Modeling Land Competition

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- Kenny Gillingham
- Geoff Blanford
  - Statistics of land allocation mechanism
  - Data for U.S. land classes
- U.S. Environmental Protection Agency

Objectives

- Extend PNNL partial equilibrium land use framework to general equilibrium
  - Forestry identified as a priority model development item in review of PNNL general equilibrium framework (Second Generation Model) by U.S. EPA Science Advisory Board
  - What is the right level of abstraction for a recursive CGE model?
    - Forest dynamics
    - Number of crops, animal products, forest products
    - Geographic detail
- Improve ability to simulate impact of carbon price on land use
  - Biofuel incentive
  - Forest management (increased tree rotation age)
  - Value carbon in unmanaged land

Overview

- Modeling Approaches
  - Forestry optimization
  - Partial and general equilibrium economics
- PNNL Agriculture and Land Use Model (AgLU)
  - Brief history
  - Land allocation mechanism
- Disaggregation of US region into land subregions
- Forest dynamics
  - Determination of optimal tree rotation age
  - Carbon price and rotation age
- Toward General Equilibrium
- Steady-state simulation
- Conclusions

Modeling Approaches

- Intertemporal Optimization
  - Typical for sector-specific models (e.g. forestry)
- Intertemporal Equilibrium (perfect foresight)
  - Efficiency conditions (first order necessary conditions) from intertemporal optimization model become system equations
  - Allows integration with other types of economic systems (such as agriculture)
- Recursive Equilibrium
  - Absence of look-ahead capability makes it difficult to model forestry
- Steady-State Equilibrium
  - Exploratory tool
  - Steady-state modeling of forestry may be able to inform recursive models

Relationship to Specialized Forestry Models

	partial equilibrium	general equilibrium
intertemporal optimization	TSM, FASOM	Ramsey growth model
intertemporal equilibrium	AgLU 2	intertemporal CGE
recursive equilibrium		recursive CGE
steady-state equilibrium		AgLU 2x

Brief History of AgLU

- First version completed in 1996
- Design
  - Top-down
  - Partial equilibrium
  - Can be run stand-alone or as part of MiniCAM
- Studies
  - Role of biomass in carbon policy
  - Impact of ENSO on North America
  - U.S. climate impacts

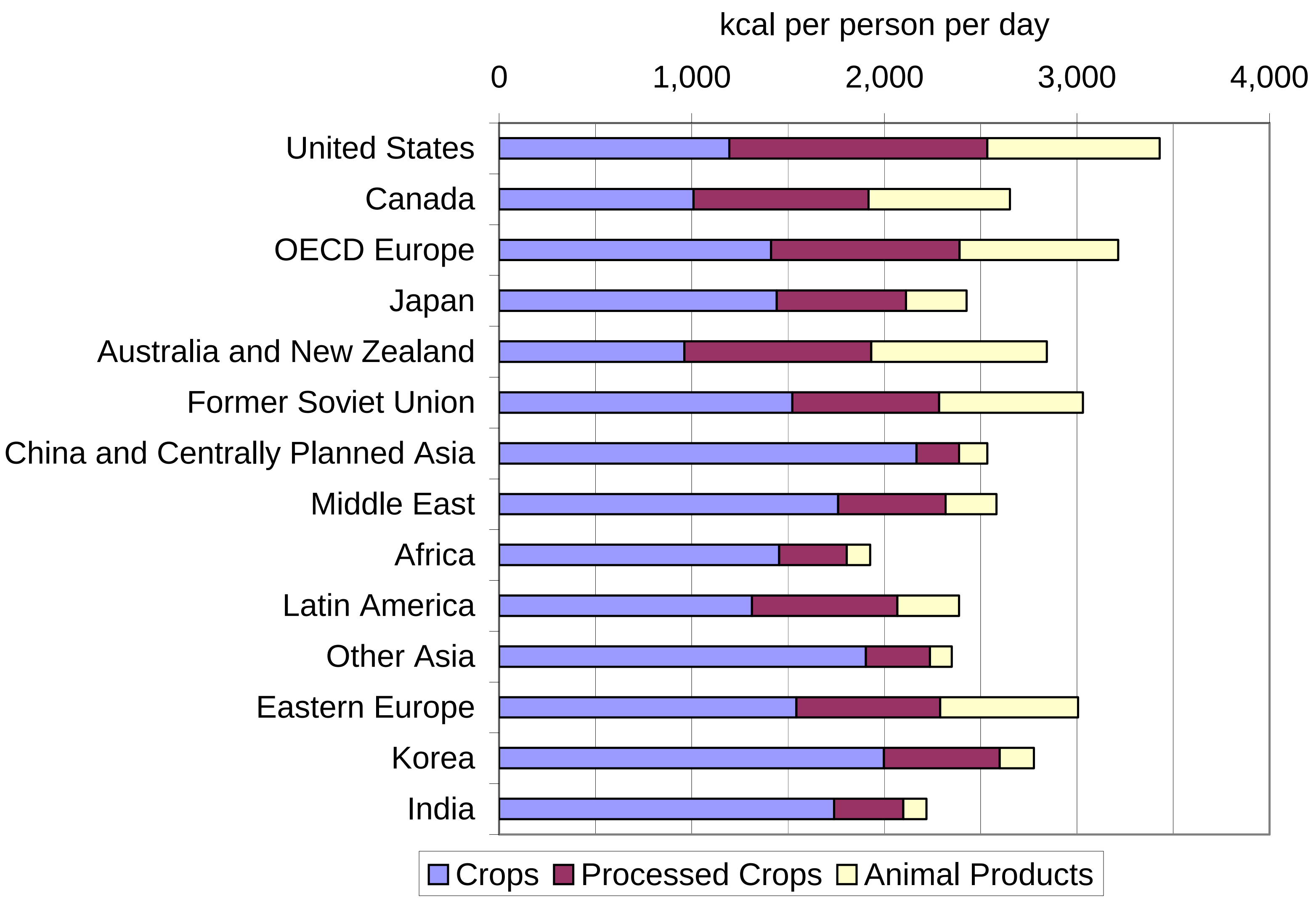
Methodology Highlights

- 15-year Time Steps from 1990 through 2095
- Land Allocation
  - Land owners compare economic returns across crops, biomass, pasture, and future trees
  - Underlying probability distribution of yields per hectare
- Forest Dynamics
  - Trees in AgLU grow for 45 years
  - Two forest markets (current and future) needed for model stability

