Land Use Changes and Consequent CO_2 Emissions due to US Corn Ethanol Production: A Comprehensive Analysis

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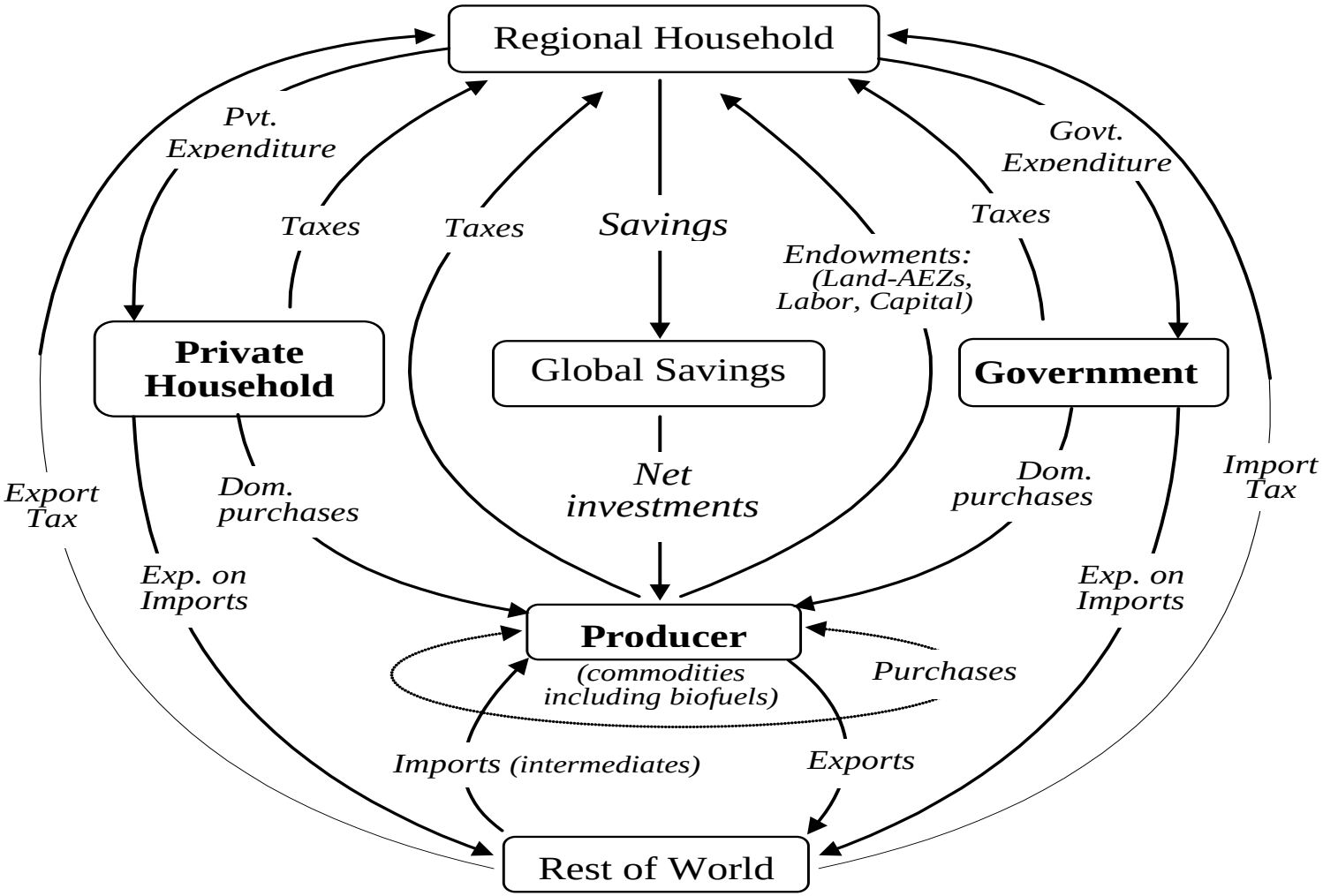
Presentation Outline

- Introduction and background,
- Analytical framework- why we need a CGE model,
- GTAP model and its modification,
- Alternative experiments and their assumptions,
- Land use implications due to the US ethanol, production under different sets of assumptions,
- Comparison of results with others,
- Land use emissions factors,
- Ethanol land use emissions,
- Well-to-Wheel ethanol and gasoline emissions,
- Summary,
- Conclusions.

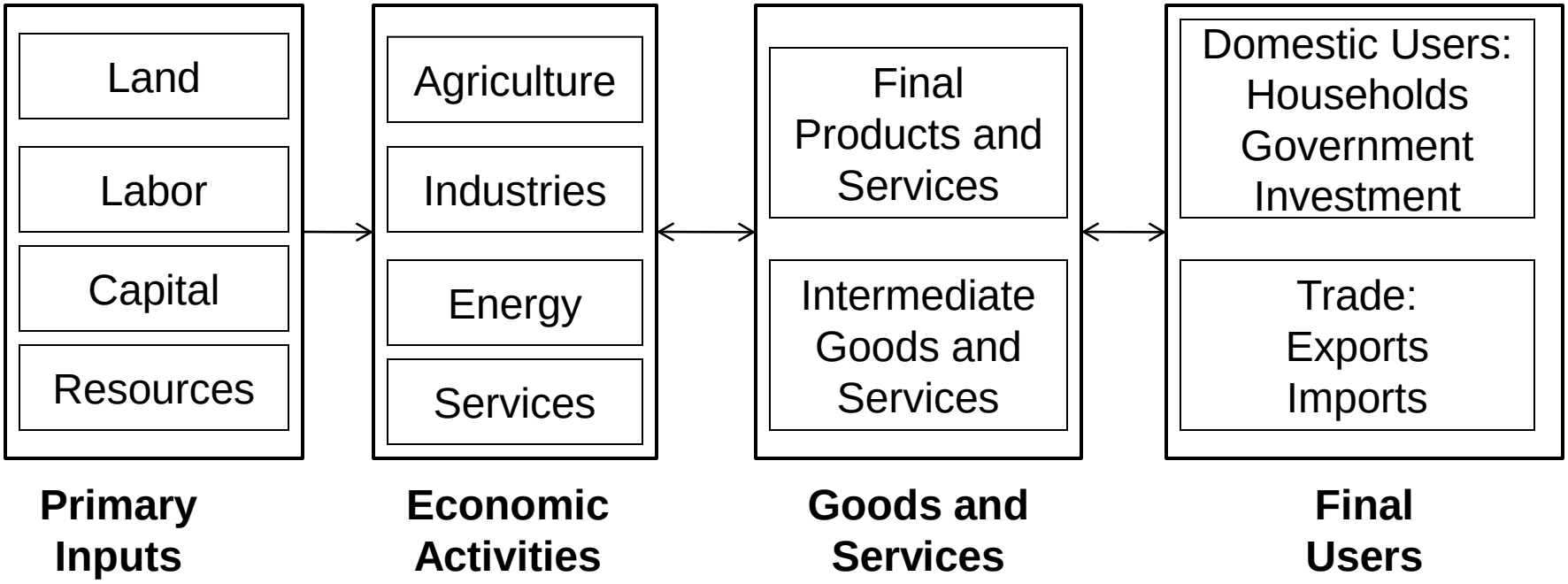
Introduction and Background

- The basic objective of this research was to estimate land use changes associated with US corn ethanol production up to the 15 billion gallons Renewable Fuel Standard level implied by the Energy Independence and Security Act of 2007.
- We also used the estimated land use changes to calculate Greenhouse Gas Emissions associated with the corn ethanol production.
- The main model that was used for the analysis is a special version of the Global Trade Analysis Project (GTAP) model. It is a global computable general equilibrium model.

