The Role of Land Use in Determining Greenhouse Gases Mitigation Costs

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Motivation

- **Land is a significant source of GHG emissions**
  - **Deforestation: 1/3 of total emissions since 1850**
  - **Land management: 75% of N_2O, 50% of CH_4**
- **Previous studies suggest land-based mitigation is cost-effective**
  - **e.g., Sohngen and Mendelsohn (2003), Rao and Riahi (in press), van Vuuren et al. (in press)**
- **Analytical challenges for land modeling**
  - **Competition for land between land-based sectors**
  - **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**

➔ Provide opportunities for improving our understanding of the role of land in determining GHG mitigation costs.

Objective:

To analyze the impact of GHG mitigation on land use change in general equilibrium framework

Outline of this presentation:

- **Land, GHG emissions/sequestration data**
- **Land supply and demand and land-based emissions modeling in GTAP**
- **Analysis set-up**
- **Results**
- **Conclusions**

GTAP AEZ Land Use Data

- Our work builds on path-breaking work by Darwin et al. at ERS/USDA, by adding:
  - More refined definition of AEZs
  - Climate dimension—tropical, temperate, boreal
  - Implementation at the 226-country level
  - Documented in Lee et al. (2005) and available on the GTAP website

Definition of AEZs in GTAP

- 18 AEZs = 6 LGPs x 3 climatic zones
  - 6 LGPs = 0–59, 60–119, 120–179,…., 300–365 days
  - 3 climatic zones = boreal, temperate, tropical
- Follows pioneering work by FAO and IIASA in definition of an AEZ as
  - land with given "length of growing period" (LGP), as determined by: temperature, precipitation, soil condition and topography, combined with information from a water balance model and knowledge of physical requirements for growing certain crop.
- Lands classified in same AEZ have homogeneous units within the country—i.e., with similar climate and soil conditions for crop growing.

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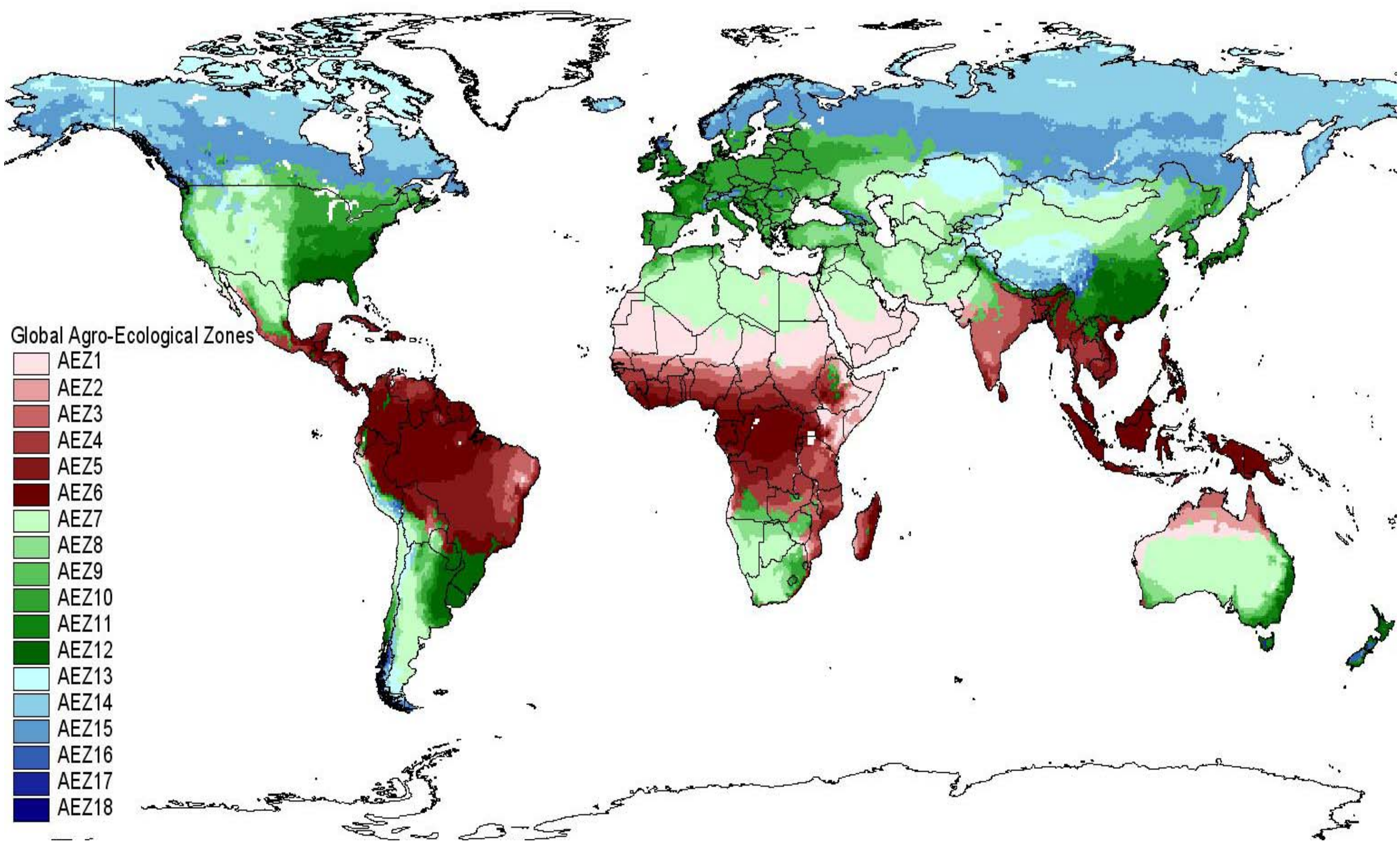
Global Distribution of AEZs



