Modeling the Competition for Land Owing to Food, Fuel, Climate Policy and Climate Change

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Outline

- **Data base infrastructure:**
  - **What we have and what we need to improve**
- **Modeling framework:**
  - **Paths taken; alternatives ruled out**
- **Applications:**
  - **Cropland cover change due to biofuels**
    - **GTAP only**
    - **Multilayered analysis of EU policies**
  - **Role of land in climate mitigation**
  - **Climate volatility ag productivity and poverty vulnerability**
  - **Impact of economic growth and policy on long run demand for land in agriculture and forestry**

Data base infrastructure combine with next slide

- **Spatial data on land use:**
  - **Crop harvested area and yields: Monfreda, Ramankutty etc**
  - **Land cover: *Gap between crop land cover and harvested area is problematic; not reconciled on a global basis***
  - **Forestry data by AEZ: Sohngen**
- **Estimates of existing/potential productivity are key to the economic model:**
  - **Differential productivity by AEZ for given crop driven by observed yield data**
  - **Differential productivity by sector driven by aggregate land rentals: Can give rise to extreme results (e.g., US pasture vs. cropland: 1 to 7 rental ratio)**

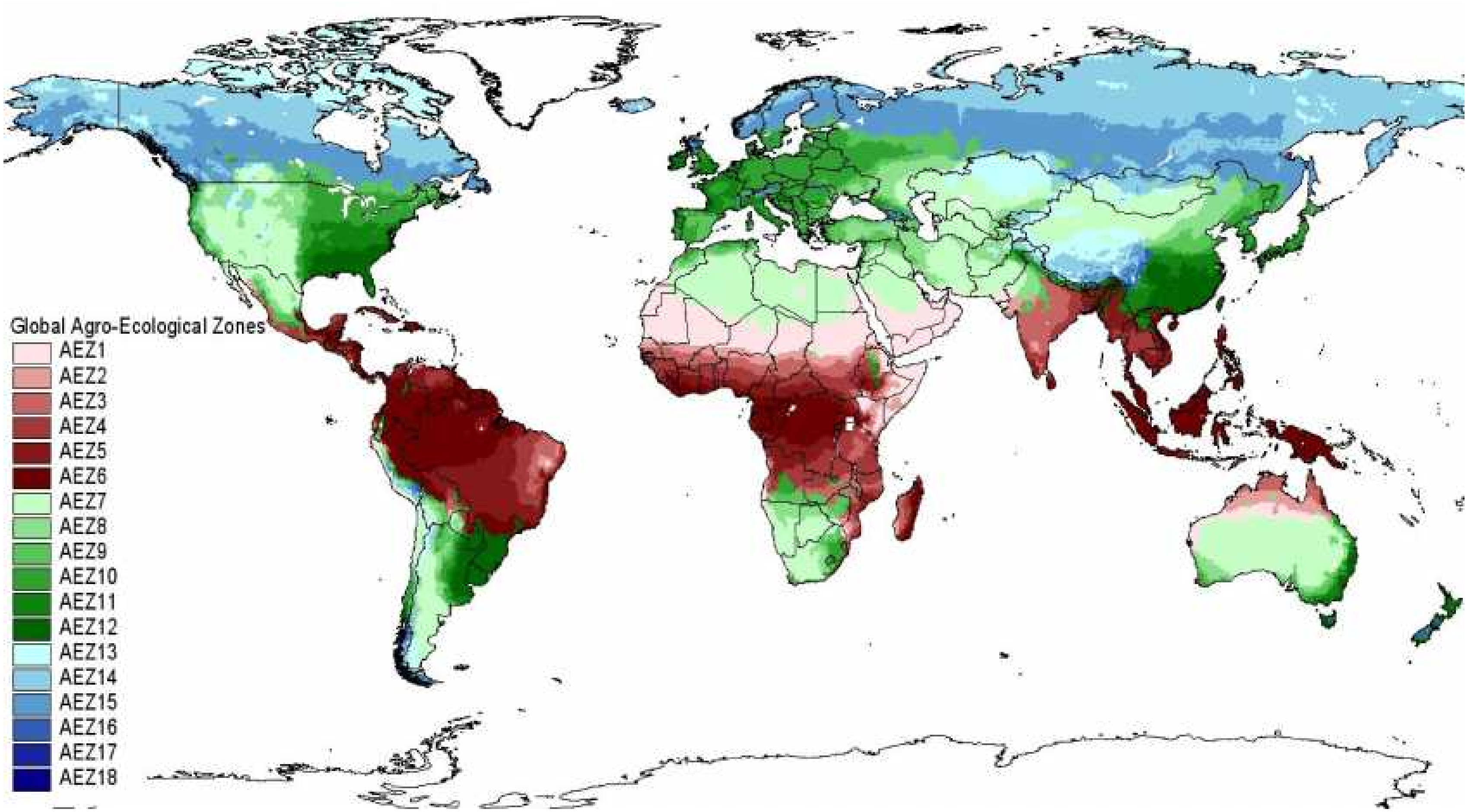
Data base issues

- Data we do not have
  - How much do yields fall as area expands?
  - What about land that is currently idle? How productive is it?
  - Input use by AEZ
  - Investments in land:
    - Irrigation
    - Investments in access (esp. forestry)
- Carbon stock data key for GHG emissions from land cover change: in need of comparison and reconciliation:
  - Woods Hole; UCB modifications
  - Winrock work for EPA
  - Sohngen data
  - TEM-based estimates

What is the appropriate level for modeling land competition? *(Agro-Ecological Zones)*

- **AEZs are relatively homogeneous units within each country, with similar growing conditions**
- **If too large: heterogeneity dominates/overstate competition**
- **If too small: limit alternative uses/limit competition**
- **Follows work by FAO and IIASA (also ERS); definition of AEZs as "length of growing period", as determined by:**
  - **Temperature, precipitation, soil and topography**
  - **Combined with a water balance model and knowledge of crop requirements**
- **Generally use 18 AEZs = 60 day LGPs x 3 climate zones**
- **Using 108 AEZs (10 day LGPs) for Tanzania work on climate impacts**

Global Distribution of AEZs



How do we handle diversification of activities within an AEZ?

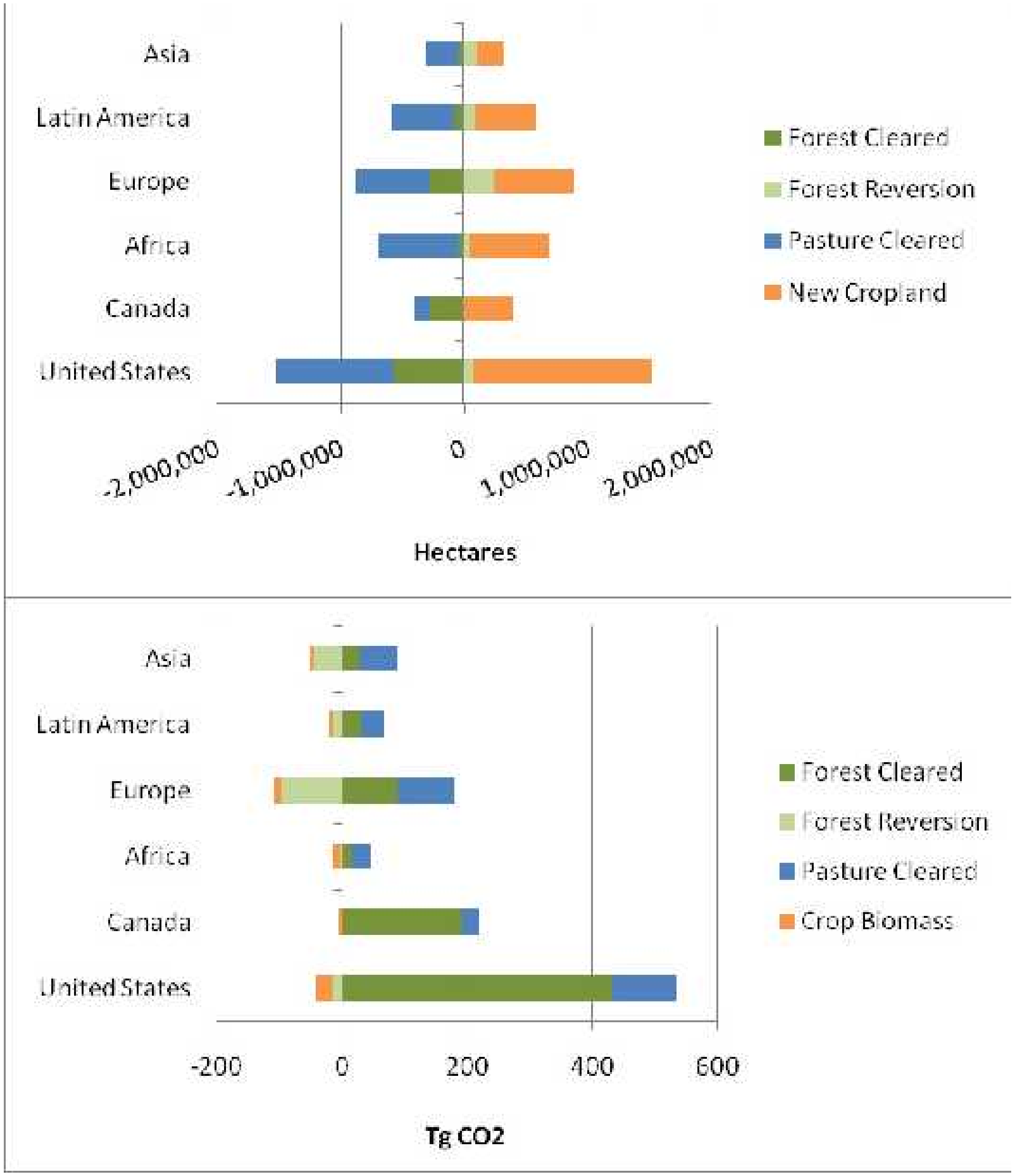
- Have tried several approaches (see book):
  - Risk-based approach (KLUM)
  - Explicit distribution of productivities (AgLU)
  - CET approach: single elasticity of transformation governs ease of movement across uses; motivated by land heterogeneity, but not explicit
- Keep returning to CET: Simple and robust
  - Use two levels of nesting: first LC then HA
  - Retain a constant difference between crop LC and HA
  - Focus on net changes, not gross land transitions
  - Key issue is size of CET parameter: take guidance from Ruben Lubowski's work – elasticity rises over time
  - Introduce an endogenous AEZ-specific productivity adjustment to retain fixed total hectares in CET function