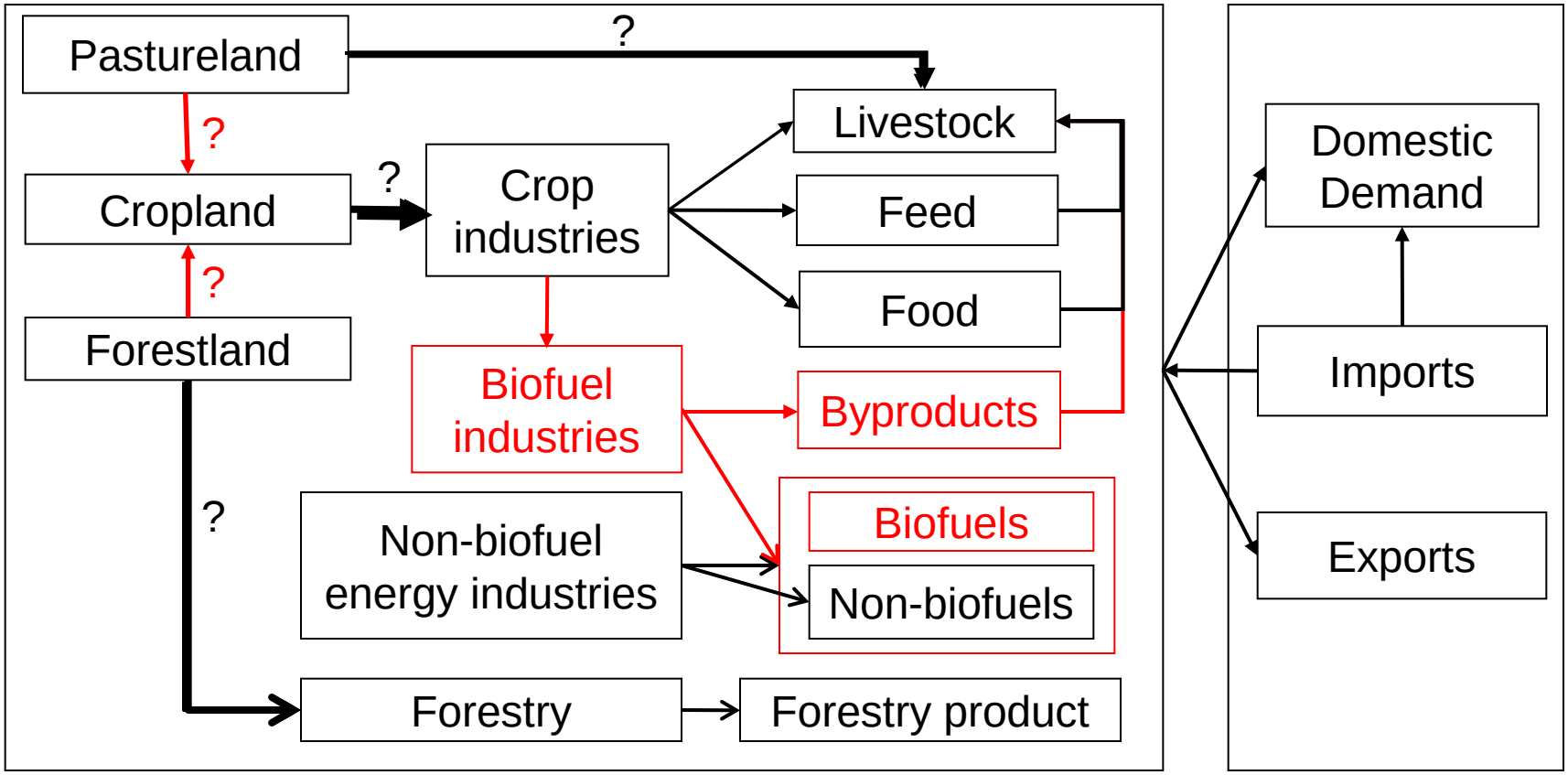
Analytical framework – GTAP model



Analytical framework - why we need a CGE model



Analytical framework – Major biofuel links



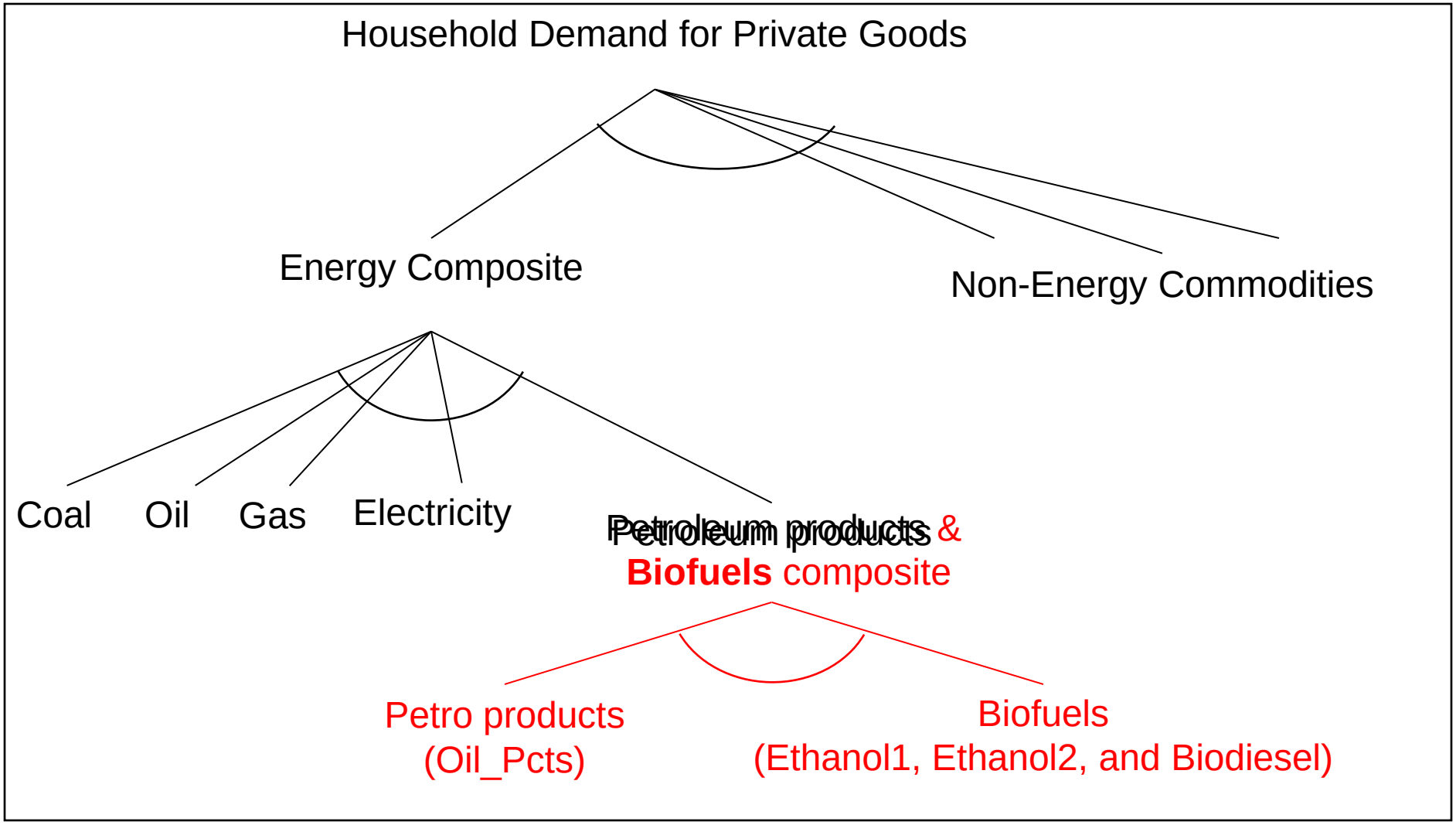
Production and intermediate demands

Final demands

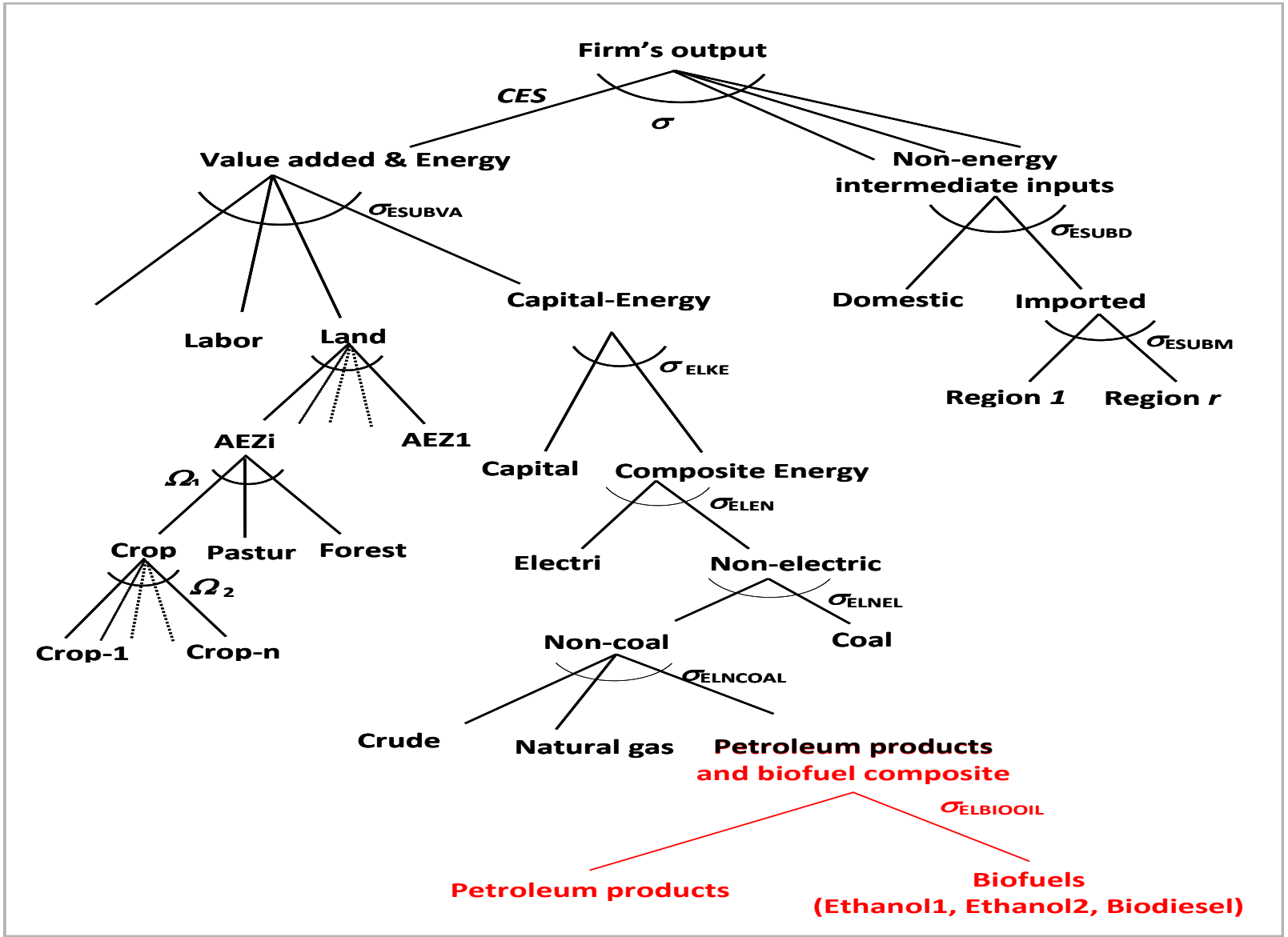
GTAP model and its modifications – Database

- **GTAP Database Version 6:**
  - Original database represents 2001 world economy (87 regions and 57 commodities)
  - New database, GTAP-BIO (87 regions and 62 commodities, and 60 industries)