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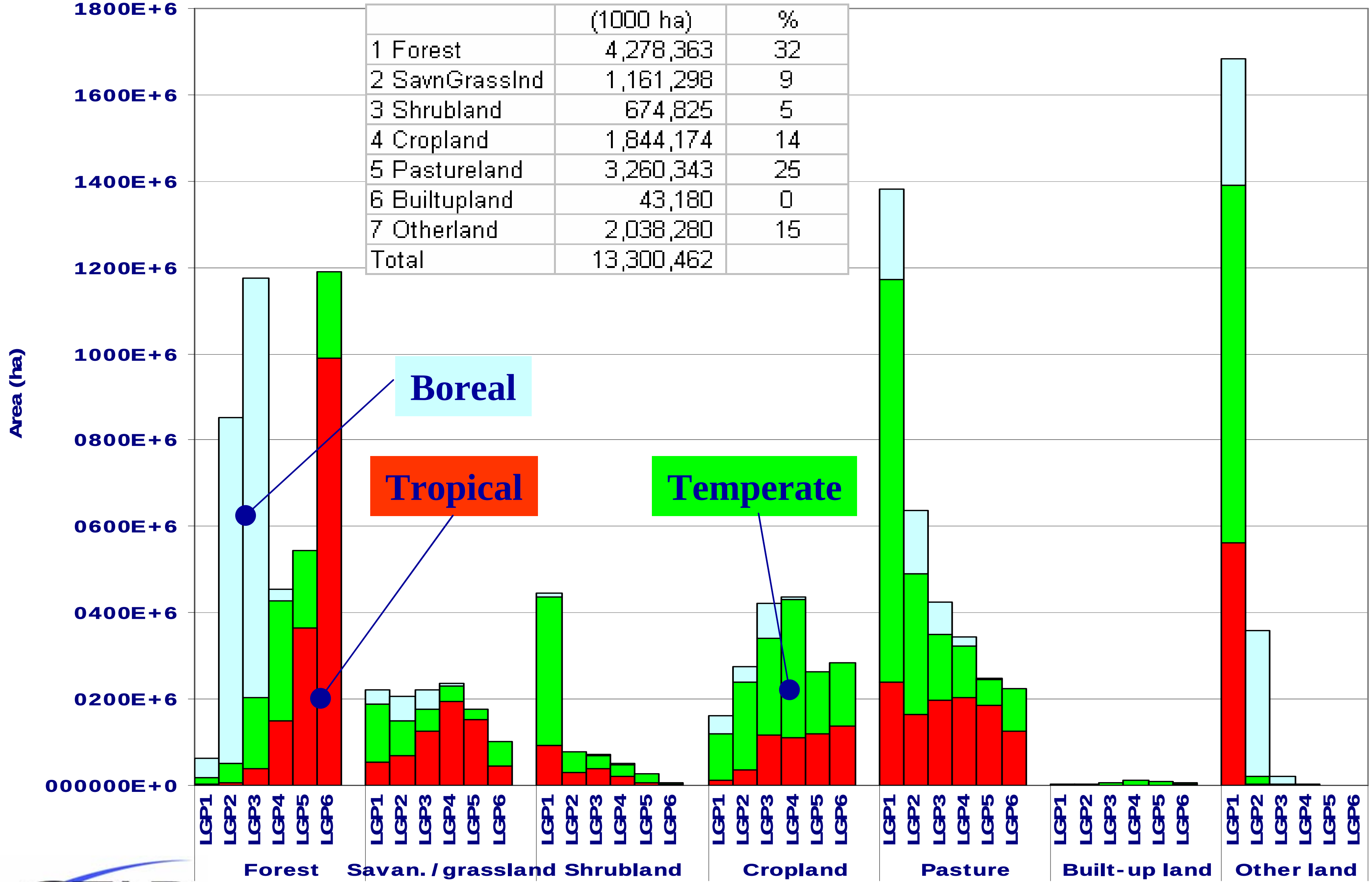
Global Land Cover: distribution



	(1000 ha)	%
1 Forest	4,278,363	32
2 SavnGrassInd	1,161,298	9
3 Shrubland	674,825	5
4 Cropland	1,844,174	14
5 Pastureland	3,260,343	25
6 Builtupland	43,180	0
7 Otherland	2,038,280	15
Total	13,300,462	