Application to Biofuels Debate

- **Research published last year in *Science* raised the issue of "indirect" LUC:**
  - **Induced land use change (crop land conversion) due to increased demand for agricultural products could result in emissions which dwarf the direct gains of replacing petroleum with biofuel**
- **Purdue approached by UC Berkeley and CARB to provide improved estimates of iLUC:**
  - **Results to be replicable in Sacramento/elsewhere**
  - **Using these estimates in CA LCFS regulations**

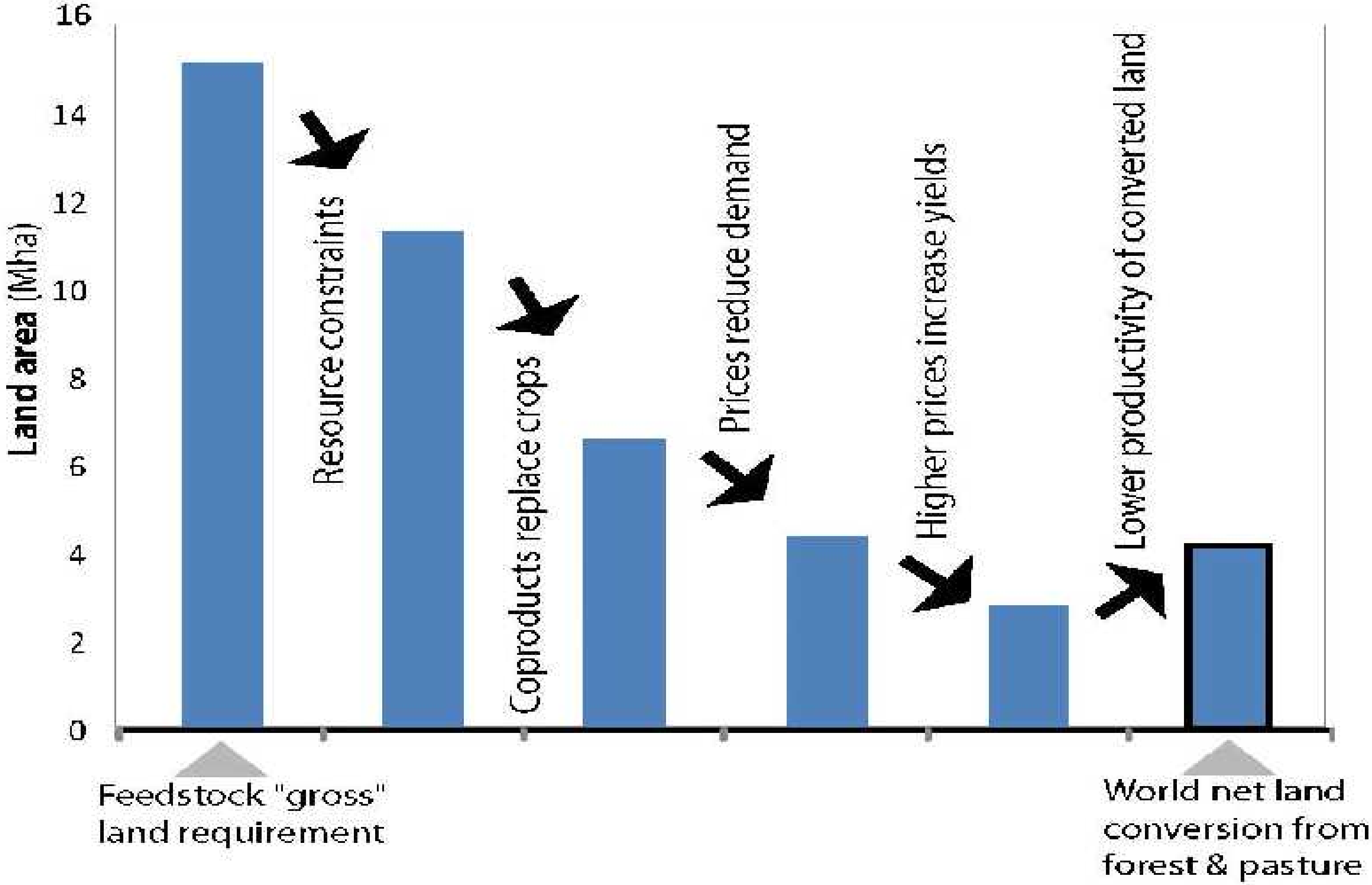
Land Conversion and Emissions due to increased US corn ethanol production

- Use modified GTAP model: AEZs and Biofuel
- Estimate cropland expansion into accessible forest land and pasture
- Greatest portion of land conversion in US; from pasture
- Emissions factors based on Woods Hole
- Majority of emissions from forest land conversion



Source: Hertel, Golub, Jones, O'Hare, Plevin and Kammen, 2009

GTAP estimates of iLUC are only ¼ of Searchinger et al. estimates due to market-mediated effects