    - Ethanol 1 produced from coarse grains,
    - Ethanol 2 produced from sugarcane,
    - Biodiesel from oilseeds .
    - DDGS – co-product of ethanol 1,
    - Meals – co-product of vegetable oil.
  - Data on production, consumption and trade of biofuels are obtained from the International Energy Agency (IEA)
  - Aggregation scheme in April 2010 report (19 regions, 34 commodities, and 32 industries)

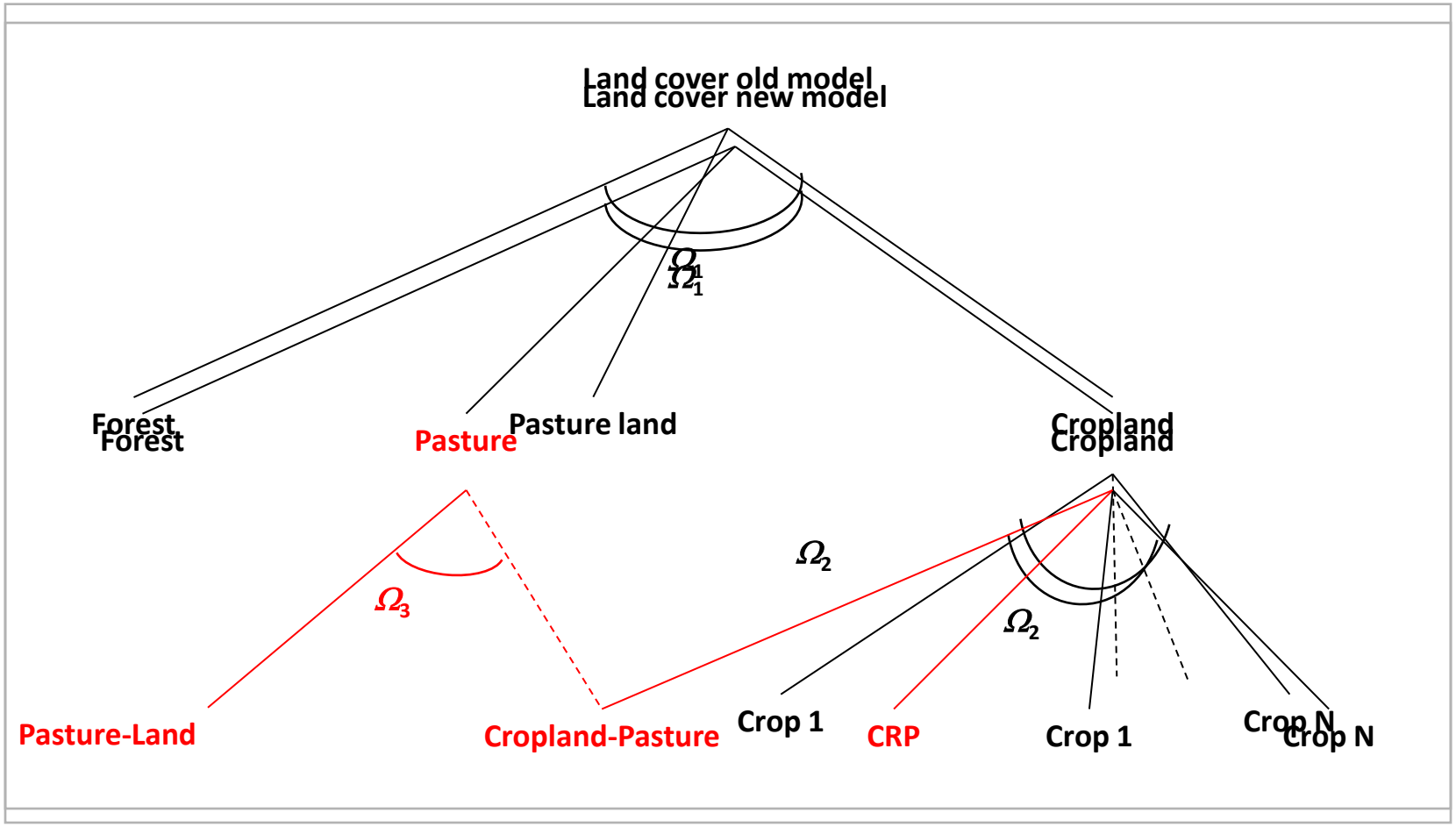
GTAP model and its modifications – Household demand