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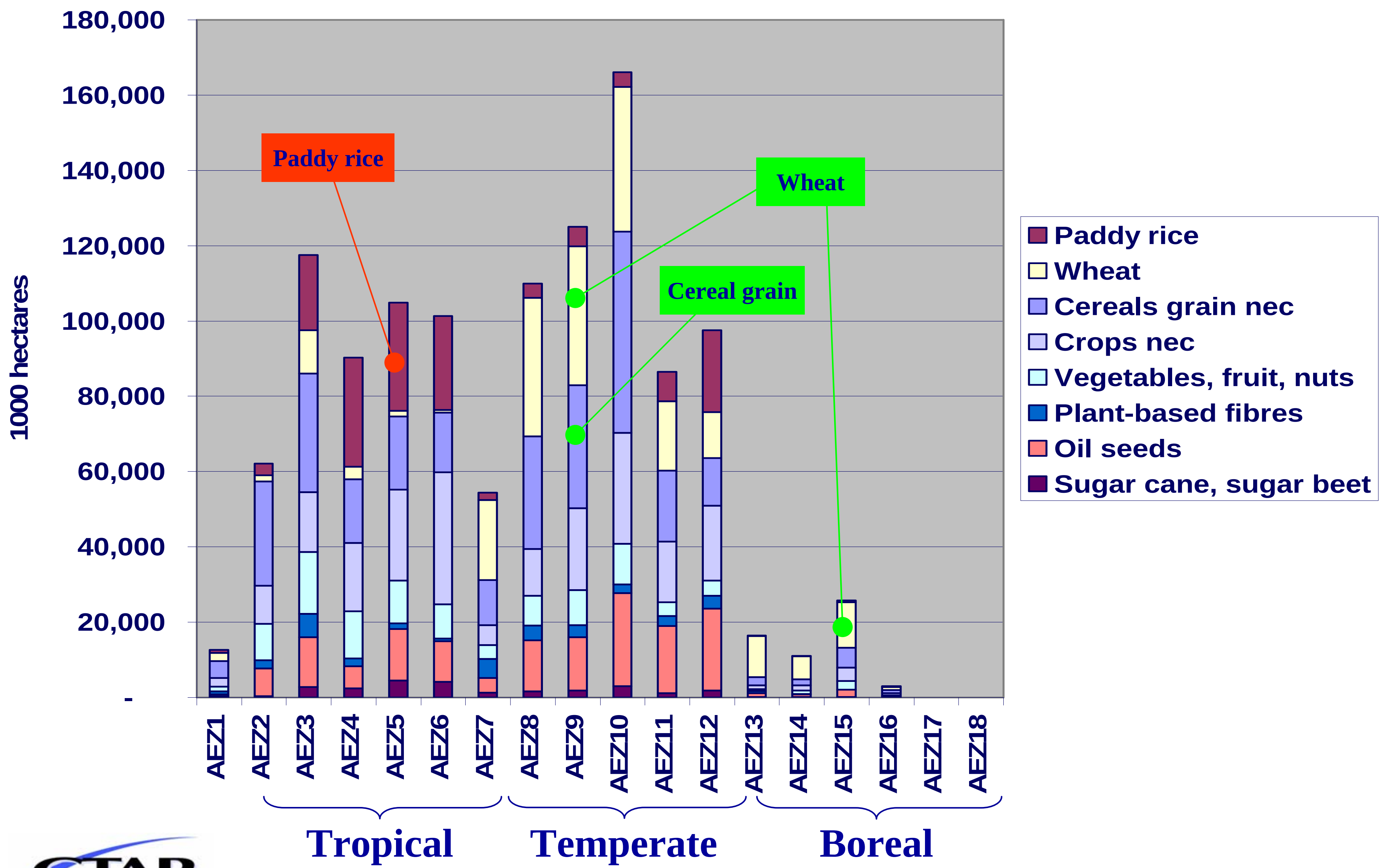
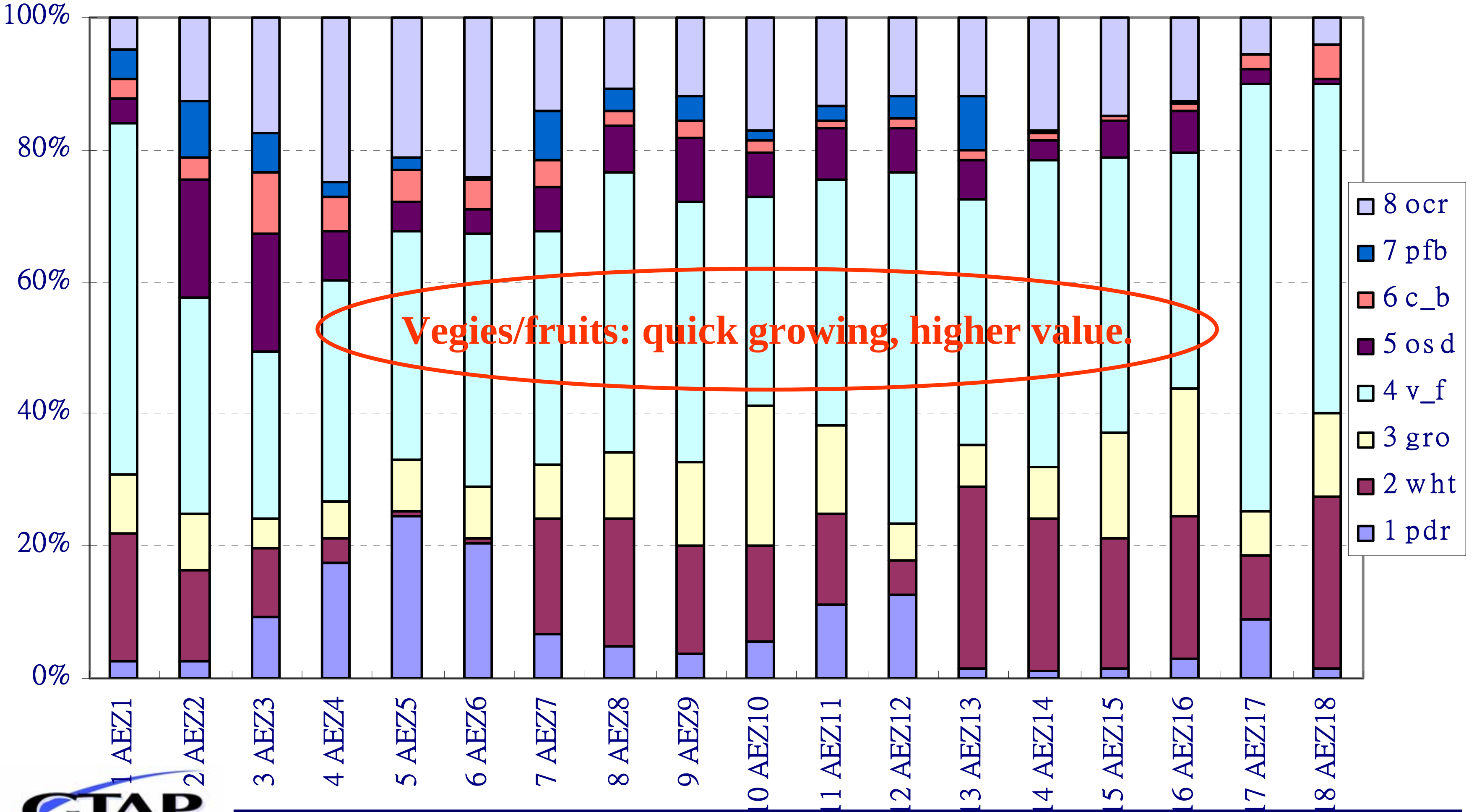
Cropland Hectares by AEZ and crop



Distribution of Crop Land Rents, within AEZs



Non-CO2 emissions & forest sequest’n data

- New 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
    - 21 non-CO2 GHG emissions categories (N2O, CH4, F-gases)
      - ~145 types of emissions with subcategory disaggregation
- Regional 2000 forest carbon stock data by AEZ, management type, and tree age cohort
- Soil carbon stock data and Other CO2 (non-fossil fuel combustion) emissions data also available (but yet implemented in the model)

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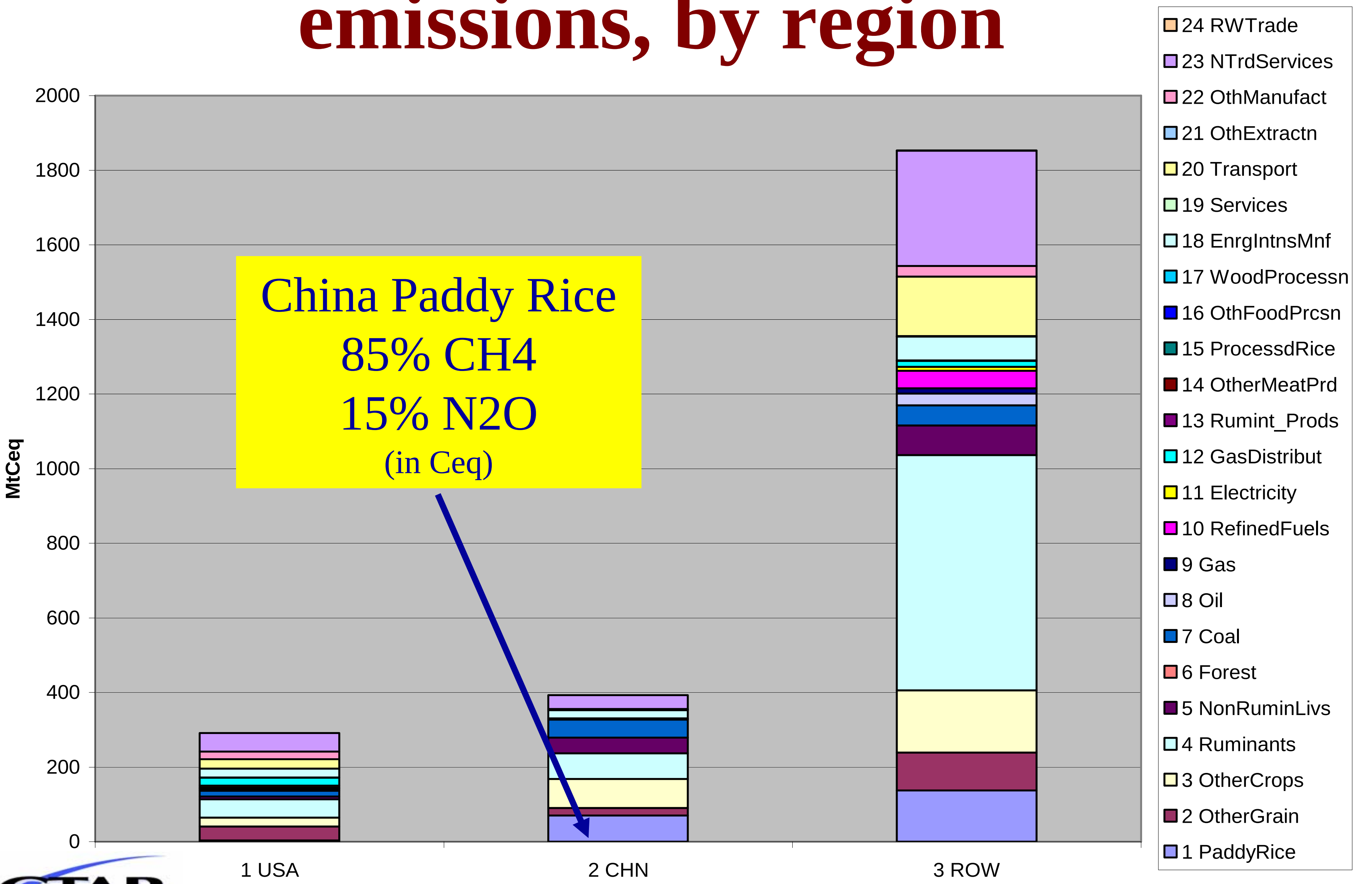
Sectoral distribution of non-CO2 emissions, by region