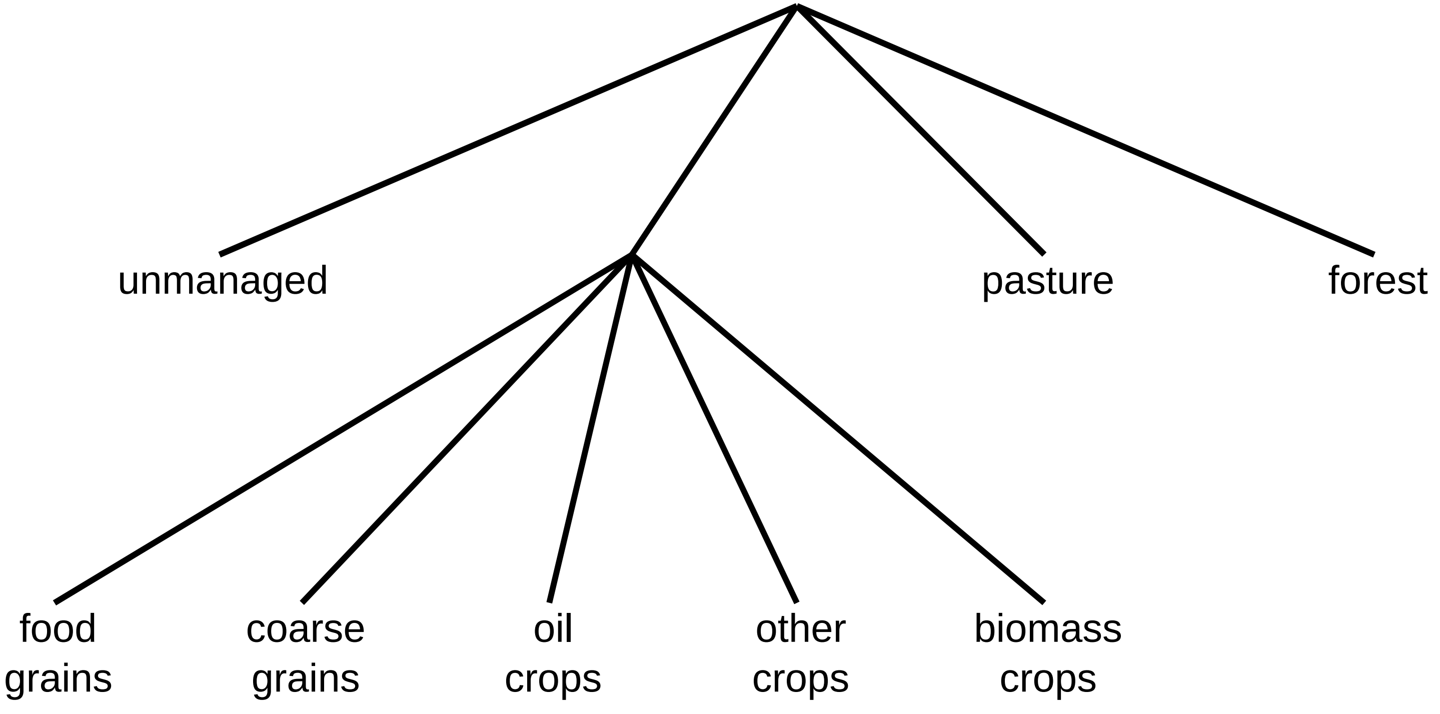
Products in AgLU

- Crops (calories)
  - Rice and Wheat
  - Coarse Grains
  - Oil Crops
  - Other Crops
- Processed Crops (calories)
  - Vegetable Oils
  - Sweeteners and Alcoholic Beverages
- Animal Products (calories)
  - Beef and other Ruminant Livestock
  - Pork and Poultry
- Commercial Biomass (calories or metric tons)
- Forest Products (cubic meters)

Food Consumption by AgLU Region



AgLU Land Allocation



Calculation of Land Shares

$$s_i = \frac{\overline{\pi}_i^{1/\lambda}}{\sum_k \overline{\pi}_k^{1/\lambda}}$$

Land share for land use i is an increasing function of profit rate (lambda is positive).

$$\overline{\pi}_i = \overline{y}_i \left(P_i - G_i \right)$$

Profit rate equals average yield times price received less non-land cost of production.