GTAP model and its modifications – Production function



GTAP model and its modifications – Land cover



GTAP model and its modifications – Land Productivity

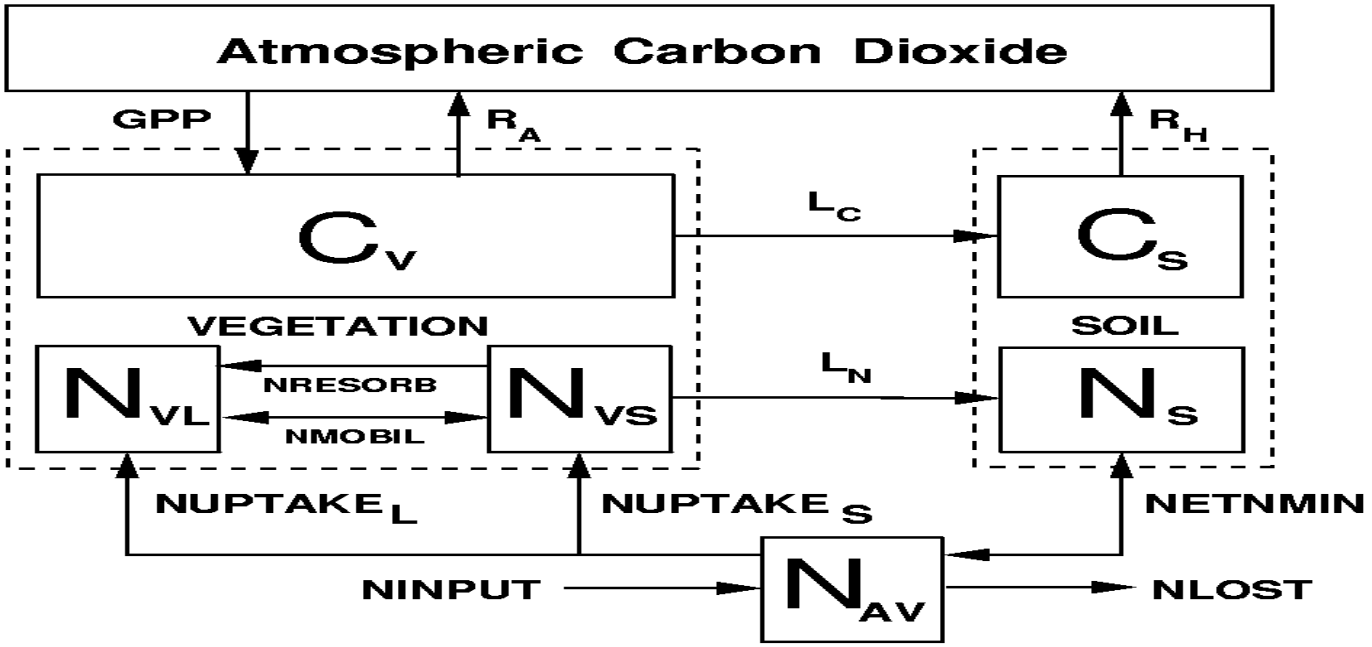
- Yield *intensification*:
  - Change in yield due to change in price,
  - An elasticity of 0.25 is used based on Hertel et al. (2009),
  - An increase of 10% in crop price, *relative to variable input prices*, would result in roughly a 2.5% rise in yields,
- Yield *extensification:*
  - Change in yield due to crop land expansion, including:
    - Change in yield due to substitution among crops – included in theGTAP database,
    - Change in yield due to moving into pasture and forest – GTAP previously had no data on this item.

GTAP model and its modifications – Extensive margin

- Moving into forest and pastureland*:*
  - We measure productivity of new cropland versus existing cropland with a parameter called ETA,
  - In our earlier work, we used ETA=0.66 for all regions across the world.
- We developed a new set of regional ETA by AEZ using a process-based biogeochemistry model (Terrestrial Ecosystem Model (TEM)) along with spatially referenced information on climate, elevation, soils, and vegetation land use data.

GTAP model and its modifications – TEM model

- In TEM, the net ecosystem exchange of CO_2 between the land ecosystems and atmosphere is calculated (known as Net Primary Product -NPP)