The GTAP-AEZ model

- Static global CGE
- 3 Regions (for now): USA, China, ROW
- 24 Sectors – 5 land-based sectors (3 crops, ruminant livestock, forestry)
- Key features:
  - Land in 6 AEZs: aggregated from the 18 AEZs
  - 3-tier CET structure of AEZ-specific land supply
- GHG emissions and sequestration modelling
  - Incorporate new detailed non-CO2 GHG emissions data (N2O, CH4, F-gases) and forest carbon sequestration data
  - 3 classifications of emissions – output, intermediate inputs, primary factor related emissions
  - Introduce emissions pricing
  - Calibrate mitigation responses

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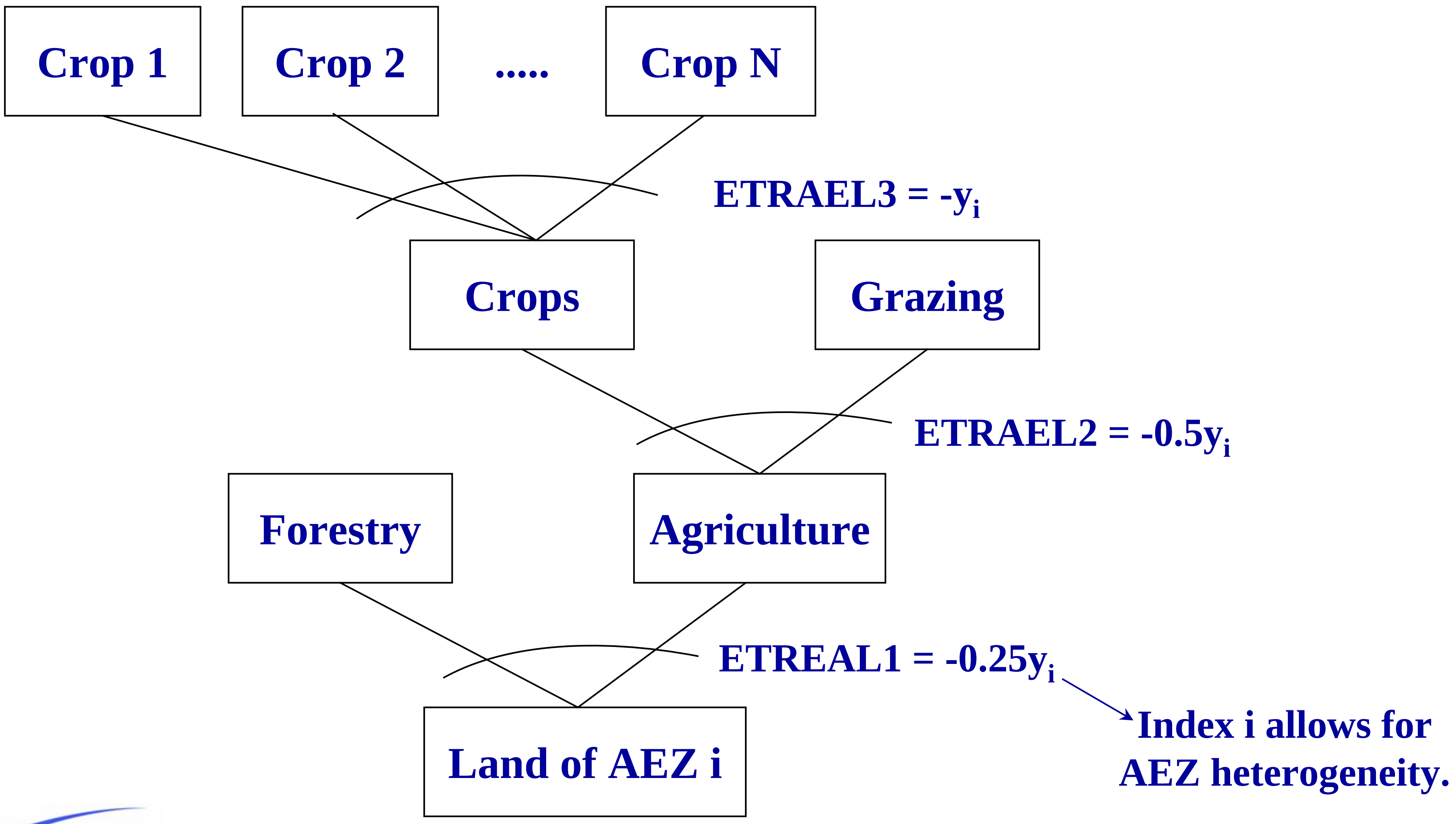
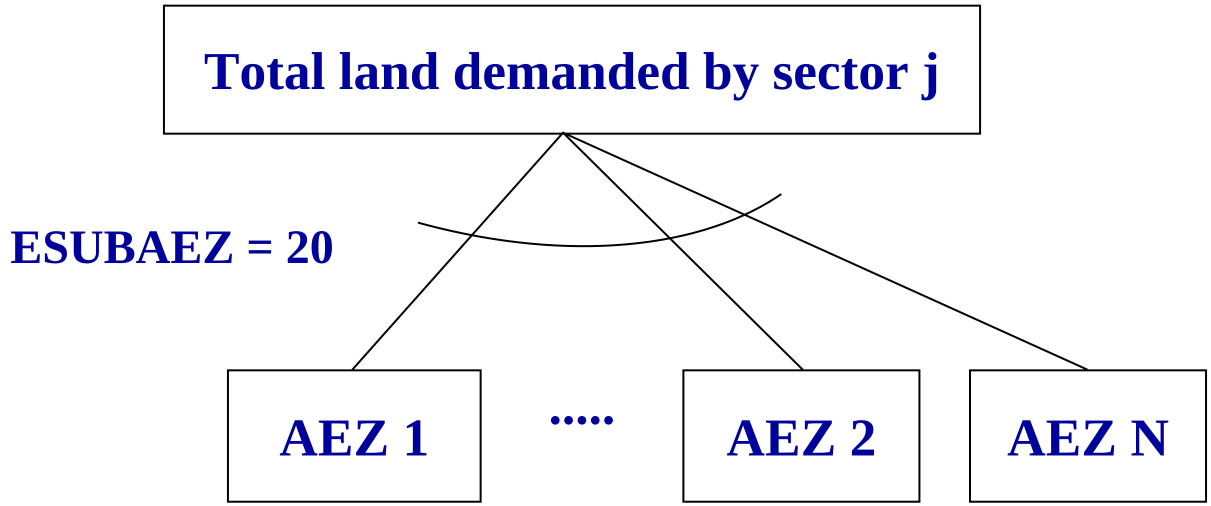
Land supply in GTAP