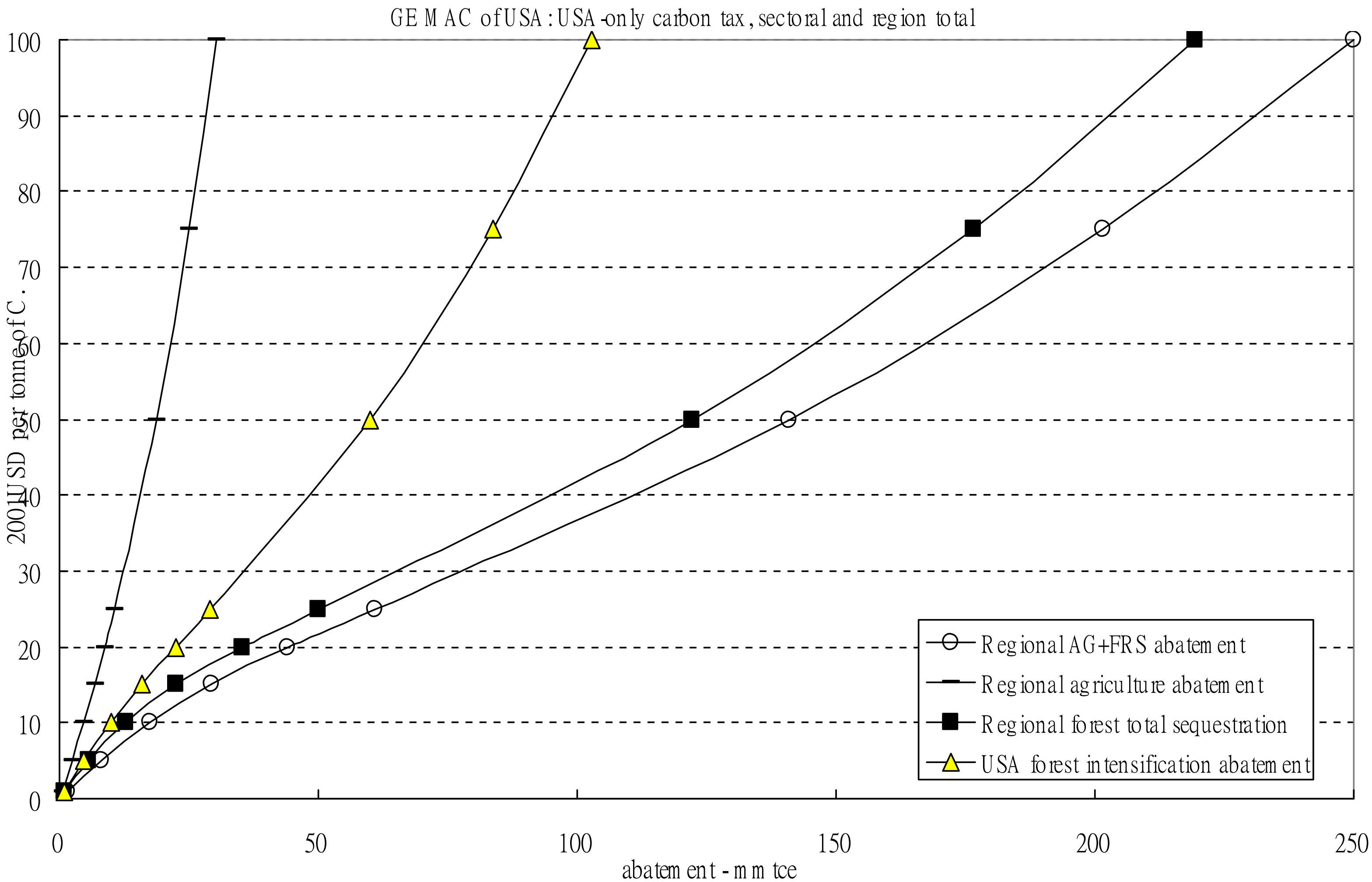


Source: Hertel, Golub, Jones, O'Hare, Plevin and Kammen, 2009

Role of Land in Climate Change Mitigation

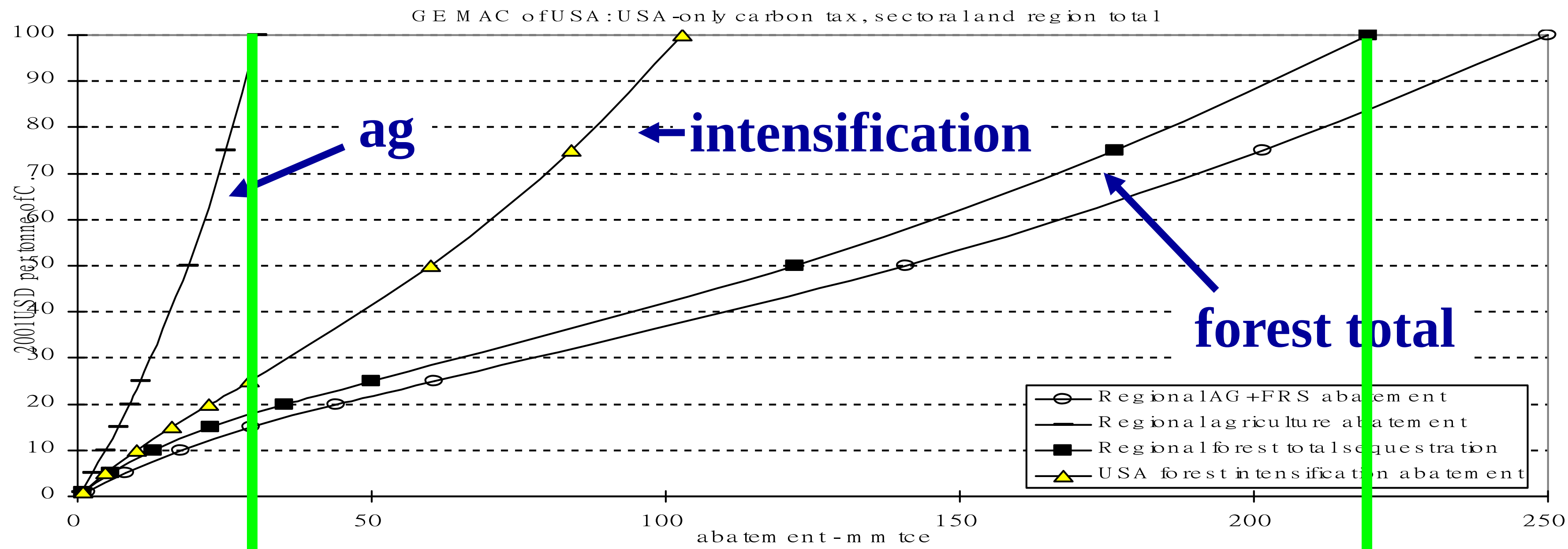
- Land-based emissions (deforestation, methane from rice and livestock, N2O from fertilizer, etc.) account for a significant share of GHG emissions
- Yet bulk of global CGE research to date has focused on industrial GHG emissions & emissions from fossil fuels
- Project funded by EPA incorporates land-based emissions (forestry and agr) into GTAP framework
- Collaboration with Brent Sohngen at OSU and Steve Rose (EPA, now EPRI)
- Key findings:
  - Carbon taxes change pattern of comparative advantage and hence trade in agricultural and forest products
  - Global tax shifts US agr abatement supply curve to left (less abatement at any given carbon price)

USA agriculture and forestry general equilibrium GHG annual abatement supply schedules: USA-only carbon tax

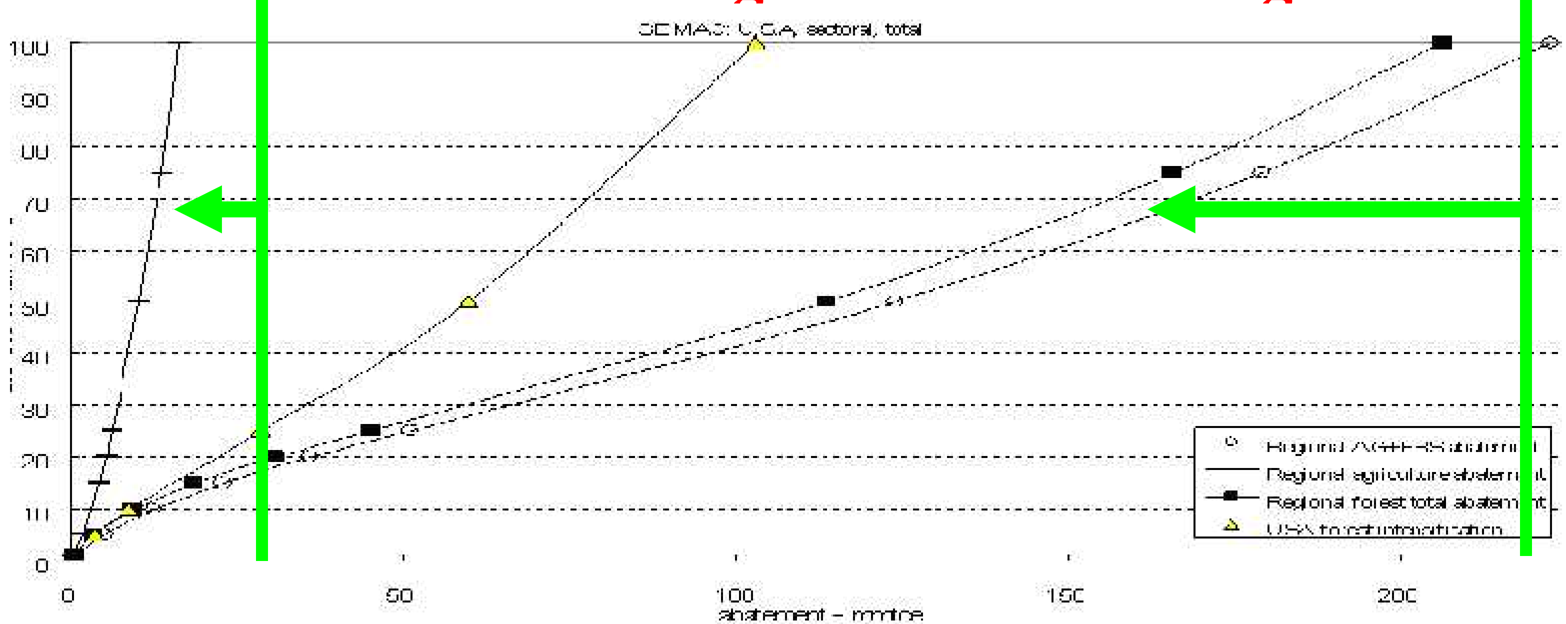


Source: Golub, Hertel, Lee, Rose and Sohngen, 2009

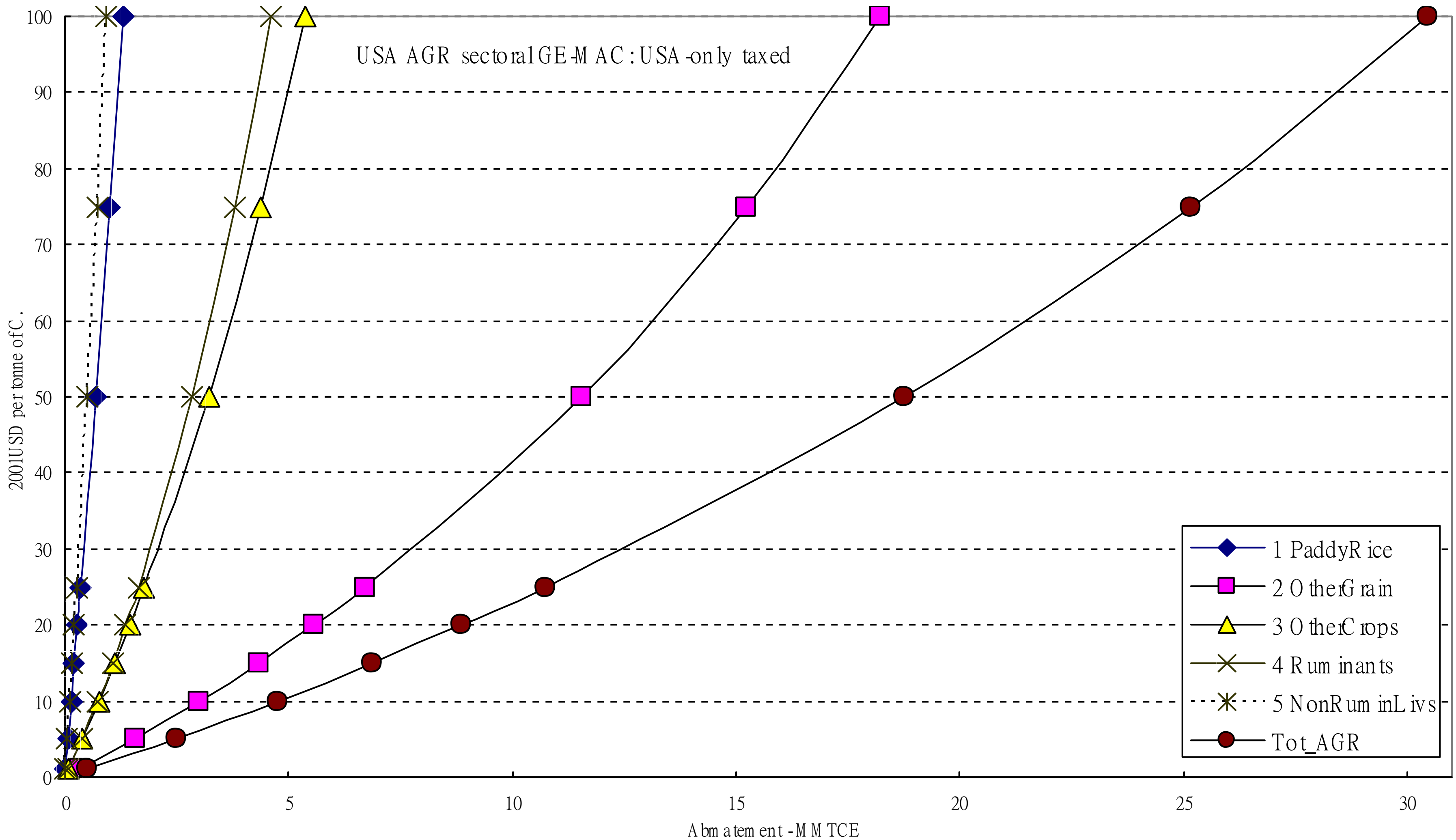
USA sectoral mitigation w/ US carbon tax