Efficiency Condition

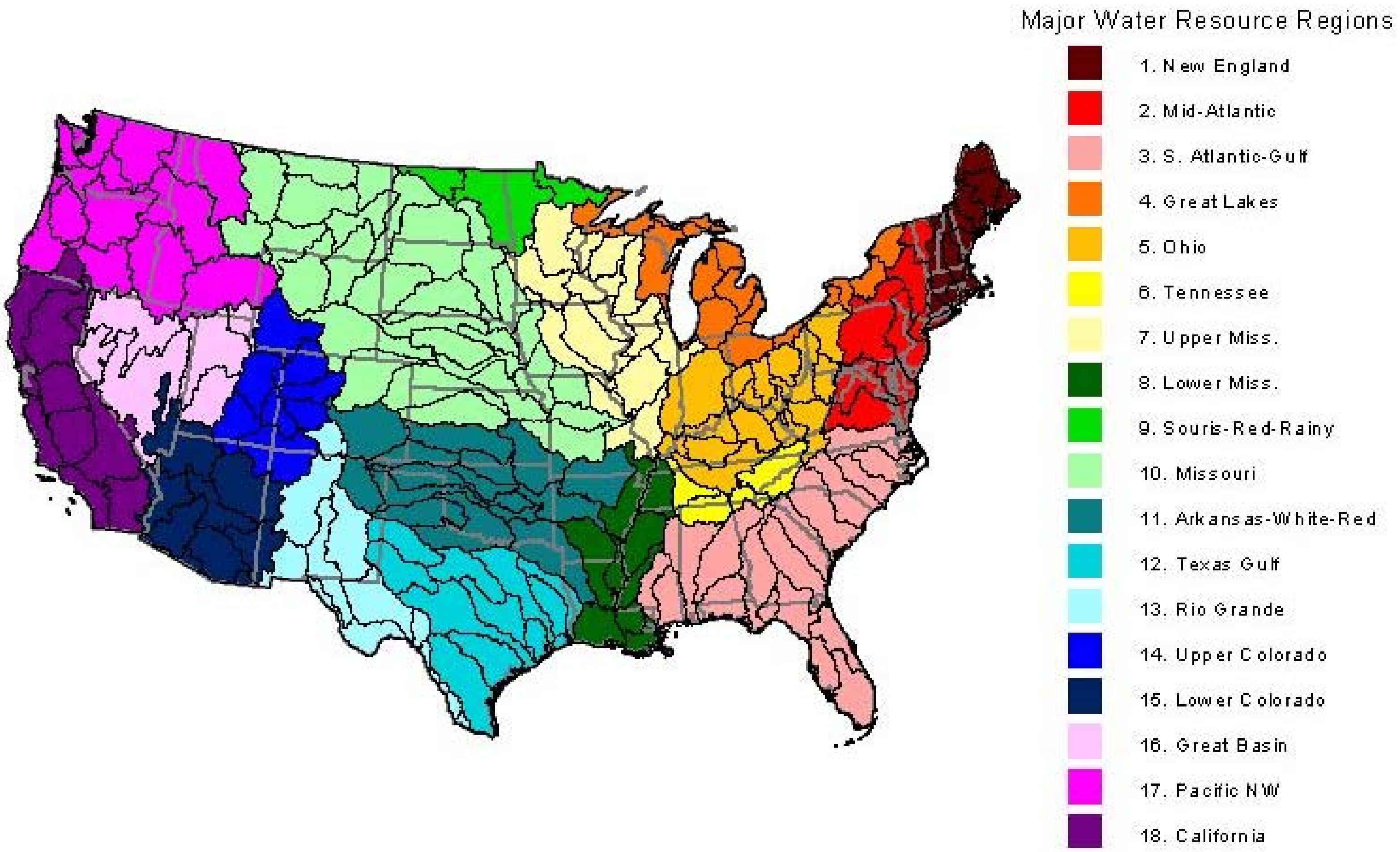
- Price received for forest at harvest time must cover land rent over lifetime of tree plus cost of harvesting
- All terms are discounted to the present for comparison (intertemporal efficiency condition)
- AgLU approximation

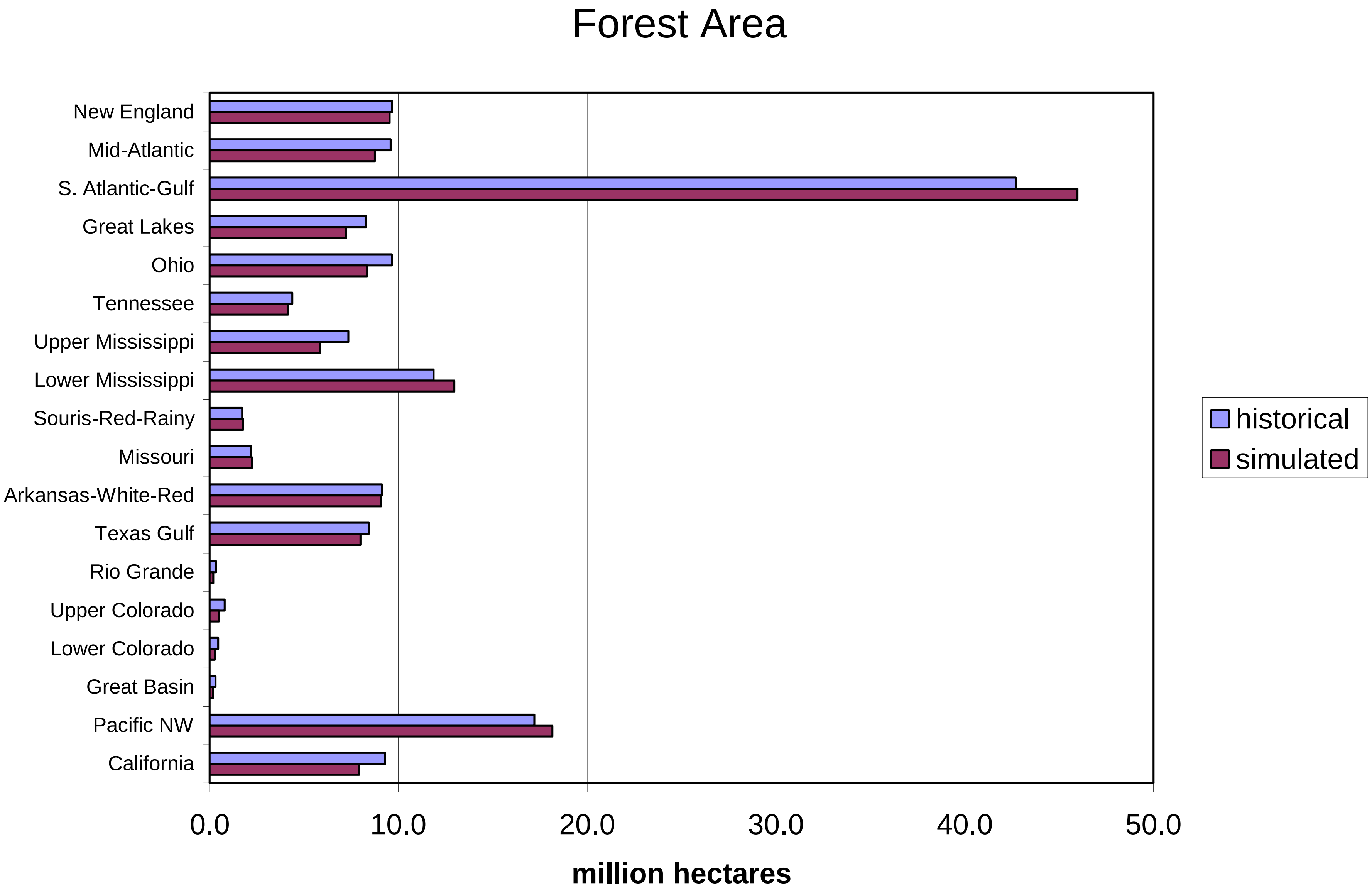
$$\bar{\pi}_{forest} = \frac{r}{(1+r)^{45} - 1} \bar{y}_{forest} \left(\tilde{P}_{forest} - G_{forest} \right)$$