- Standard, yet counterfactual
  - 1 type of ag. land, imperfect mobility across uses
- Now: Agro-ecologically zoned land
  - Heterogeneous in terms of rainfall, temperature, topography, soil type and moisture, etc.
  - length of growing period (LGP) varies
  - Suitability for growing of certain crops
  - Restricting land mobility across uses

3-tier CET structure for AEZ-specific land supply



Sector-specific CES structure for AEZ land demand



- Big enough ESUBAEZ ensures returns to AEZ lands to move closely together
- A good approximate of an alternative specification where:
  - one prod. function for each AEZ in each activity
  - AEZ-specific comm. are perfect substitutes
  - Similar production function for AEZ-specific activity
  - Each AEZ-specific sector faces same input/factor prices.

The GTAP-AEZ model

- Static global CGE
- 3 Regions (for now): USA, China, ROW
- 24 Sectors – 5 land-based sectors (3 crops, ruminant livestock, forestry)
- Production with intra- and inter-regional land heterogeneity
  - Land in 6 AEZs: aggregated from the 18 AEZs
  - CET – 6 different AEZ land endowments
- GHG emissions and sequestration modelling
  - Incorporate new detailed non-CO2 GHG emissions data (N2O, CH4, F-gases) and forest carbon sequestration data
  - 3 classifications of emissions – output, intermediate inputs, primary factor related emissions
  - Introduce emissions pricing
  - Calibrate mitigation responses

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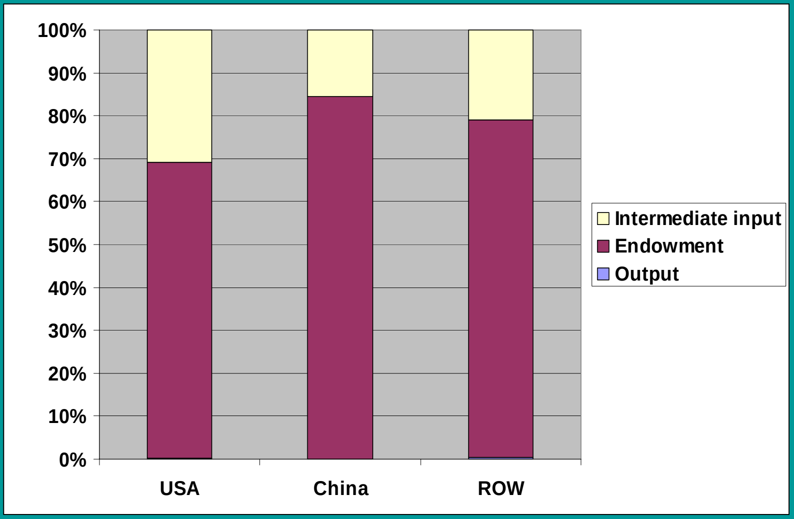
Modeling emissions
- 3 categories -

- Output – **emissions treated as an input to production, represents alternative technologies, introduce new CES elasticity**
  - **Follows Hyman et al. (2003)**
  - **e.g., coal, oil, energy intensive manufacturing**
- **Input – emissions proportional to input use**
  - Endowment **– e.g, ruminant : capital stock (animal herd)**
  - Intermediate input **– e.g., grain crop : fertilizer use**

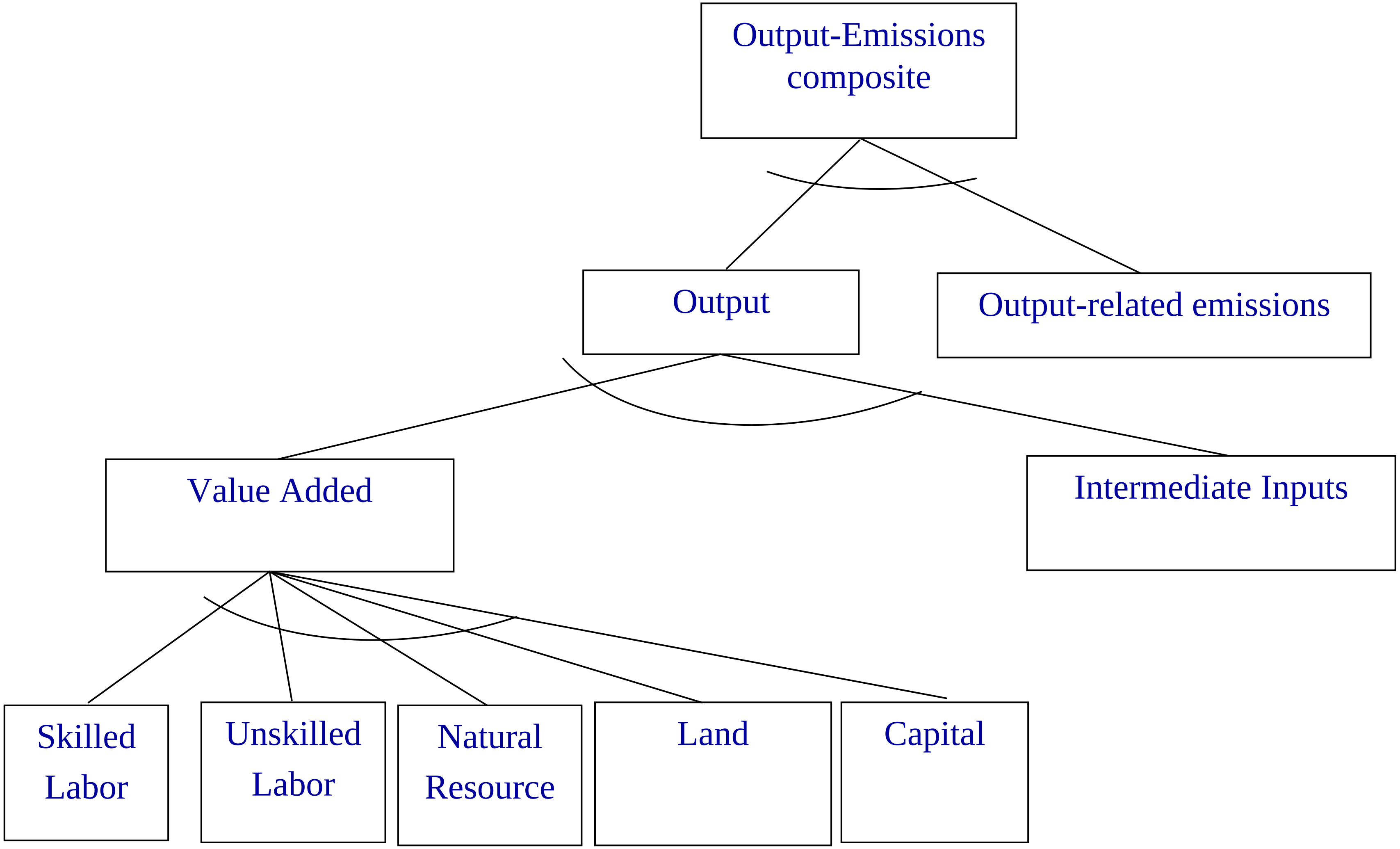
Total non-CO2 GHG emissions (MtCeq)

