax)

Type/region of taxation		Emissions/sequestration change from region (%) USA	CHN	ROW
Output related emissions	**USA**	-0.01	0	0
	CHN	0	0	0
	ROW	0.03	0.01	-0.02
Purchased input related emissions	**USA**	-8.27	0.08	0.61
	CHN	0.28	-4.26	0.32
	ROW	1.73	0.27	-2.54
Primary factor related emissions	**USA**	-1.98	0.01	0.19
	CHN	-0.04	-12.88	-0.04
	ROW	0.79	0.15	-7.41
Forest sequestration	**USA**	-75.37	0.04	0.6
	CHN	0.09	-42.96	0.18
	ROW	6.27	0.9	-131.58
Total Impact		-76.48	-58.63	-139.69

-24 vs. 11 MtCeq

-2438 vs. 18 MtCeq

1. Comparative mitigation advantages evident (via carbon intensities and input prices – e.g., ruminant intensities 0.9562 for China and 0.0099 for USA)
   - Unique regional responses to an identical tax
   - Unique regional mitigation portfolios (in levels in particular)
2. Leakage associated with most individual taxes

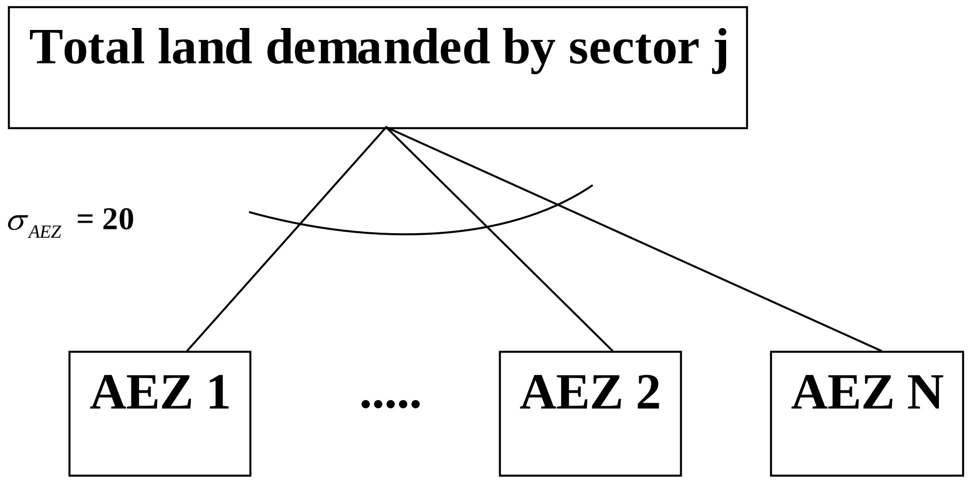
Conclusions

- Biophysical and economic land characteristics create comparative abatement advantages for land endowments