US Land Classes

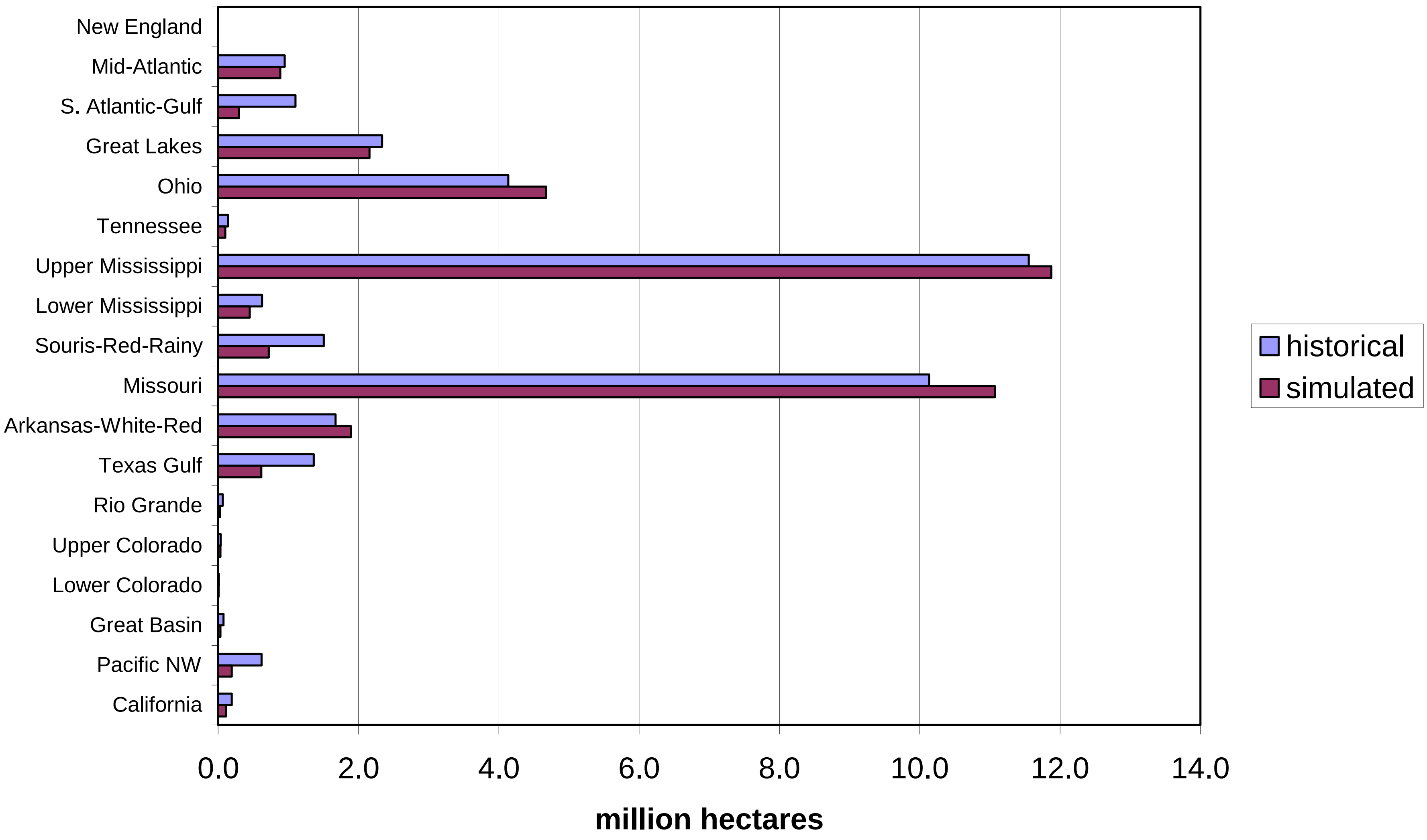
- Why Disaggregate?
  - Capture geographical heterogeneity
  - Terrestrial mitigation opportunities vary by land class
  - Climate impacts will vary by land class
- Hydrologic Unit Areas (HUAs)
  - 18 two-digit water basins in US
  - Fixed location
  - Useful for climate impact studies
  - Link to water supply will be important for future work on water and potential for biofuels
- Base-Year Calibration
  - No unique way to calibrate base year (calibration is something of an art)
  - Not easy to calibrate all of the following: land area by product and land class, output by product and land class, prices, costs of production
  - Exact calibration doesn't tell you where your model structure can be improved