	USA	China	ROW
1 PaddyRice	2.971	70.160	137.364

Paddy Rice



Prod. structure: output related emissions incl.



Emissions pricing

- **The economic impact of an emissions tax associated with input usage depends on <u>the size of the tax AND the emissions intensity (tC/$) of the input</u>.**
- **The larger the emissions intensity, the greater the impact of a given carbon tax on the sector's input use and production.**

Emission intensities (tC/$ of input)

Input	USA	China
Fertilizer in crops production	0.0061	0.0043
Ruminant livestock capital	0.0099	0.9562
Land in paddy rice	0.0040	0.0125

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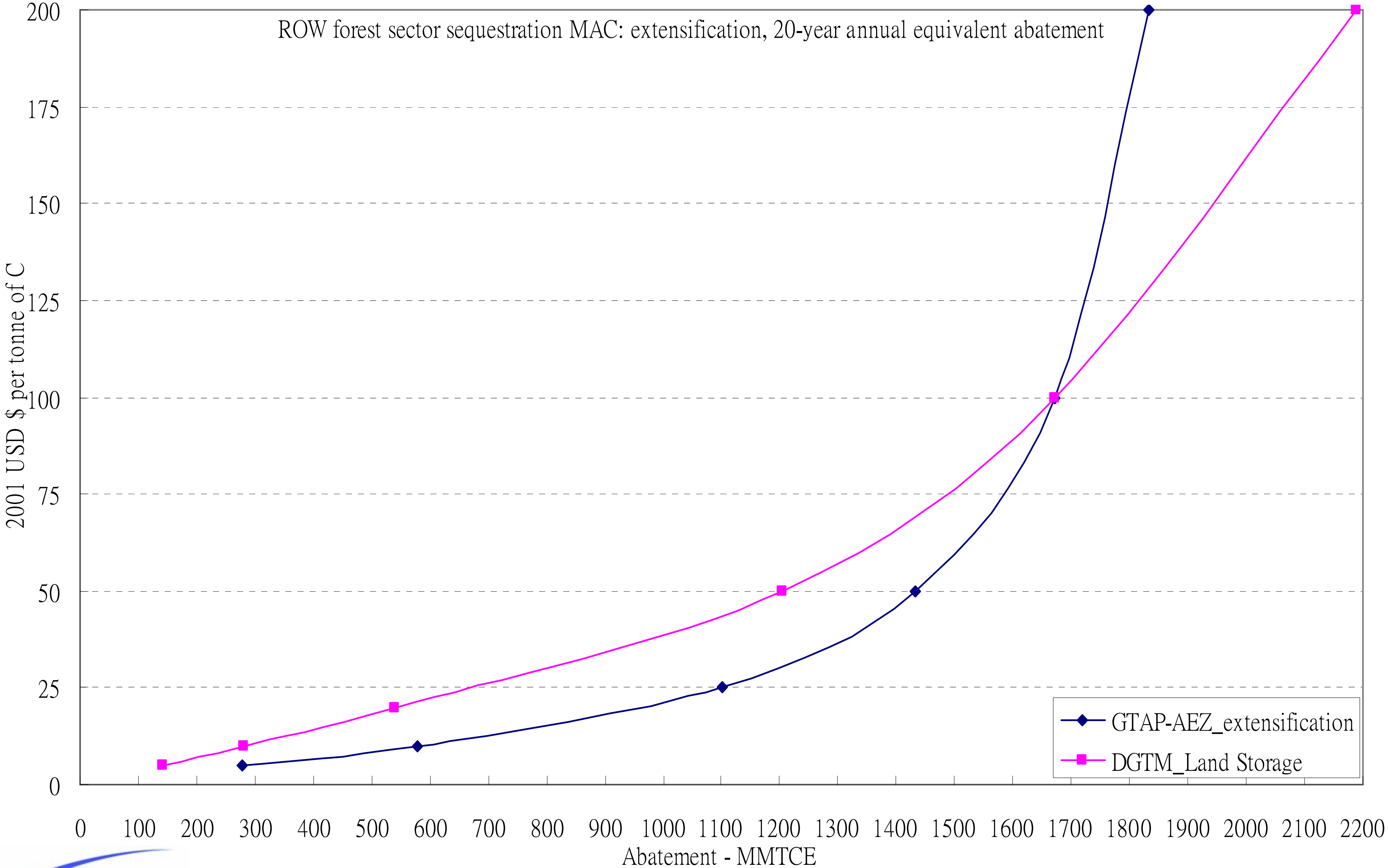
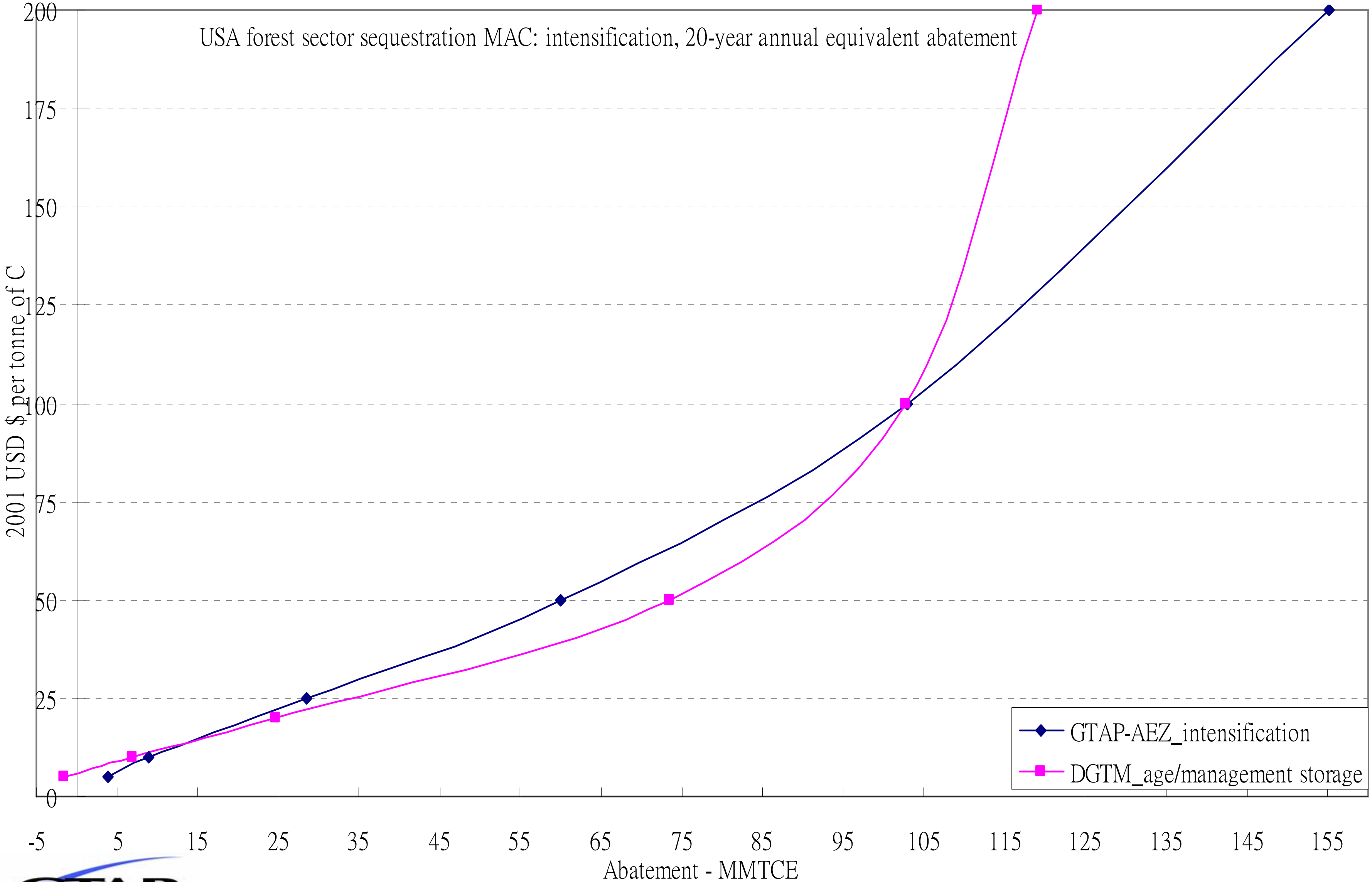
Calibrating mitigation responses