USA sectoral mitigation costs rise w/ global tax

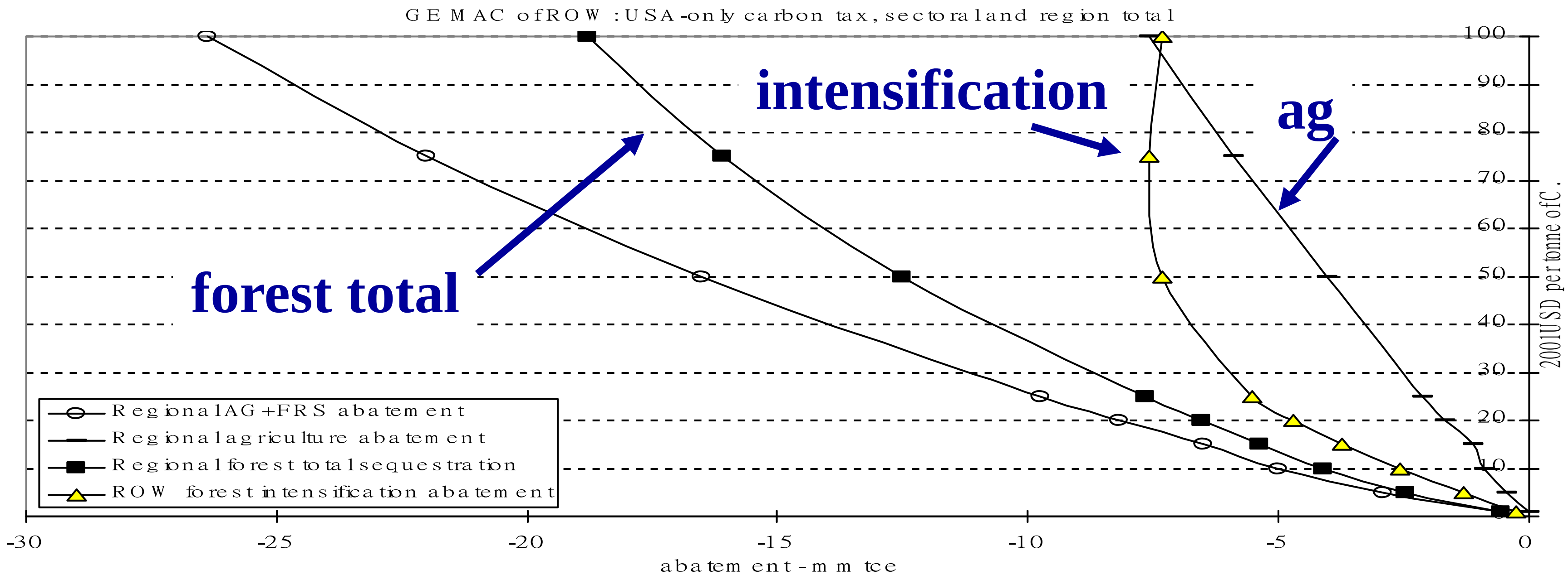


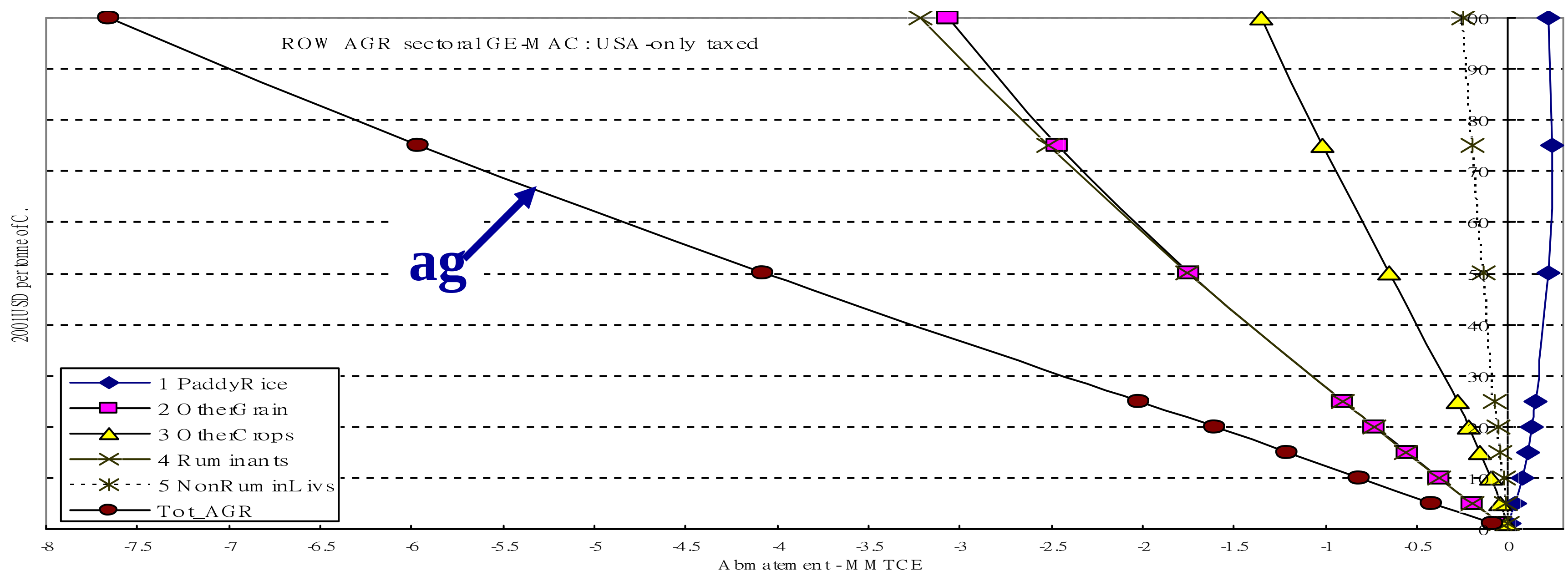
US Agricultural Supply of GHG Abatement, by sector (mill m.ton carbon as vary carbon price)



Source: Golub, Hertel, Lee, Rose and Sohngen, 2009

Leakage in ROW due to US carbon taxes

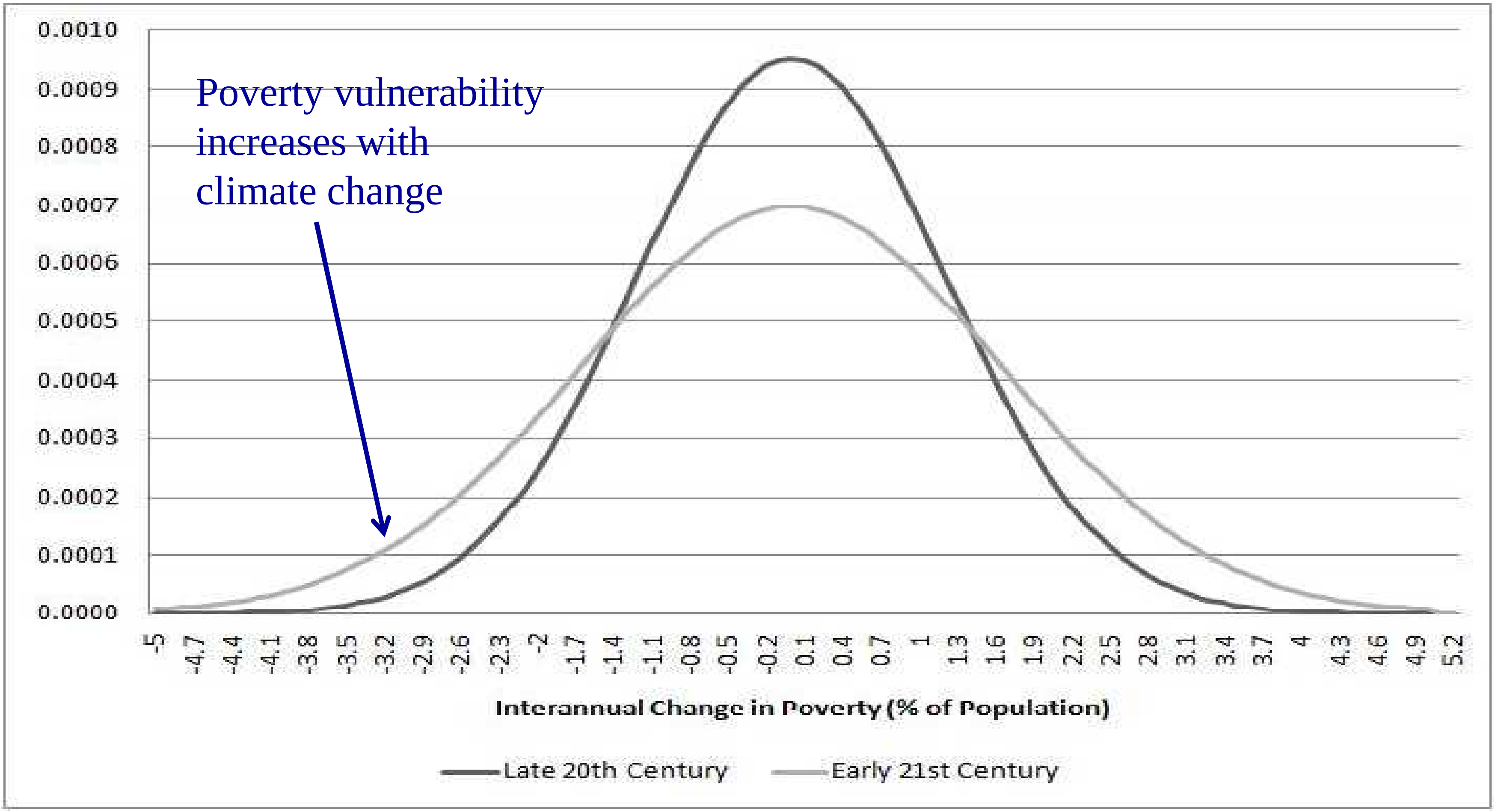




Analyzing the impact of changes in climate volatility on agriculture productivity and poverty vulnerability