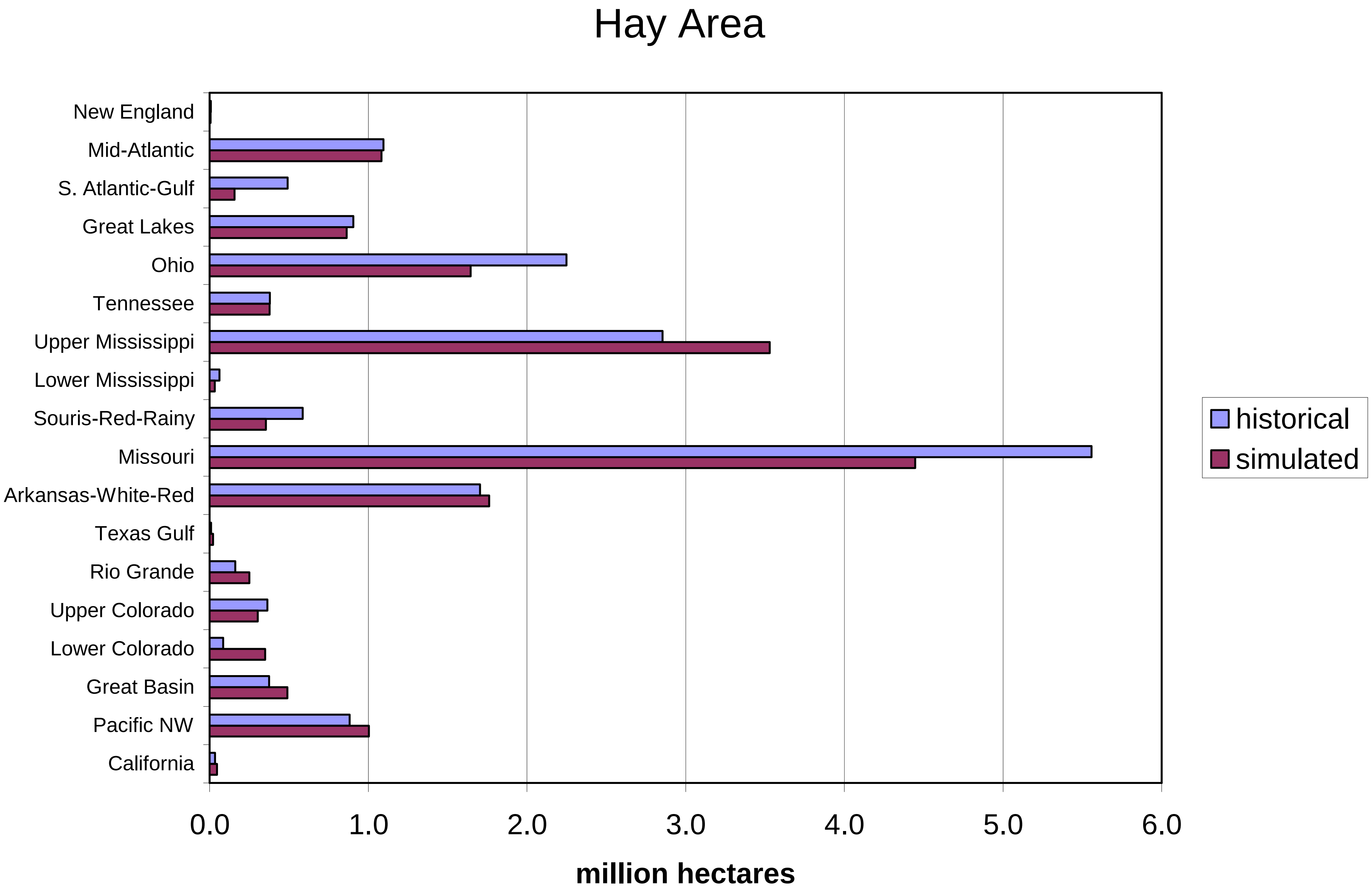
Major Water Resource Regions




Forest Area
New England
Mid-Atlantic
S. Atlantic-Gulf
Great Lakes
Ohio
Tennessee
Upper Mississippi
Lower Mississippi
Souris-Red-Rainy
Missouri
Arkansas-White-Red
Texas Gulf
Rio Grande
Upper Colorado
Lower Colorado
Great Basin
Pacific NW
California
0.0
10.0
20.0
30.0
40.0
50.0
million hectares
historical
simulated

Coarse Grains Area



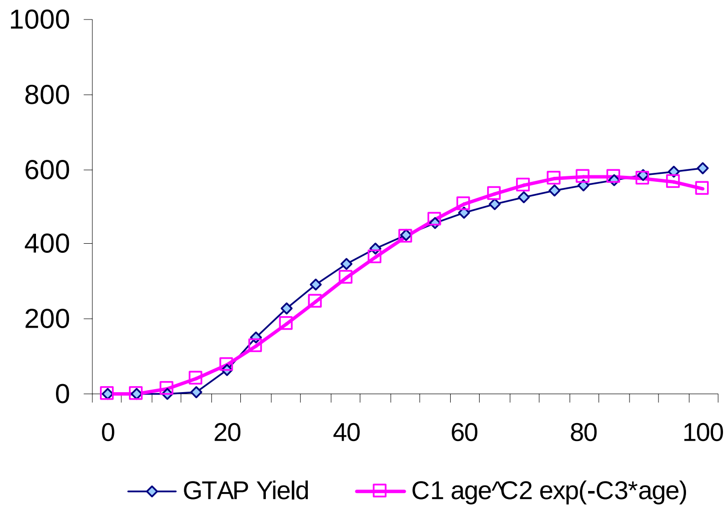


Hay Area
New England
Mid-Atlantic
S. Atlantic-Gulf
Great Lakes
Ohio
Tennessee
Upper Mississippi
Lower Mississippi
Souris-Red-Rainy
Missouri
Arkansas-White-Red
Texas Gulf
Rio Grande
Upper Colorado
Lower Colorado
Great Basin
Pacific NW
California
0.0
1.0
2.0
3.0
4.0
5.0
6.0
million hectares
historical
simulated