- Non-CO2 mitigation
  - Engineering mitigation cost estimates for detailed technologies (Delhotal and Kruger, in press; USEPA, 2006)
  - Calibrate substitution elasticities with partial equilibrium closure
    - Output emissions – ESUBMAC
    - Endowment emissions – ESUBT
    - Intermediate input emissions – ESUBVA
- Forest sequestration supply
  - Calibrated to regional forest carbon supply curves Sohngen (2005) – afforestation (extensification) and forest management (intensification)
  - Calibrated to forest carbon intensities due to presence of unmanaged land in the base year data

Calibrated ROW forest carbon sequestration curve via extensification (20-year annual equivalent abatement)



Calibrated USA forest carbon sequestration curve via intensification (20-year annual equivalent abatement)



Analysis of mitigation responses

1. **GE global competition: USA-only vs. global carbon tax**
2. **GE inter-sector competition: USA-only v.s. global carbon tax**

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Mitigation affects regional land competition

GE % change in land rents and land use by sector due to a $50/tonne carbon tax: USA only

Percentage change in land rents

	Forest	PaddyRice	OtherGrain	Other Crops	Ruminants
AEZ1	253.5	-15.9	2	3.3	5.1
AEZ2	254.3	-15.3	1.9	3.2	5.1
AEZ3	236.9	-15.5	1.9	3.2	5.1
AEZ4	267.5	-15.5	2	3.2	5.1
AEZ5	295.2	-16.5	2	3.3	5.2
AEZ6	320.2	-20.2	2.3	3.6	5.4

Percentage change in land use, weighted by AEZ land rent share

	Forest	PaddyRice	OtherGrain	Other Crops	Ruminants
AEZ1	0.286	-0.023	-0.211	-0.05	0
AEZ2	0.013	-0.017	-0.226	0.068	0.162
AEZ3	0.009	-0.029	-0.131	0.098	0.053
AEZ4	0.427	-0.026	-0.431	-0.003	0.034
AEZ5	2.134	-0.412	-1.215	-0.391	-0.084
AEZ6	5.604	-0.626	-1.366	-3.242	-0.153

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**

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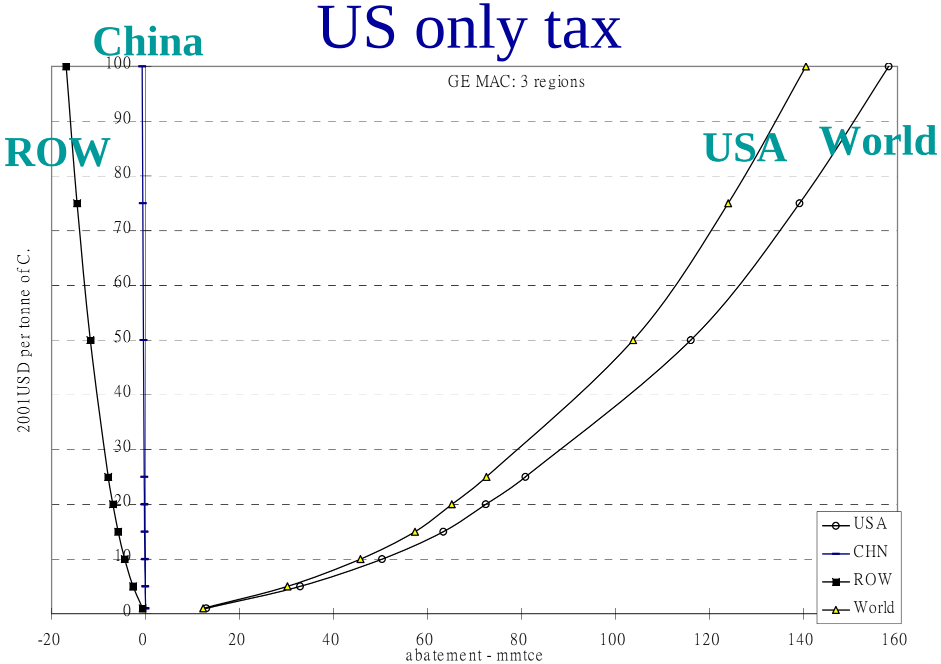
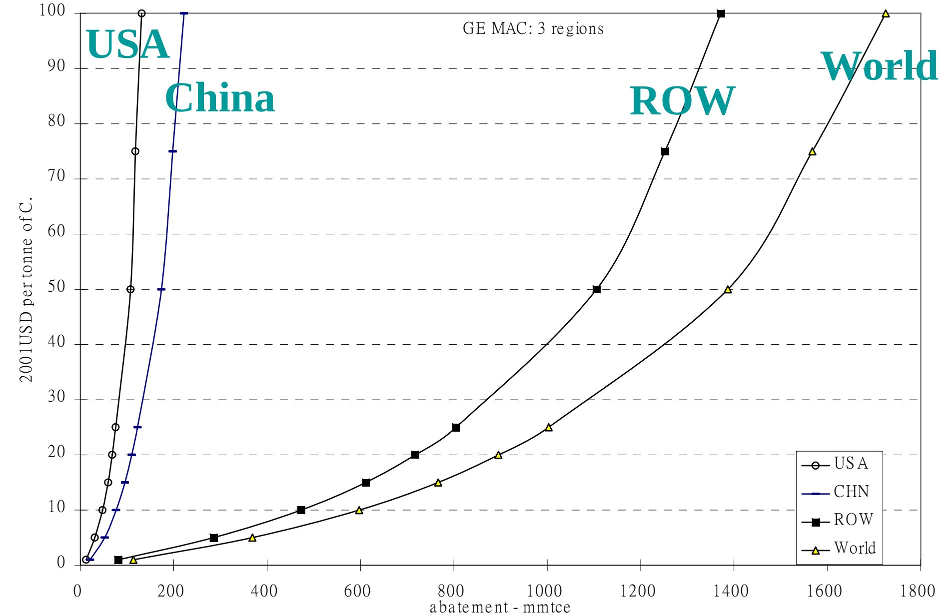
Mitigation affects global competition - Regional