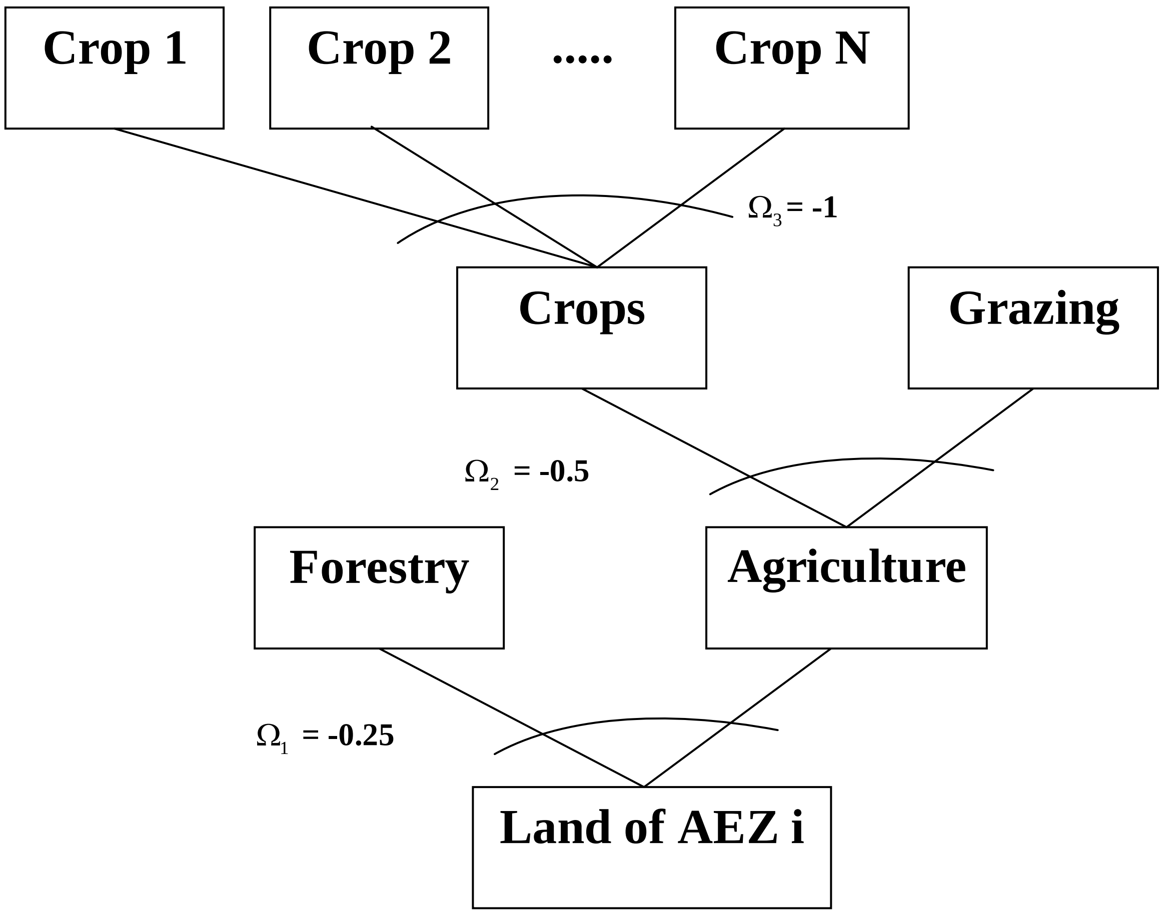
  → intra- and inter-regional land reallocations
- International market structure influences regional mitigation responses
- International leakage is an important component of total GHG emissions
- Global GE feedbacks can increase the profitability of production despite increasing emissions subject to a carbon tax

Extra slides

Land demand



Land supply



Crop 1
Crop 2
.....
Crop N
Ω3 = -1
Crops
Grazing
Ω2 = -0.5
Forestry
Agriculture
Ω1 = -0.25
Land of AEZ i

Emissions/sequestration pricing

- The economic impact of an emissions tax associated with input usage depends on <u>the size of the tax AND the emissions intensity of the input</u>.

- The larger the emissions intensity, the greater the impact of a given carbon tax on the sector/input in question.