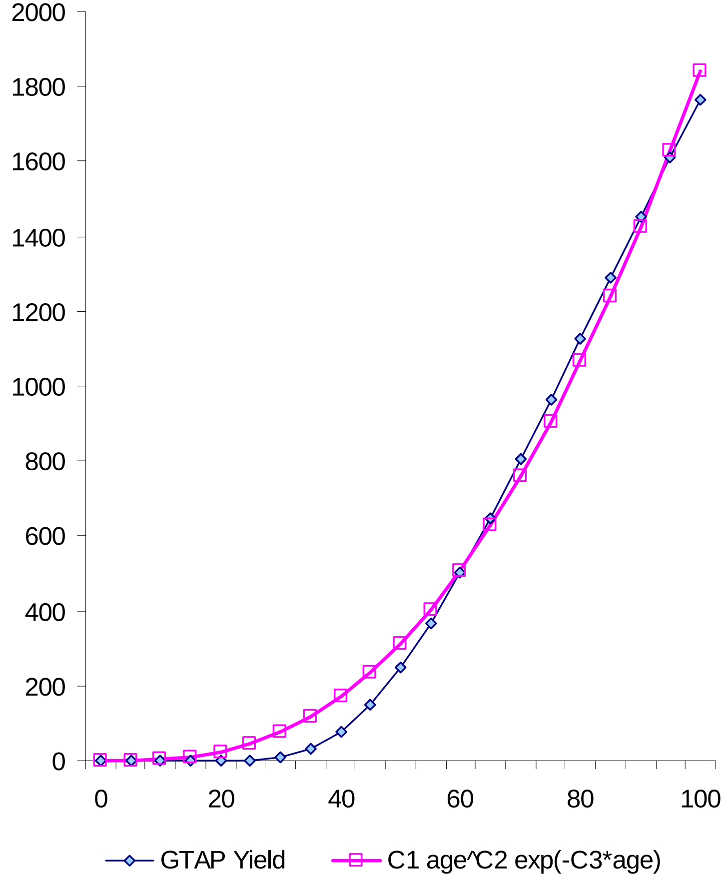
Forest Dynamics

- Tree growth curves vary across United States
- Calibration of growth curve to data provided through GTAP
- Response of forest production to carbon incentive
  - Optimal tree rotation age increases with carbon price
  - Faustmann equation (modified by carbon incentive) is an extra system equation paired with unknown rotation age
  - Modified Faustmann equation includes term that integrates carbon stock or increment of carbon sequestered over tree growth curve
  - Can calculate carbon incentive either as a rental paid for carbon storage or as full payment for increment sequestered
  - Computational burden can be reduced by selecting functional form for tree growth curve that has closed-form integral

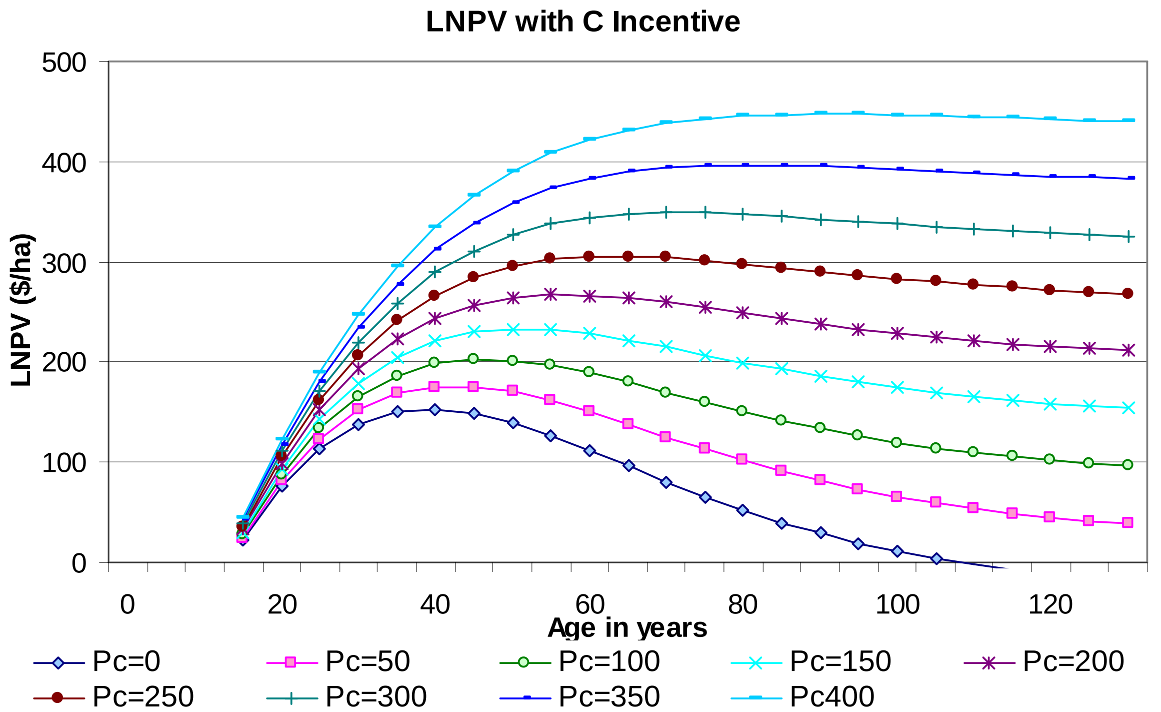
Tree growth curve for southeastern pine plantations
(yield in cubic meters as a function of tree age)