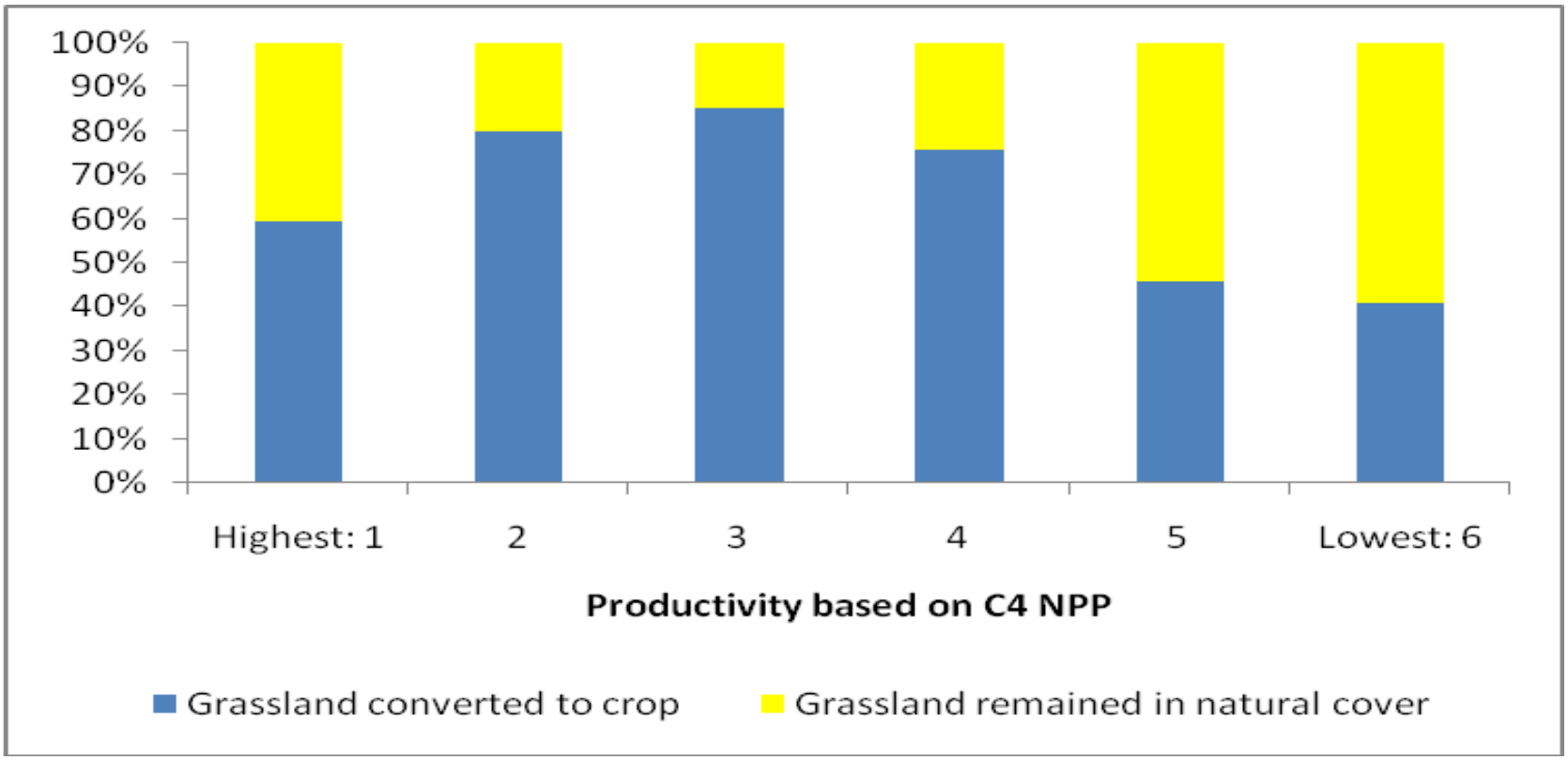


The Terrestrial Ecosystem Model (TEM)

GTAP model and its modifications – Data used in TEM

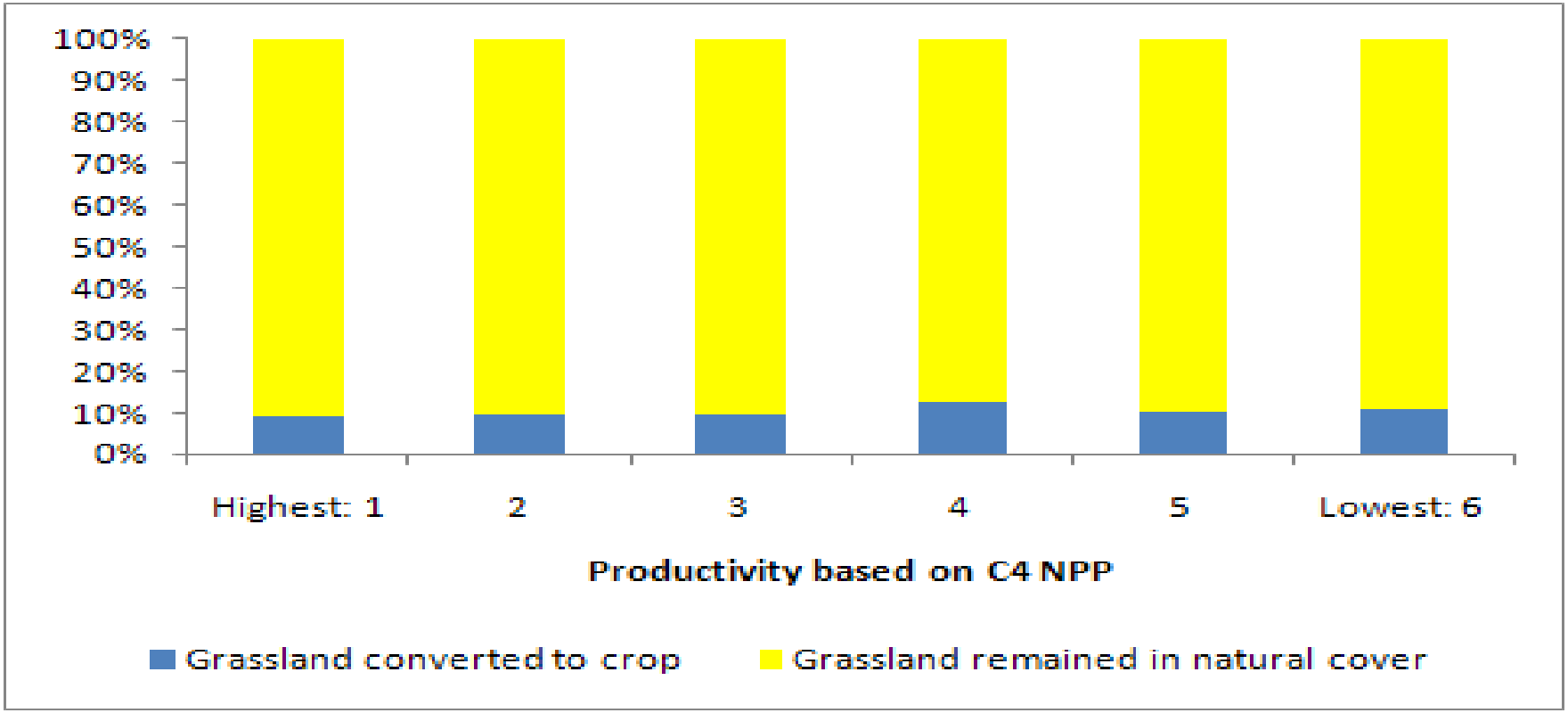
- Parameters in TEM may be specific to different vegetation types. We assigned two sets of parameters:
  - Parameters on original land type,
  - Parameters for a generic C4 crop.
- To run TEM for the globe, we used data on atmosphere, vegetation, soil texture, and elevation at 0.5°latitude x 0.5° longitude resolution from 1900 to 2000.
- We dropped lands not suitable for crop production.
- To derive regional ETAs we compared NPP-C4 of areas with natural cover with NPP-C4 of cropland areas at AEZ level.

GTAP model and its modifications – Land availability



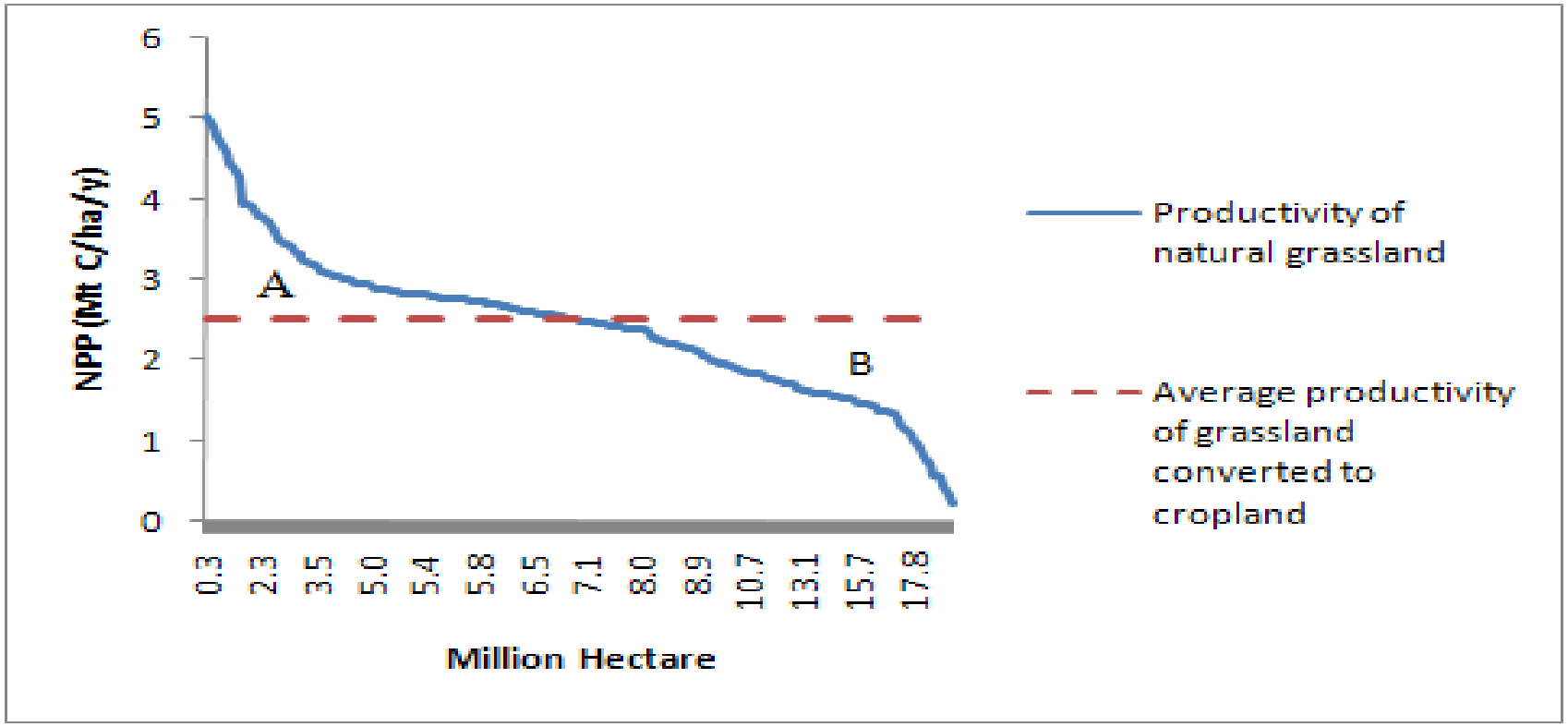
Availability of grassland suitable for crop production in US-AEZ10