US only tax

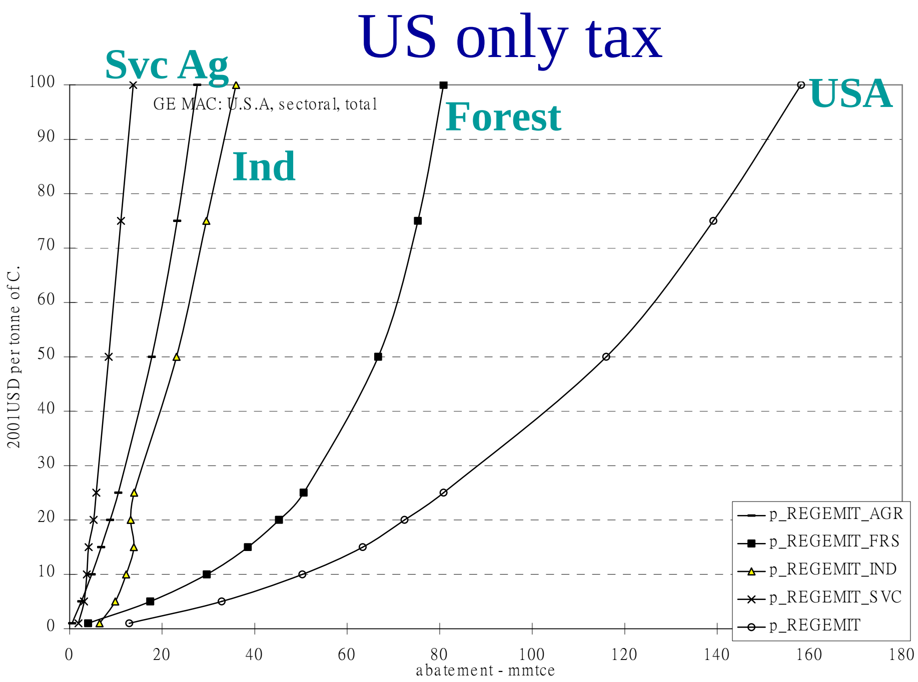


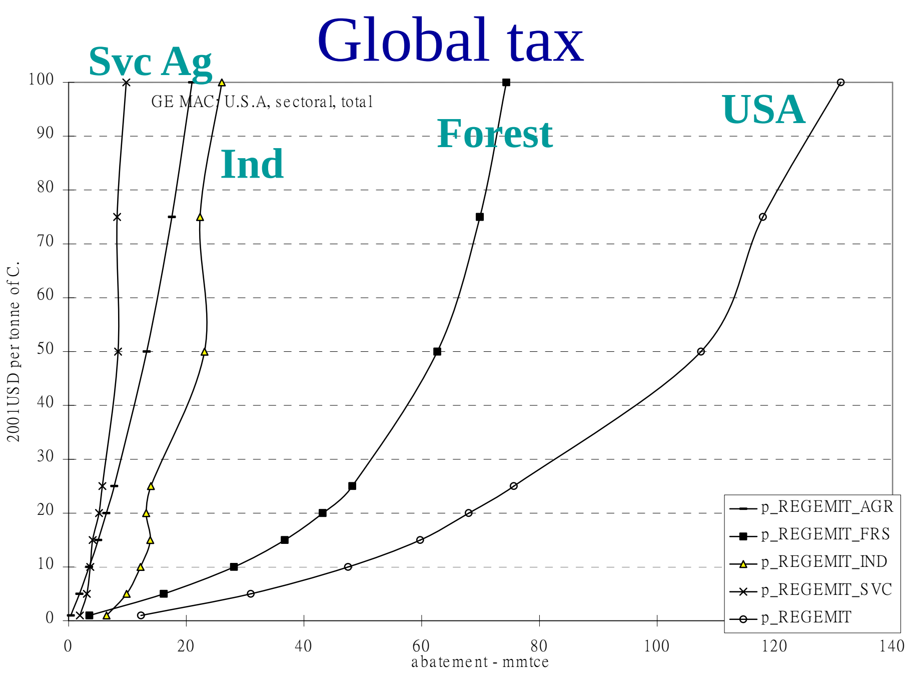
Global tax



1. **USA only carbon tax – USA less competitive, international emissions leakage (primarily deforestation)**
2. **Vs. global carbon tax – all regions with net reductions, global emissions reductions large, ROW mitigation least expensive (primarily forest carbon increases), USA mitigation most expensive.**

Mitigation affects global competition – sectors





Global vs. US tax – US mitigation responses diminished in all sectors.

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Conclusions

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

  ➔ intra- and inter-regional reallocation of production, and thus land use change.
- International market structure influences regional mitigation responses
- International leakage is an important component of total GHG emissions

Access to LU/GHG data and WP

- **Land use data:**
  - https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1900
- **Greenhouse gas emissions data:**
  - CO2:
    - https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1143
  - CH4, N2O, F-gases:
    - https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1186
- **GTAP Working Paper No. 36:**
  - https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=2230