Tree growth curve for Pacific Northwest
(yield in cubic meters as a function of tree age)

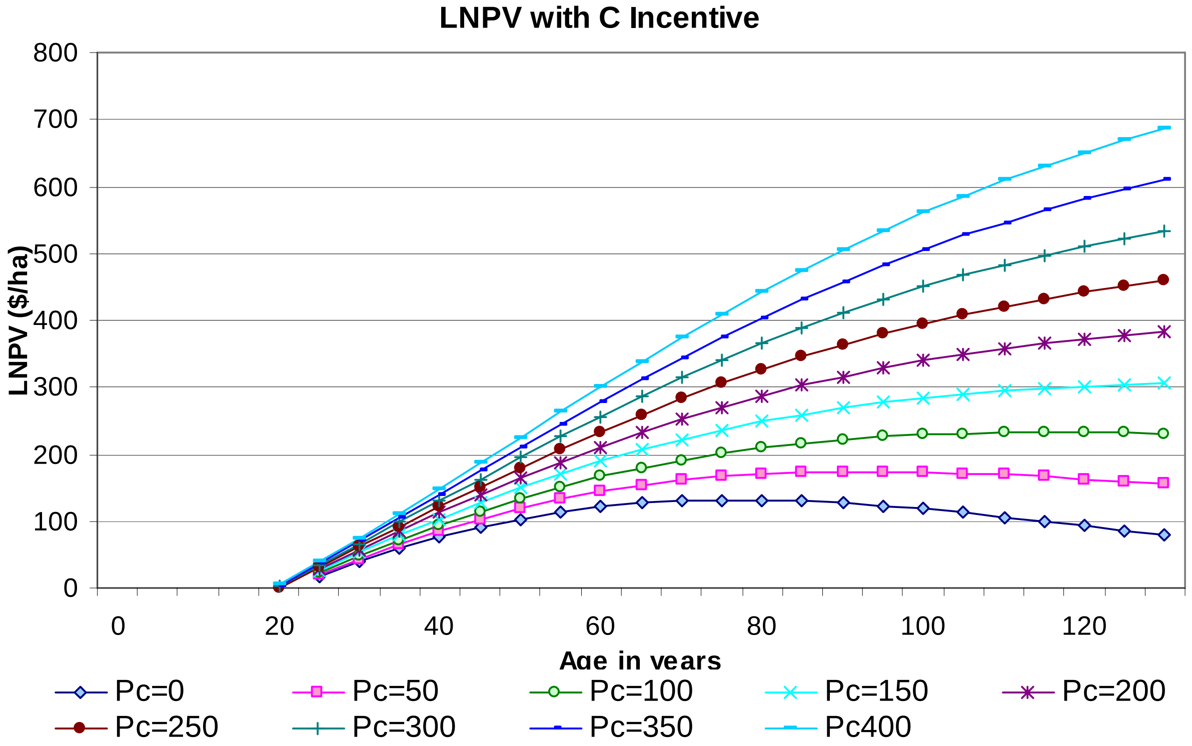


Levelized net present value per hectare at various carbon prices: southern pine plantation trees



Assumptions: p_t = \$49 per cubic meter, c_g = \$1,000 per hectare,
k = 0.2 metric tons carbon per cubic meter of wood,
r = 3%, all stored carbon is released to the atmosphere at harvest

Levelized net present value per hectare at various carbon prices: Pacific Northwest trees



Assumptions: p_t = \$49 per cubic meter, c_g = \$750 per hectare,
k = 0.2 metric tons carbon per cubic meter of wood,
r = 3%, all stored carbon is released to the atmosphere at harvest

Toward General Equilibrium

- It is possible to embed partial-equilibrium AgLU in a CGE framework
- This demonstration combines AgLU for the US with an everything else (ETE) sector
- US (18 land classes) trades with composite Rest of World
- Approach is to combine system equations for AgLU with CGE system equations
  - Market clearing for labor and capital
  - Market clearing for “everything else” sector
  - Zero-profit condition for “everything else” sector
- Benefits of CGE formulation
  - Utility-based consumer demand system
  - Walras’ Law test helps find accounting errors
  - Test model integrity by changing numeraire price and checking that quantities remain unchanged

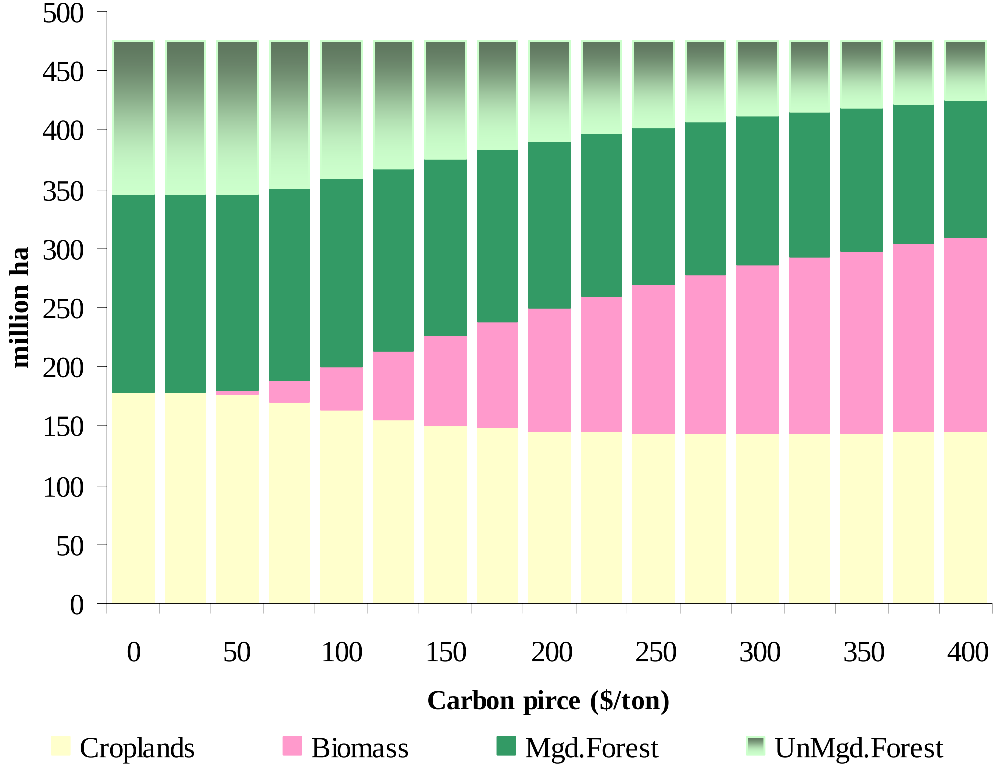
AgLU-CGE: Equations that Solver must handle