GTAP model and its modifications – Land availability



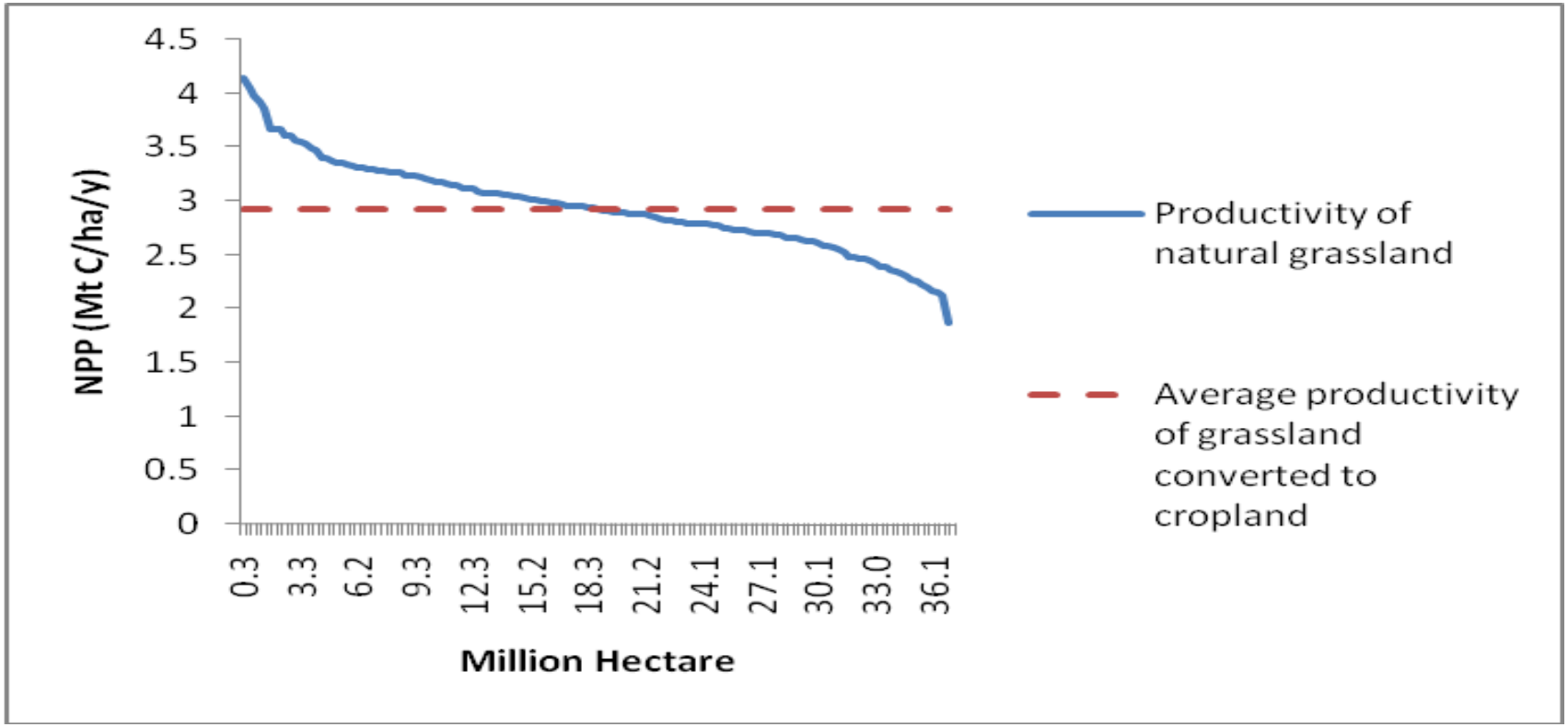
Availability of grassland suitable for crop production in Brazil –AEZ4

GTAP model and its modifications – Derivation of ETA



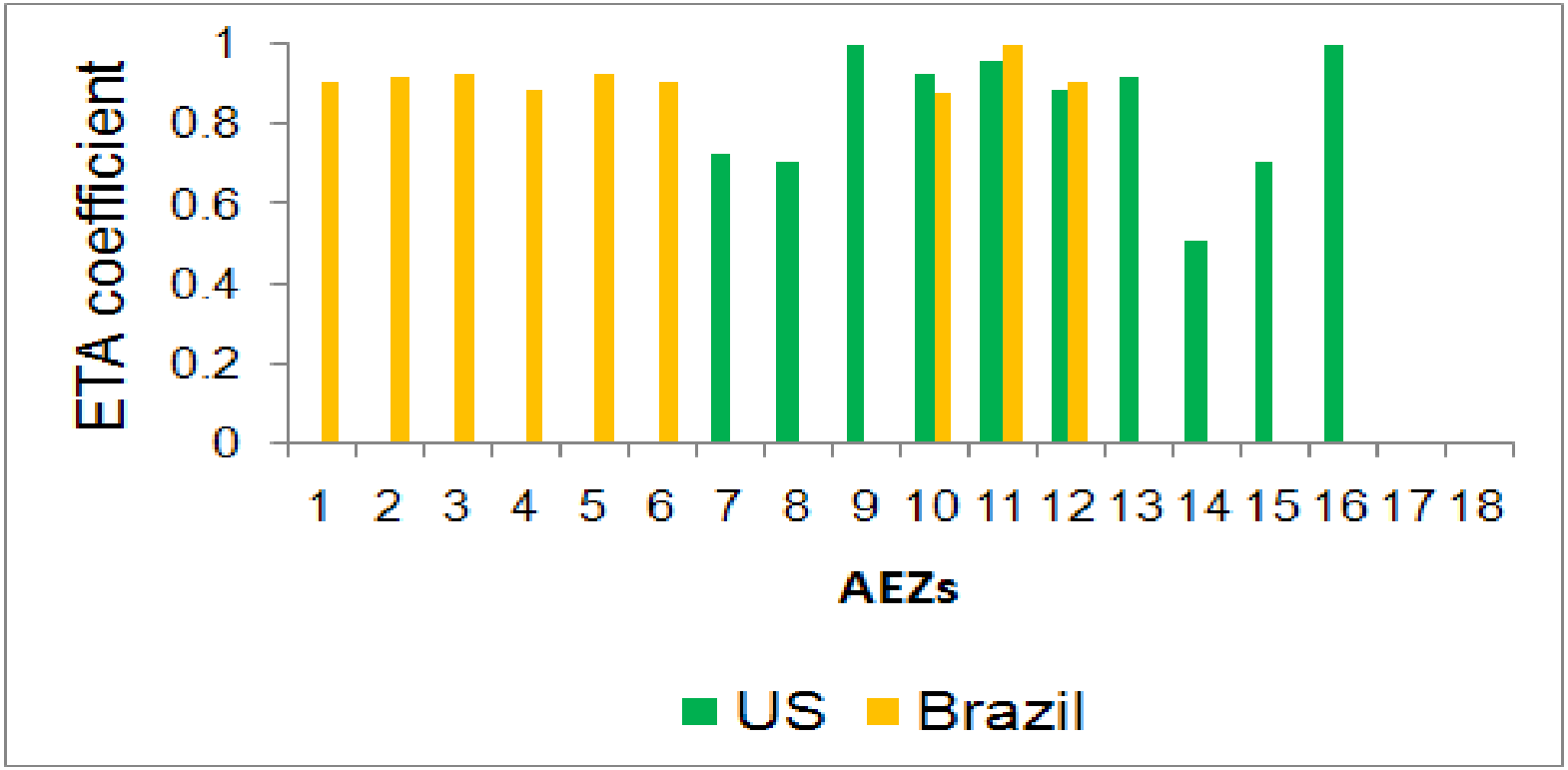
Average and marginal productivities in US AEZ10 for grassland