  - **Equation** CHNGETAXFD

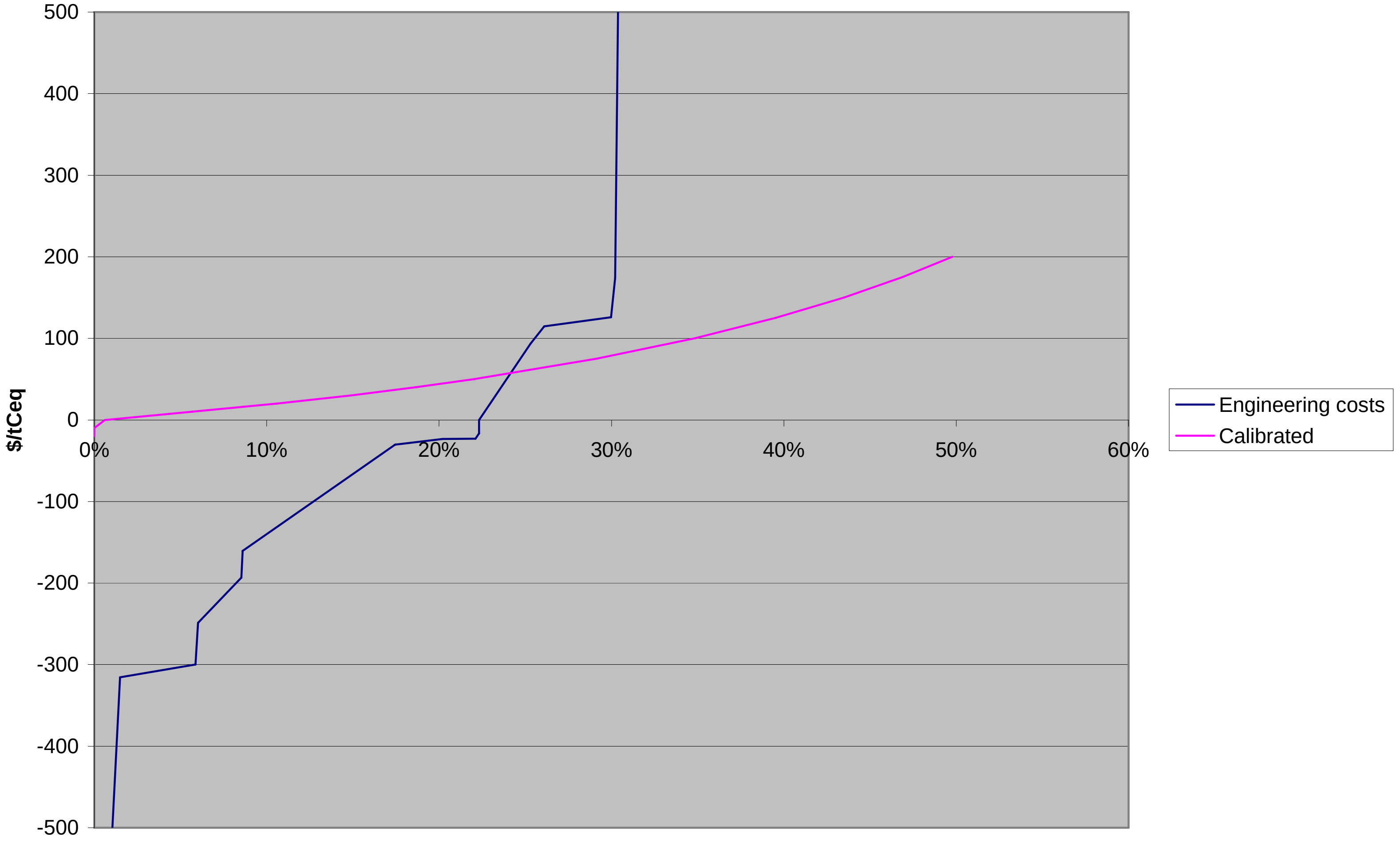
    (**all**,i,TRAD_COMM)(**all**,j,PROD_COMM)(**all**,r,REG)
    del_TFD_L(i,j,r) = del_TFDO_L(i,j,r) +
    [UNITDEMIT(i,j,r)/PM_L(i,r)] *
    [c_TAUIEMIT(i,j,r) - (PM_L(i,r)*AVEDTAUI(i,j,r)/100) * pm(i,r)**]**;

    Emissions intensity

  - **Formula** (**all**,i,TRAD_COMM)(**all**,j,PROD_COMM)(**all**,r,REG)
    UNITDEMIT(i,j,r) = QFDEMIT(i,j,r)/QFD_L(i,j,r) ;

	Emission intensities (MtC/$ of input)			Forest carbon intensities (MtC/$ of land rent)		
Input	USA	China	ROW	USA	China	ROW
Fertilizer in crops production	0.0062	0.0044	0.0044	0.057	0.016	0.148
Ruminant livestock capital	0.0099	0.9562	0.0154			
Land in paddy rice	0.0040	0.0125	0.0049			

Calibration example – USA cropland



Modeling forest carbon