	Equation	Unknowns
Primary Agriculture		
Crop1: Food Grains	market clearing	price
Crop2: Coarse Grains	market clearing	price
Crop3: Oil Crops	market clearing	price
Crop4: Other Food Crops	market clearing	price
Crop5: Hay	market clearing	price
Forestry	market clearing	price
Other Products		
Processed Food	market clearing	price
Feed1	market clearing	price
Pork/Poultry	market clearing	price
Feed2	market clearing	price
Beef	market clearing	price
Other Products		
Processed Food	zero-profit condition	output level
Feed1	zero-profit condition	output level
Pork/Poultry	zero-profit condition	output level
Feed2	zero-profit condition	output level
Beef	zero-profit condition	output level
ETE	zero-profit condition	output level
Primary Factors		
labor	market clearing	factor rental
capital	market clearing	factor rental
Dropped Equation (Walras' Law test)		
ETE	market clearing	numeraire price

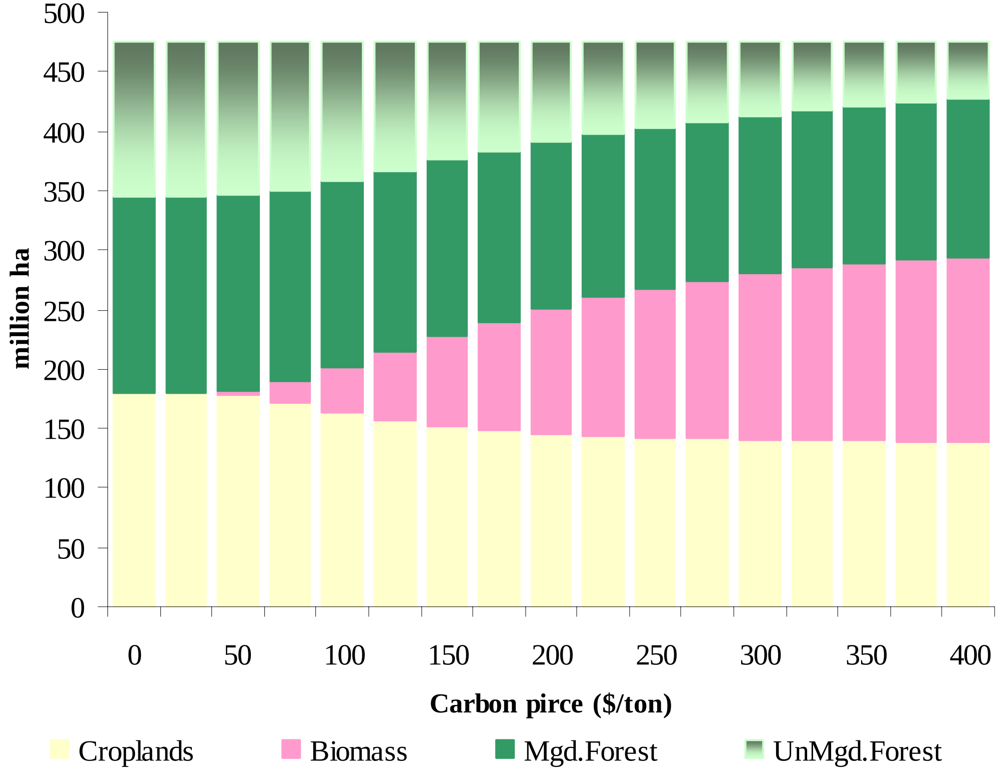
Steady-state land use simulation for the United States

- Land use at carbon prices up to US$400 per metric ton of carbon
- Scenarios
  - Carbon incentive for biofuel producers only
  - Carbon incentive for biofuel producers and forest land owners
- Land prices increase with carbon incentive and the area of managed land increases
- How can we value the carbon stored in unmanaged land, especially unmanaged forests?

Carbon incentive for biofuel producers only
(US land use at various carbon prices)



Carbon incentive for biofuel producers and forest land owners (US land use at various carbon prices)



Conclusions

- Disaggregation of US into 18 subregions for agriculture and forest products supply
  - Works well but is data intensive
  - Base-year calibration: exact match to benchmark data at the country level, but not necessarily for smaller land areas within country
- Forest Dynamics
  - Optimal tree rotation age increases with carbon price
  - Endogenous tree rotation age is difficult to handle in recursive models, but the forestry steady state is not difficult to calculate
- Toward General Equilibrium
  - Keep track of equations and unknowns when adding land allocation framework
  - Recursive models: Consider intermediate strategy of modeling forests in their steady state
- Complexity of Modeling Agriculture, Land Use and Forestry
  - This problem is hard!
  - How can we simplify yet maintain key interactions?
- Key Remaining Issues
  - Tropical forests and deforestation
  - Valuing carbon in unmanaged land
  - Role of water in limiting agricultural and biofuel production