GTAP model and its modifications – Derivation of ETA



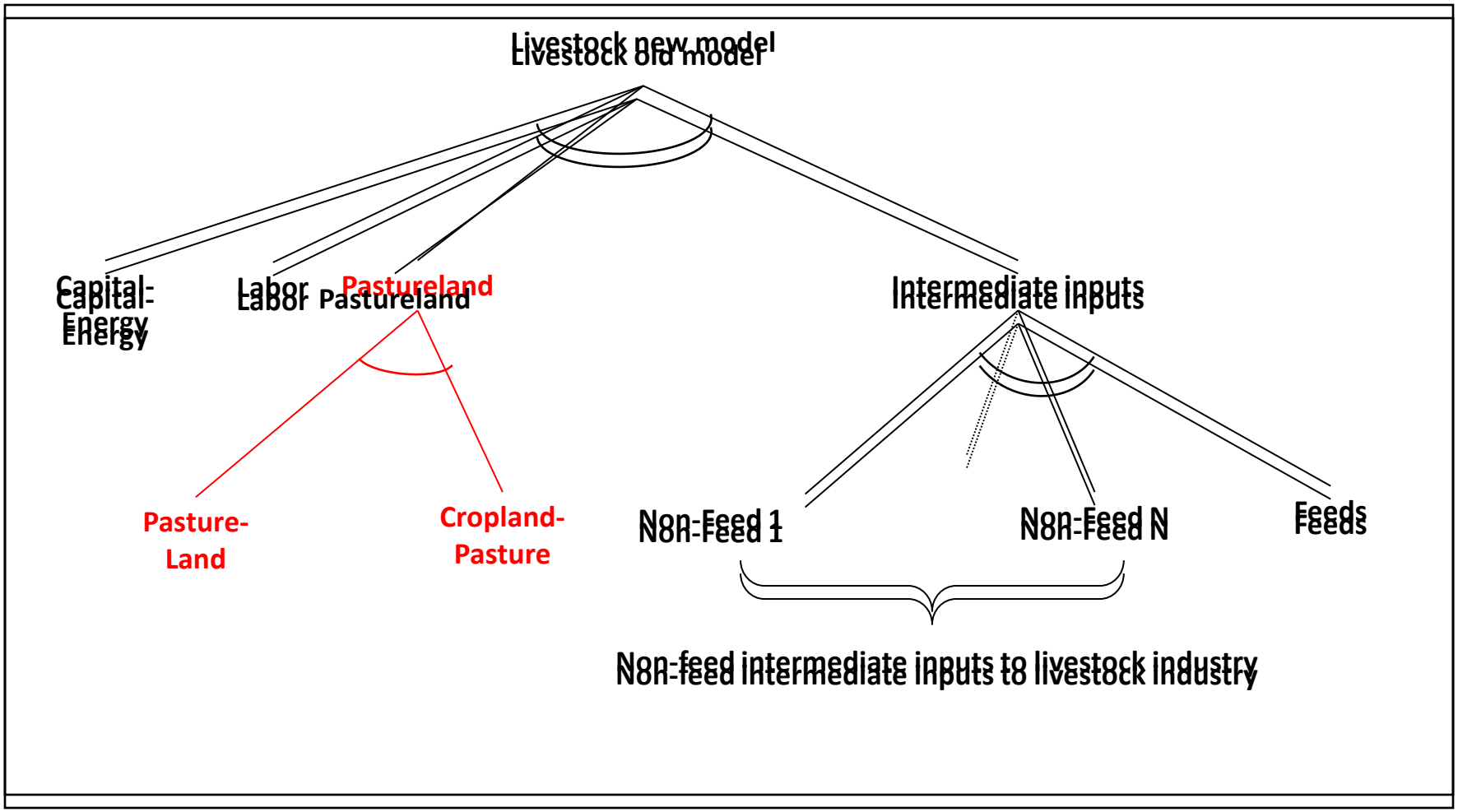
Average and marginal productivities in Brazil AEZ4 for grassland