- **Tanzania pilot study supported by World Bank**
- **Collaborators: climate science (Diffenbaugh@Purdue), ecology (Ramankutty and Rowhani@McGill, also Lobell@Standford) as well as economy (Ahmed, Arndt, Hertel, Thurlow)**
- **Sequence of analysis:**
  - **Start with characterization of current production volatility and validation of CGE model wrt observed variance in grains prices**
  - **Climate analysis: current focus is on temperature and precipitation at grid cell level; also measures of climate extremes (e.g., CDD)**
  - **Regression analysis a la Lobell using sub-national data from Ramankutty et al; focus on identifying key variables/periods during growing season for explaining crop yields**
  - **Use historical data to inform bias correction of data series**
  - **Based on changes in mean and variance of bias-corrected distributions, shift current distribution of productivities**

Poverty Vulnerability in the Late 20th Century and Early 21st Century Measured as the Poverty Changes Arising from Inter-annual Productivity Volatility



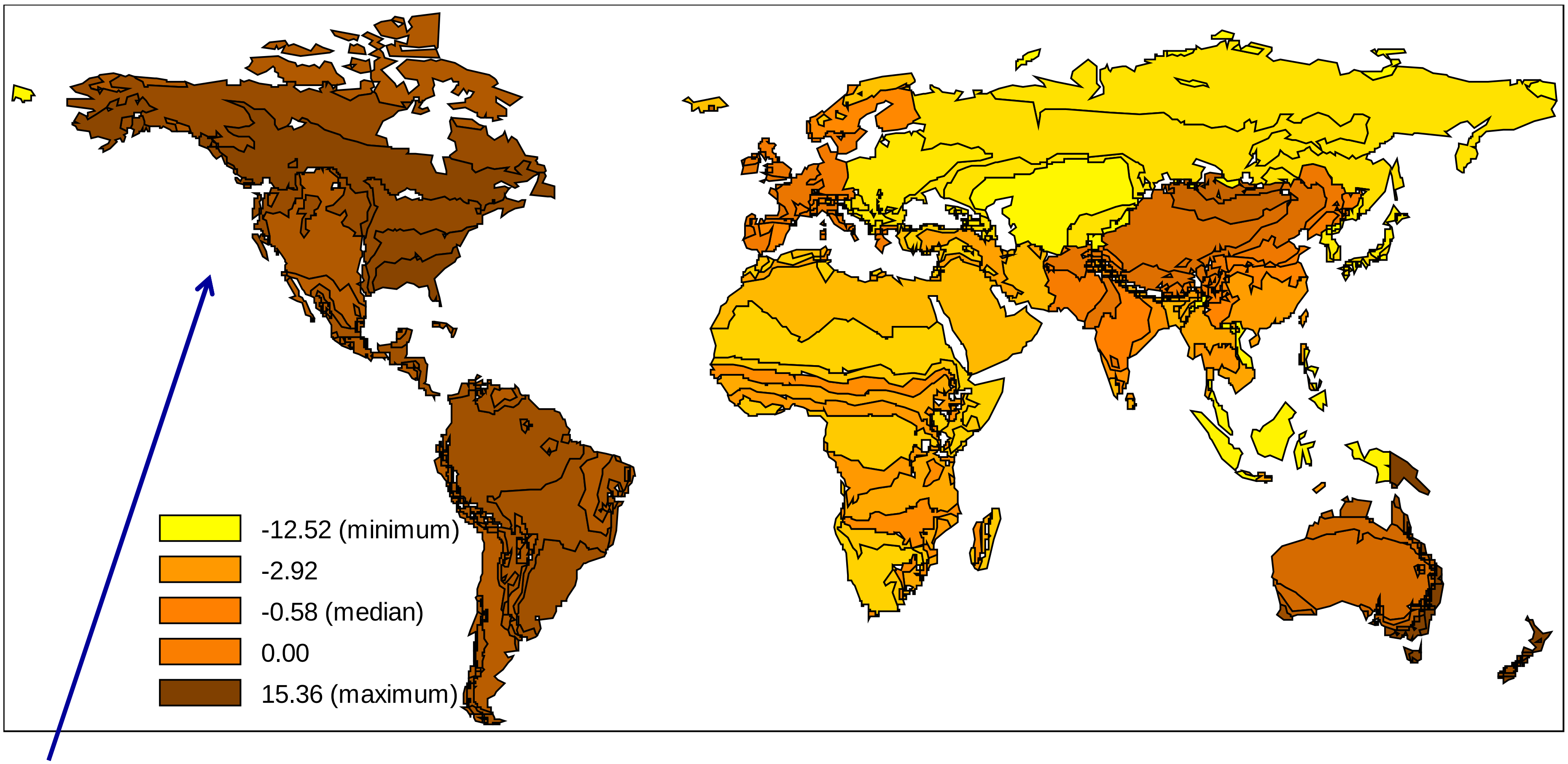
Source: Ahmed, Diffenbaugh, Hertel, Ramankutty, Rios and Rowhani, 2009

Long Run Projections of Demand for Agricultural Land

- **International trade has grown strongly since WWII; will this continue?**
- **Trade is a key mediator between resource abundant, low population density and high density regions**
- **Examine impact of *freezing intensity of imports in total use* of agric products:**
  - **Reduces demand for land in ANZ, NAM, LAM, EU**
  - **Boosts demand in Asia, MENA regions**

Impact of Global Trade Integration on Land Use Change: Productivity-Weighted Changes in Land Used in Agriculture

(% difference between baseline and restricted trade scenarios, positive number means restricted trade reduces demand for land: 1997-2025)



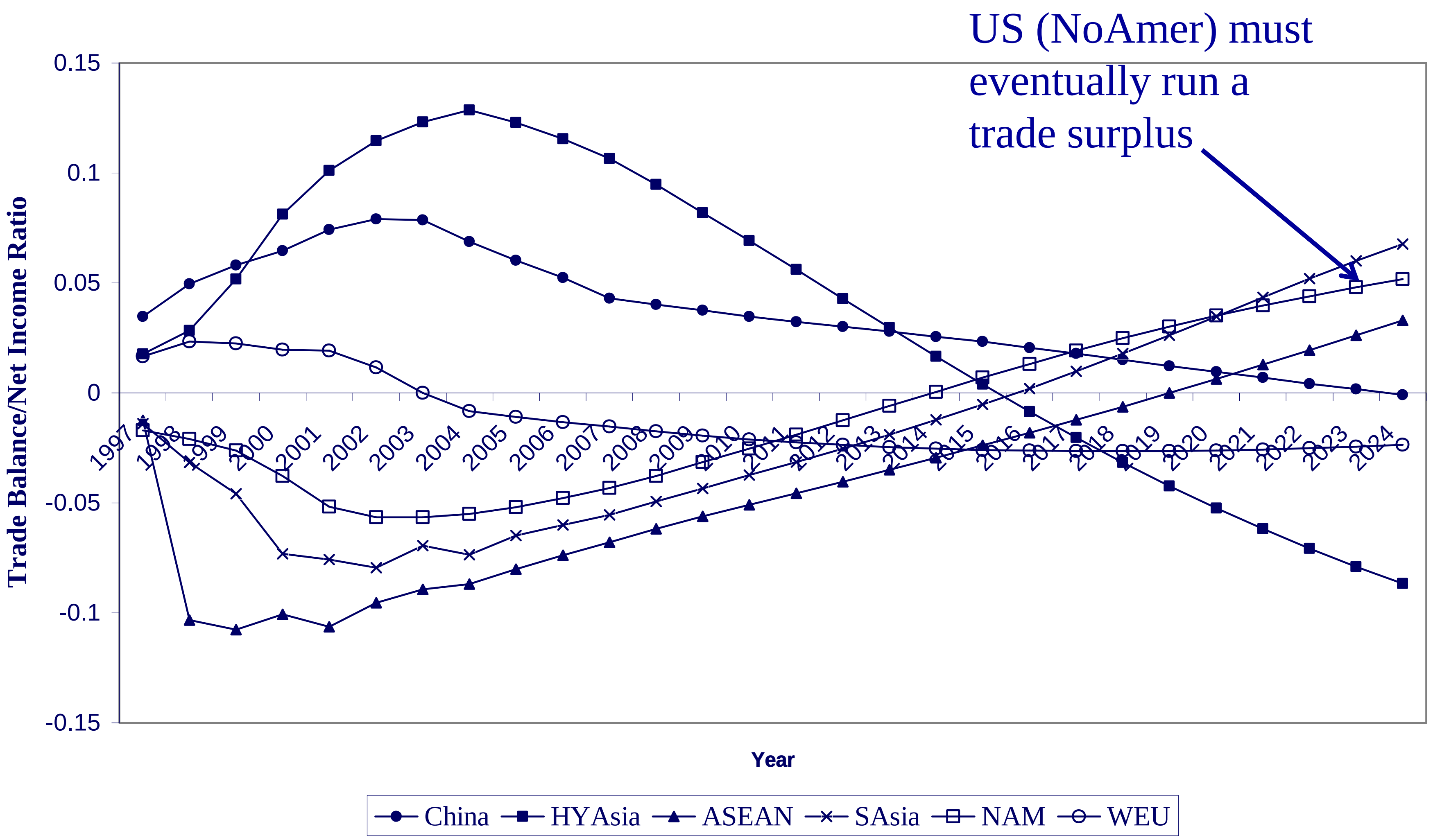
Baseline demand for land higher in the Americas than restricted trade scenario

Source: Golub and Hertel, 2008

Macro-economics matter for global land use: Evolution of regional trade balances is key

- **Most CGE models make a simple assumption about the evolution of regional trade balances, e.g., constant share of GDP; yet recent trade balances are surely unsustainable. What happens when lenders begin to repatriate their earnings? Will change trade patterns**
- **G-Dyn extends standard GTAP model:**
  - **Endogenous capital accumulation**
  - **International capital flows and foreign income payments**
  - **Adaptive expectations theory of investment provides imperfect capital mobility in the short run, perfect capital mobility in LR**

Evolution of the Trade Balance, by Region: 1997-2025



Source: Hertel, Golub and Ludena, 2008

Change in Sectoral Trade Balances: 1997-2025

Sector	China	HYAsia	ASEAN	SAsia	NAm	WEU	Other	Total
Agr	-224.1	-18.3	-47.7	-97.2	99.2	75.9	153.4	-58.8
PrFood	-198.2	-209.9	-70.2	-13.6	326.6	145.7	-55.3	-74.9
Mnfcing	990.3	-799	-146.1	261.3	439.3	-668.2	-555.2	-477.6
Trans/Cor	187.4	-13	-22.6	95.9	169.1	87.5	203.4	707.7
OthSvces	-320.4	-368.8	471.3	152	231.3	-120.8	-65.9	-21.3
NatResou	-483.1	154.2	-112.9	-234.6	-278.2	17.2	862.3	-75.1
Total	-48.1	-1254.8	71.9	163.8	987.4	-462.7	542.5	0

NAm trade surplus means more Agr exports, more demand for agricultural output and hence more demand for farm land

Source: Hertel, Golub and Ludena, 2008

Next steps

- **Bringing in unmanaged land using IMAGE land productivity (collaboration with LEI)**
- **Interaction of biofuels and GHG mitigation policies in the context of economic growth: Intensifies competition for land**
- **Broaden analysis of climate change impacts on agricultural productivity and poverty**
- **Combining PE and GE approaches to analyze *global* impacts of *local* policies and vice versa**
  - Using CAPRI model to generate sub-national supply response; use GE (GTAP) to generate global impacts
  - Collaboration with Bonn University

Forthcoming book
(thanks to all who contributed!)

- **Part I: Overview and synthesis**
- **Part II: Data bases**
- **Part III: Applications including:**
  - **GTAP-AEZ**
  - **AgLU**
  - **EPPA/biofuels**
  - **LETAP/IMAGE**
  - **G-Dyn/Global Timber Model**
  - **KLUM**

Economic Analysis of Land Use in Global Climate Change Policy
Edited by **Thomas W Hertel, Steven K Rose, Richard S. J. Tol**
Series: Routledge Explorations in Environmental Economics

ISBN: **978-0-415-77308-9**
Binding: **Hardback**
Published by: **Routledge**
Publication Date: **04/20/2009**
Pages: **368**

Additional References

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- Ahmed, A., N. Diffenbaugh, T. Hertel, N. Ramankutty, A. Rios and P. Rowhani (2009) "Climate Volatility and Poverty Vulnerability in Tanzania", paper to be presented at the 12th Annual Conference on Global Economic Analysis, June 10-12, Santiago, Chile.
- Britz , W. and T. Hertel (2009) "Impacts of EU Biofuels Directives on Global Markets and EU Environmental Quality" Paper presented at the AgSAP conference, The Netherlands, March 12.
- Golub, A. and T.Hertel (2008) "Global Economic Integration and Land Use Change" *Journal of Economic Integration* 23(3):463-488.
- Hertel, T., A. Golub, A. Jones, M. O'Hare, R. Plevin and D. Kammen (2009) "Comprehensive Global Trade Analysis Shows Significant Land Use Change GHG Emissions from US Maize Ethanol Production", under review with *PNAS*.
- Hertel, T., W. Tyner and D. Birur (2009). "The Global Impacts of Biofuels", *forthcoming in the Energy Journal*.

Additional slides:
Multi-layered analysis of biofuels and land use

Overview of Framework (1)

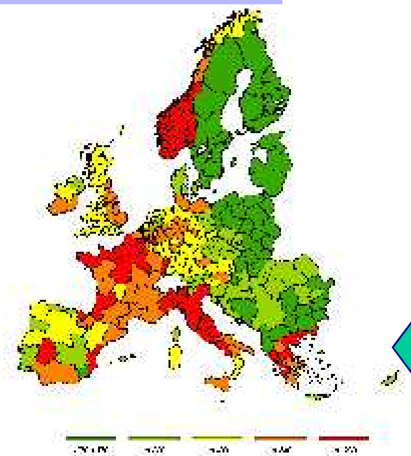
- **CAPRI (PE) Model:**
  - **Delivers supply response behaviour for GTAP-EU crops**
  - **Simulates EU impacts of GTAP generated price changes**
  - **Delivers regional impacts on environmental and economic indicators for EU agriculture**
- **Modified GTAP (CGE) model:**
  - **Incorporates EU crop sector revenue function from CAPRI:**
    - **parameterised based on compensated supply elasticities derived from price sensitivity experiments with a modified CAPRI supply module (fix inputs, subsidies and livestock)**
    - **ensures mutually compatible results in EU arable crop supply response in the two models**
  - **Implements biofuel mandates as 6.25% liquid transport fuels**
  - **Delivers global results regarding supply, demand, trade, price, induced land use change, poverty**

Overview of Framework (2)

Five Price experiments

$$\begin{matrix} \Delta p_{wht} & 0 & 0 & 0 & 0 \\ 0 & \Delta p_{cgr} & 0 & 0 & 0 \\ 0 & 0 & \Delta p_{oils} & 0 & 0 \\ 0 & 0 & 0 & \Delta p_{sug} & 0 \\ 0 & 0 & 0 & 0 & \Delta p_{oth} \end{matrix}$$

200+ Non-Linear Regional Programming models



EU-27 compensated supply elasticities

$$\begin{matrix} \varepsilon_{wht,wht} & \varepsilon_{wht,cgr} & \varepsilon_{wht,oils} & \varepsilon_{wht,sug} & \varepsilon_{wht,oth} \\ \varepsilon_{cgr,wht} & \varepsilon_{cgr,cgr} & \varepsilon_{cgr,oils} & \varepsilon_{cgr,sug} & \varepsilon_{cgr,oth} \\ \varepsilon_{oils,wht} & \varepsilon_{oils,cgr} & \varepsilon_{oils,oils} & \varepsilon_{oils,sug} & \varepsilon_{oils,oth} \\ \varepsilon_{sug,wht} & \varepsilon_{sug,cgr} & \varepsilon_{sug,oils} & \varepsilon_{sug,sug} & \varepsilon_{sug,oth} \\ \varepsilon_{oth,wht} & \varepsilon_{oth,cgr} & \varepsilon_{oth,oils} & \varepsilon_{oth,sug} & \varepsilon_{oth,oth} \end{matrix}$$

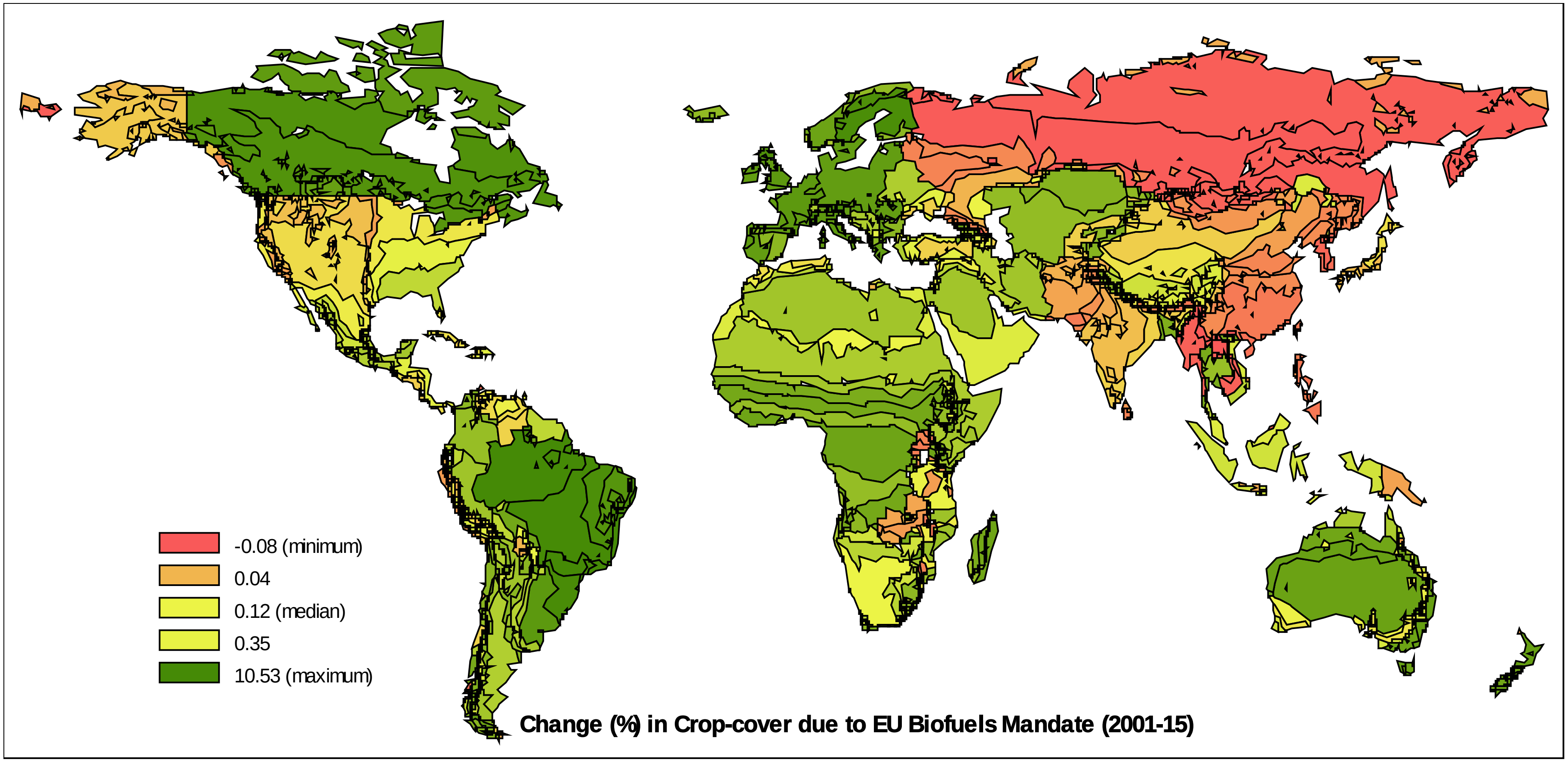
GTAP

$$\begin{matrix} \Delta p_{wht} \\ \Delta p_{cgr} \\ \Delta p_{oils} \\ \Delta p_{sug} \\ \Delta p_{oth} \end{matrix}$$

EU regional impact analysis

Global impact analysis

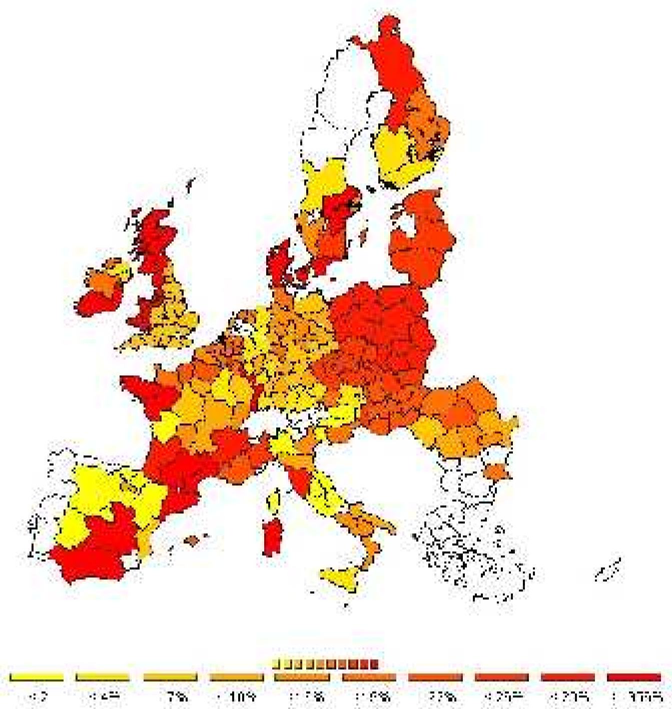
Multi-layered analysis of EU biofuels: Global crop land cover change (% of baseline)



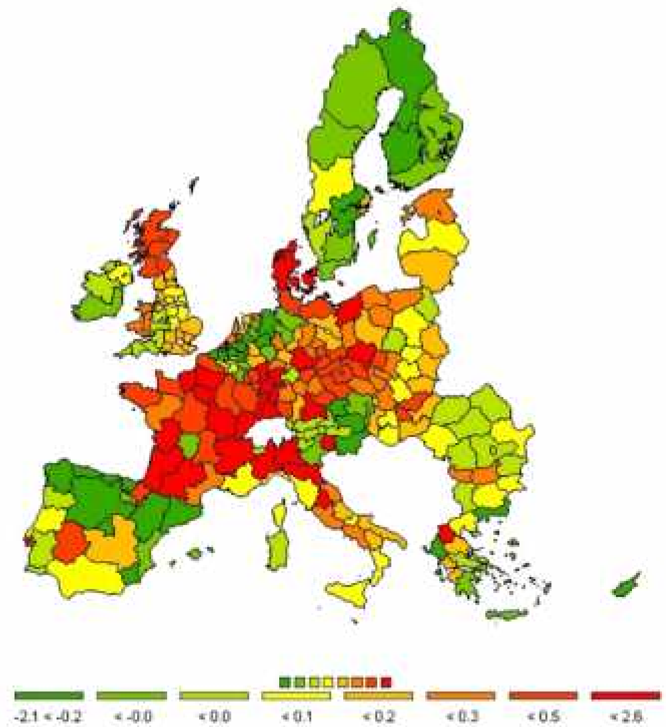
Source: Britz and Hertel, 2009

Multi-layered analysis of EU biofuels: EU land use impacts by NUTS regions

% change in rapeseed area



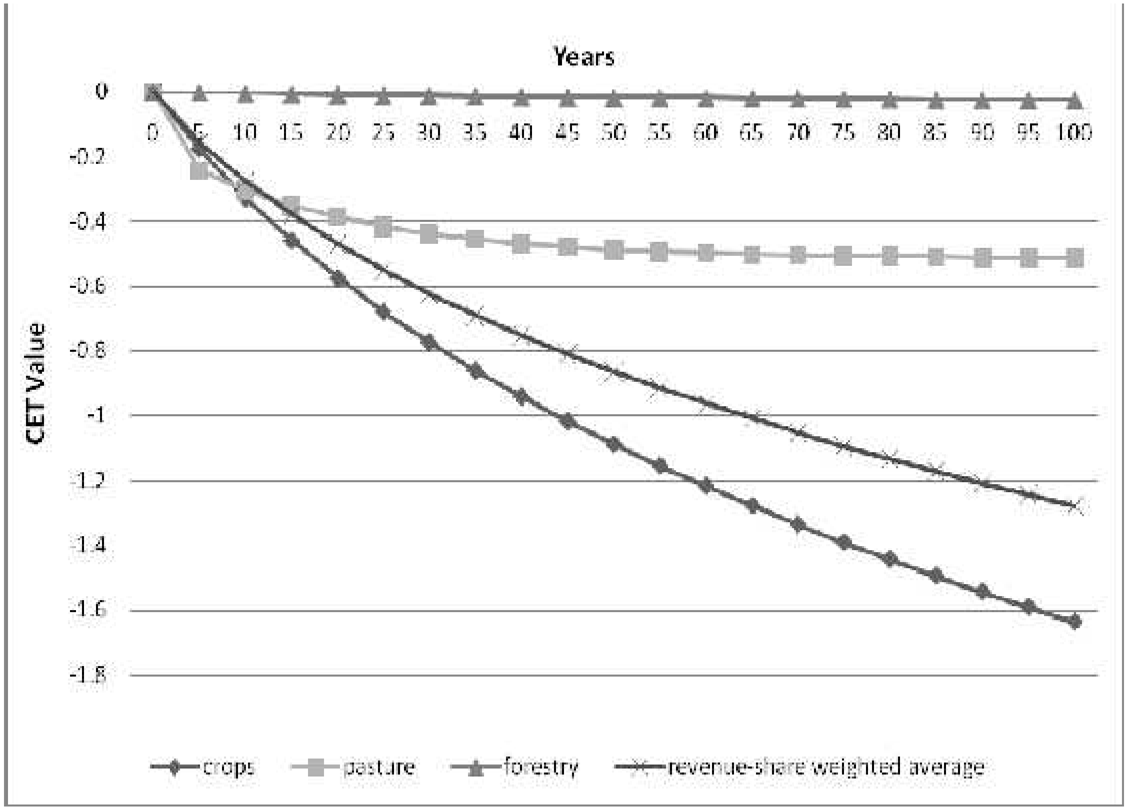
% change in nutrient surplus (kg/ha)



Source: Britz and Hertel, 2009

CET parameters over time from Ruben Lubowski's work

- **Perturb own return**
- **Increases probability of land staying in/moving into use**
- **Track increase in land cover over time**
- **Compute price elasticity and CET parameter**
- **Revenue-share-weight these across cover types**
- **Might consider more flexible form: calibrate to each type of supply but:**
  - **infeasibility problem**
  - **forest cover response is too low for global timber modeling**



Source: Ahmed, Hertel and Lubowski, 2009

Analysis of land cover changes using CET

- **CET function describes the potential for “transforming” one use of land into another. It permits us to have differential land rents across different uses, within a given AEZ**
- **Landowner maximizes revenue from renting land, to different uses/cover types and CET parameter described ease of moving land across uses**
- **Optimal supply of land to crops depends on return to land in crops, relative to average return to all land cover:**
- **Price elasticity depends on CET parameter as well as share**
- **- Small share = larger supply elasticity**
- **- Share = 1 implies supply elasticity = 0**
- **This approach allows to obtain economic or “effective” hectares, not physical hectares**
- **If effective hectares rise by 1%, crop sector output rises by 1% also**

From effective to physical hectares

- **But how do we get from effective hectares to physical hectares? Need to account for changing average yields as land expands**
- **Can do this through the AEZ endowment constraints**
- **Endowment constraint is written in terms of effective hectares; revenue share-weighted sum must equal zero:**

$$\sum_j \theta_j x_j = 0$$

- **Whereas physical hectare constraint states that quantity share-weighted sum of land use changes must be zero:**

$$\sum_j \Omega_j x_j = 0$$

- **Can only both hold if land rents are equated across uses (not true!)**
- **Introduce a slack variable into the latter constraint:** $\sum_j \Omega_j (x_j + \lambda) = 0$
- **λ becomes an *AEZ-wide productivity adjustment***

An illustration: AEZ12/USA from EU-US mandates

Table 1. Illustrative results for AEZ 12/USA

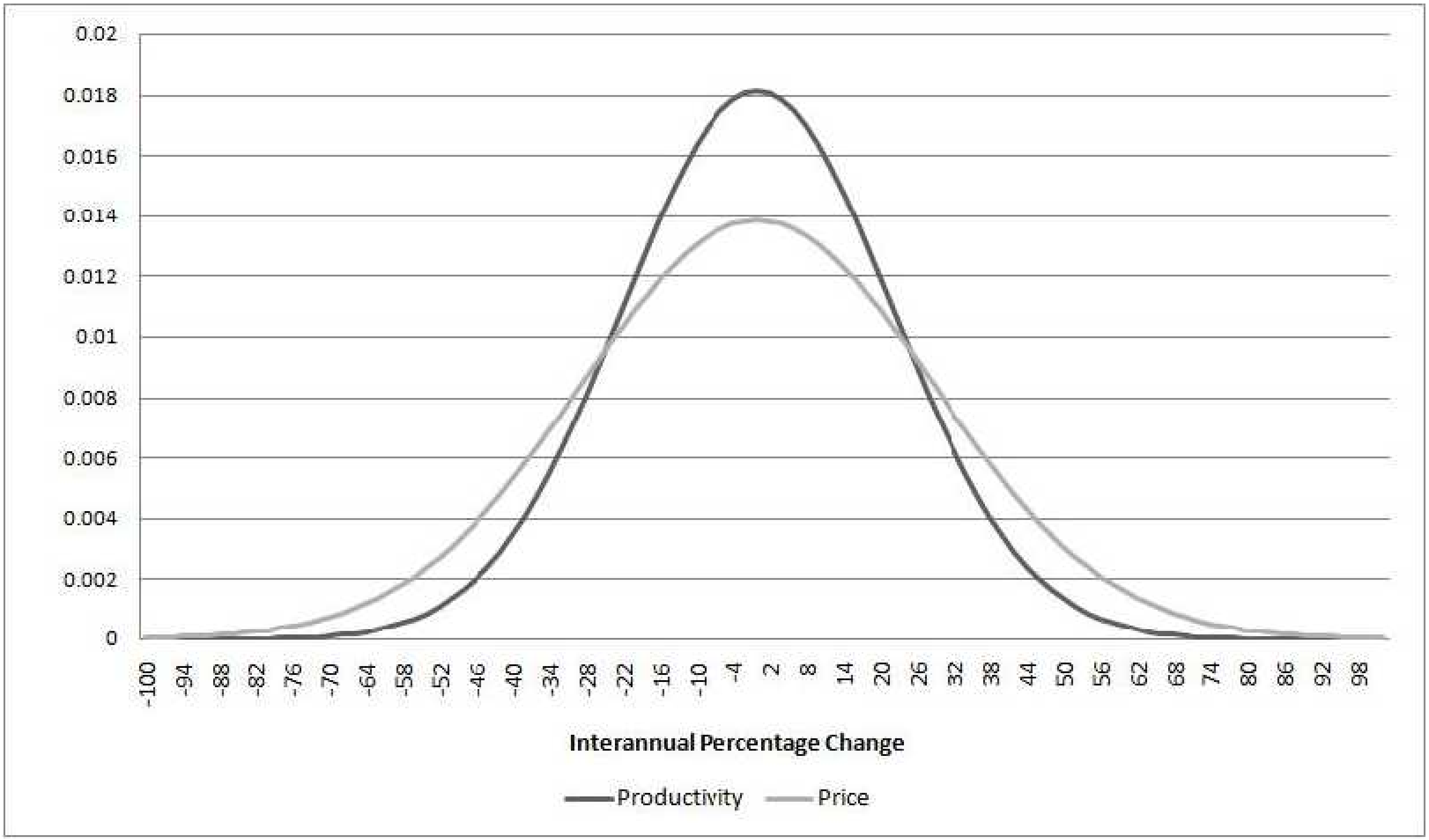
	percentage change			Hectares Land	
cover type	CET land	Yld Adjst	Phys land	Initial	Ending
Forestry	-2.48	1.53	-0.98165	63,364,724	62,742,705
Grazing	-3.07	1.53	-1.58409	7,009,711	6,898,671
Cropland	2.89	1.53	4.461562	16,430,536	17,163,595
Total				86,804,971	86,804,971

Discussion: As the best grazing land is moved into crops, average grazing yields fall, so economic land falls more than physical hectares.

On the other hand, as grazing land is converted to crop land, the average productivity of crop land falls, as this land is viewed as marginal from a crops perspective, so economic land rises less than physical land.

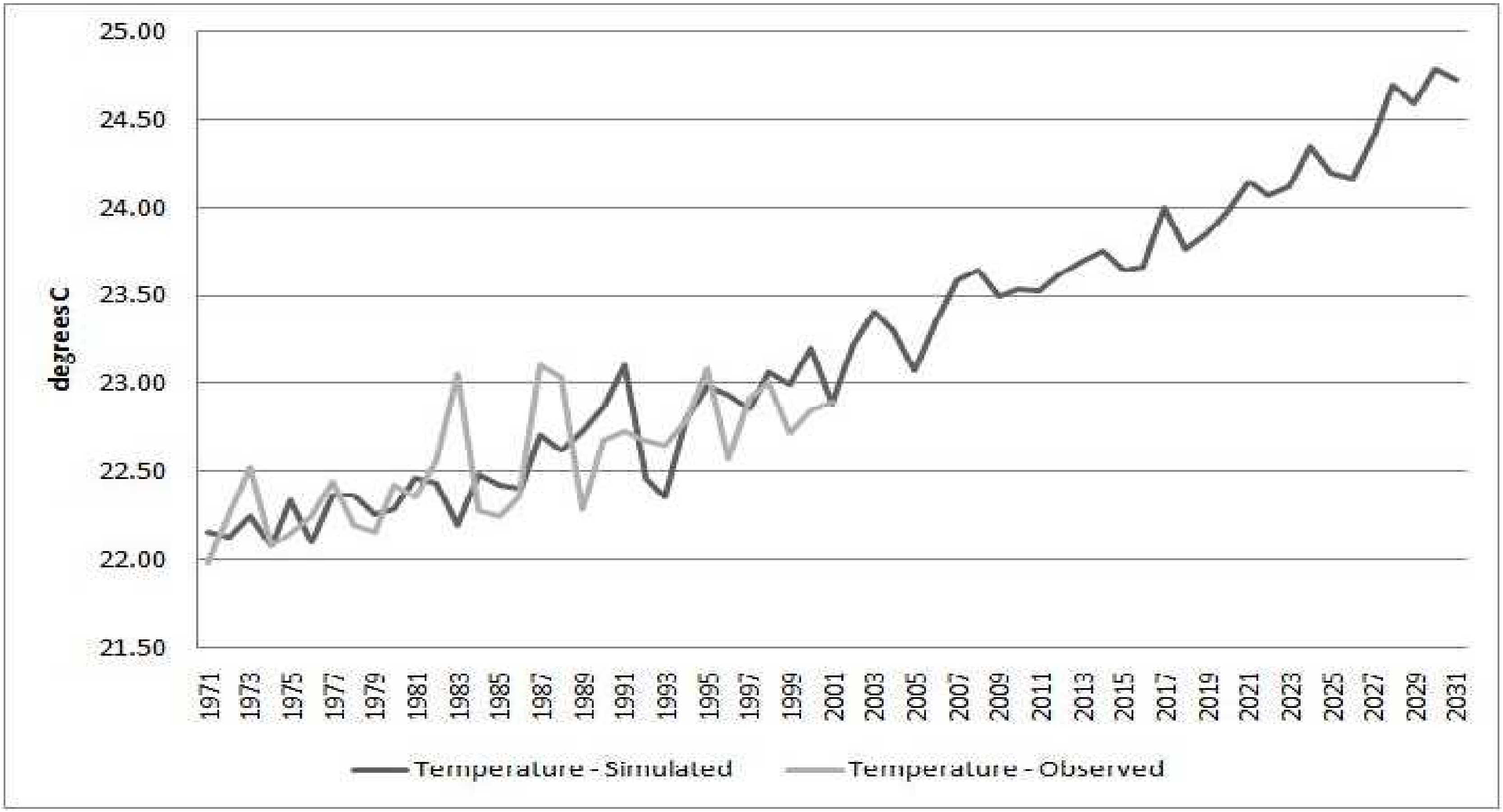
Therefore, as cropland expands, average productivity overall falls.

Grains Productivity and Price Volatilities in Tanzania Characterized as Mean-Zero Normal Distributions of Interannual Percentage Changes, 1971-2001



Source: Ahmed, Diffenbaugh, Hertel, Ramankutty, Rios and Rowhani, 2009

Observed and Simulated Annual Average Temperature in Tanzania (1971-2031)



Data sources: CRU and authors' analysis of CMIP3 data

Source: Ahmed, Diffenbaugh, Hertel, Ramankutty, Rios and Rowhani, 2009

Agricultural output & input changes (%)

	Output	Factor of Production		
		Land	Labor	Fertilizer
USA				
Paddy Rice	13	-21	11	-19
Other Grains	0.1	-5	8	-26
Other Crops	3	-7	5	-29
Ruminants	2	-7	3	
China				
Paddy Rice	-7	-19	17	-3
Other Grains	-2	1	7	-11
Other Crops	-1	-1	6	-12
Ruminants	-8	4	7	
ROW				
Paddy Rice	-4	-17	13	-5
Other Grains	-4	-16	10	-15
Other Crops	-3	-16	8	-14
Ruminants	-6	-20	7	

- US output increasing with reduced emissions

Changes in regional trade balances due to a $100/TCE global carbon tax in agricultural sectors and forestry

	Net Exports ($/year)		
Sector	USA	CHN	ROW
Rice	594	16	-619
Other Grains	2263	101	-2279
Other Crops	2066	1041	-2833
Ruminants	3686	-545	-2997
Non-Ruminants	1627	-707	-852
Other Foods	1642	633	-498
Forest Products	-4004	23	4472
Fertilizer & Energy Intensive Manufacturing	-1613	4965	-1571
Other Manufacturing and Services	-4761	-2449	3866
Total	1499	1812	-3311

USA expands agriculture

RoW expands forestry

Source: Golub, Hertel, Lee, Rose and Sohngen, 2009