GTAP model and its modifications – ETA US and Brazil

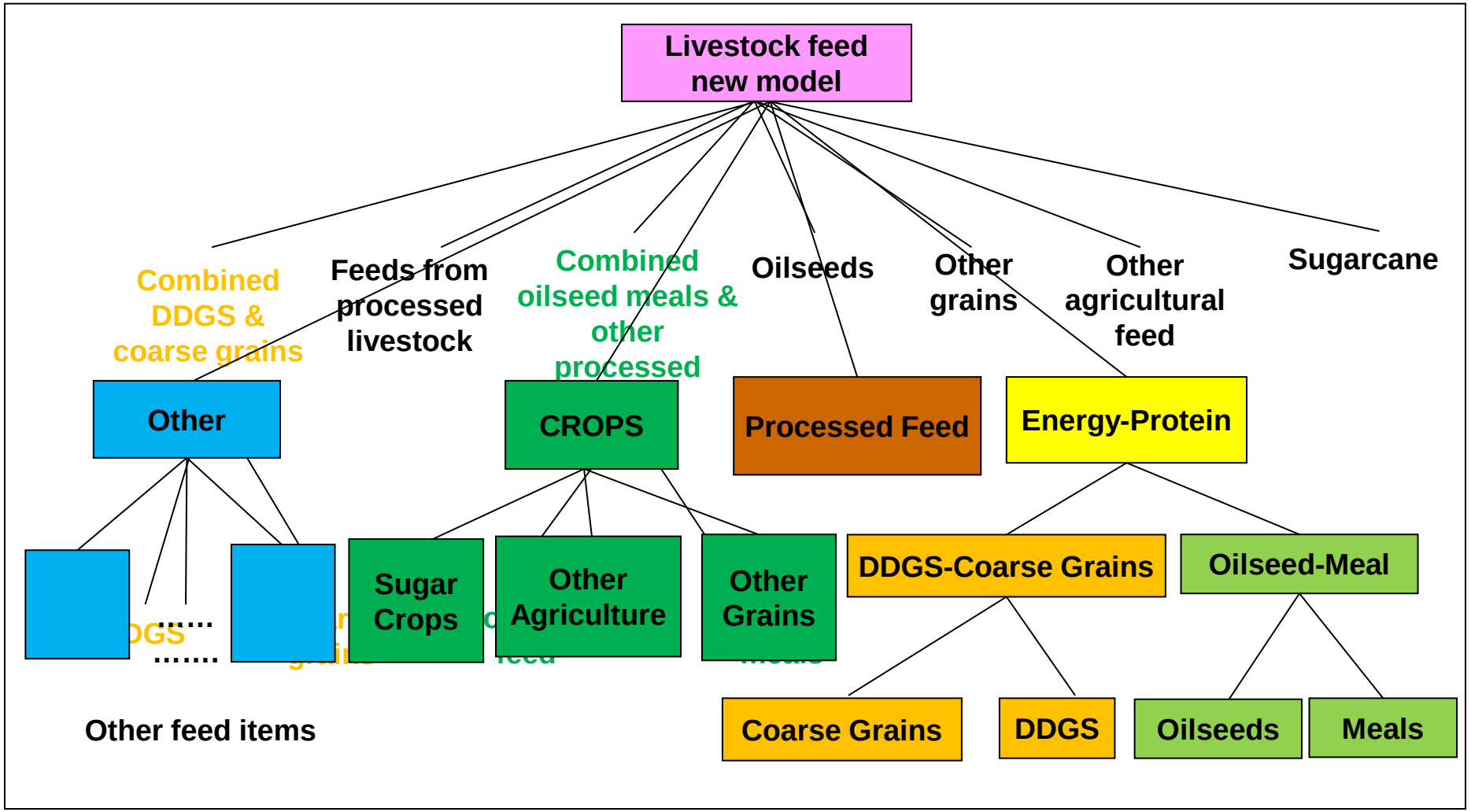


ETA parameters for US and Brazil by AEZ

GTAP model and its modifications – Livestock industry



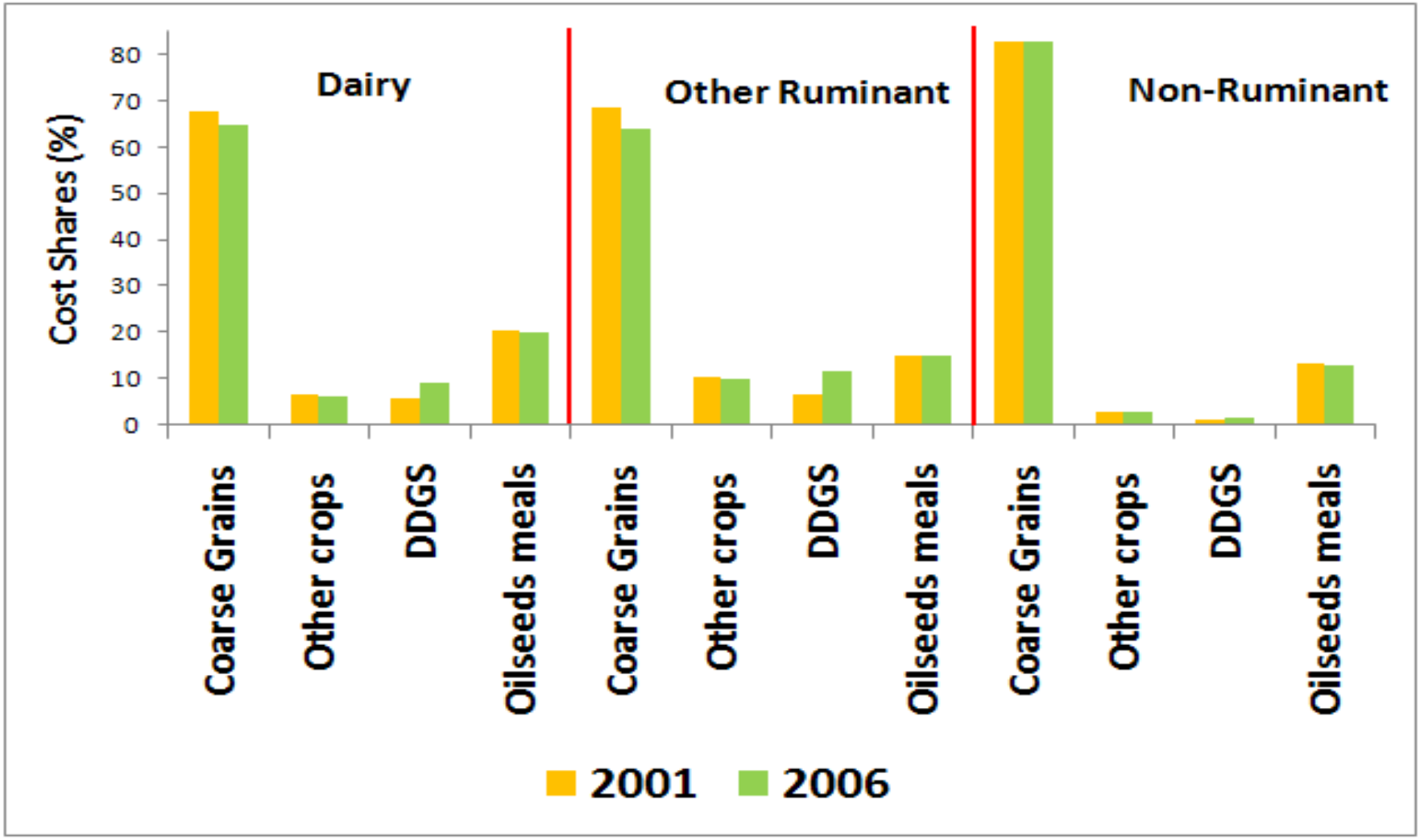
GTAP model and its modifications – Feedstuff demand



GTAP model and its modifications – Feed elasticities

- **Feedstuff elasticities of substitution:**
  - Top level of the nest:
    - 0.9 is taken from Hertel et al, (2005),
  - Second level of the nest:
    - 0.3 in the energy-protein feed composite,
    - 1.5 in other composite feed items,
  - Third level:
    - 20 in the meal-oilseed composites of all types of livestock industries,
    - 20, 25, and 30 in the DDGS-corn composites of non-ruminant, dairy, and meat ruminant industries respectively.

GTAP model and its modifications – Major feed costs



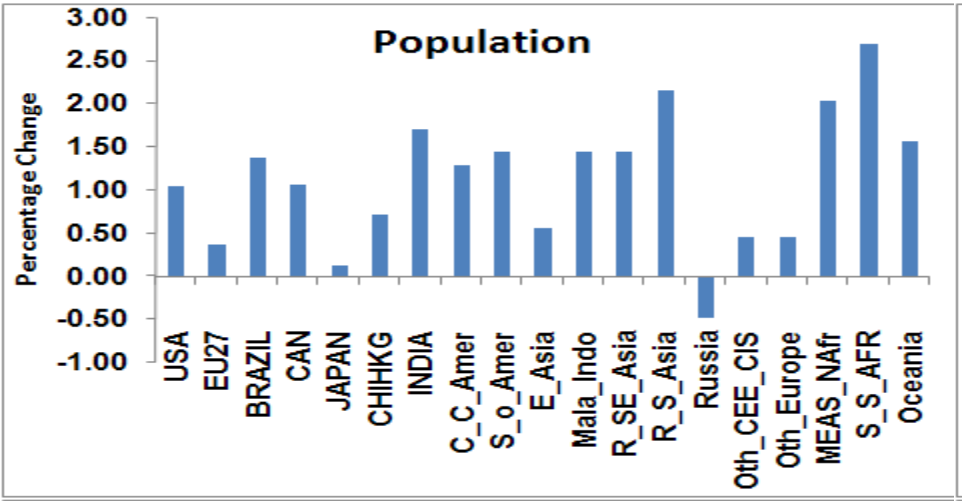
Experiments and their assumptions – Group 1

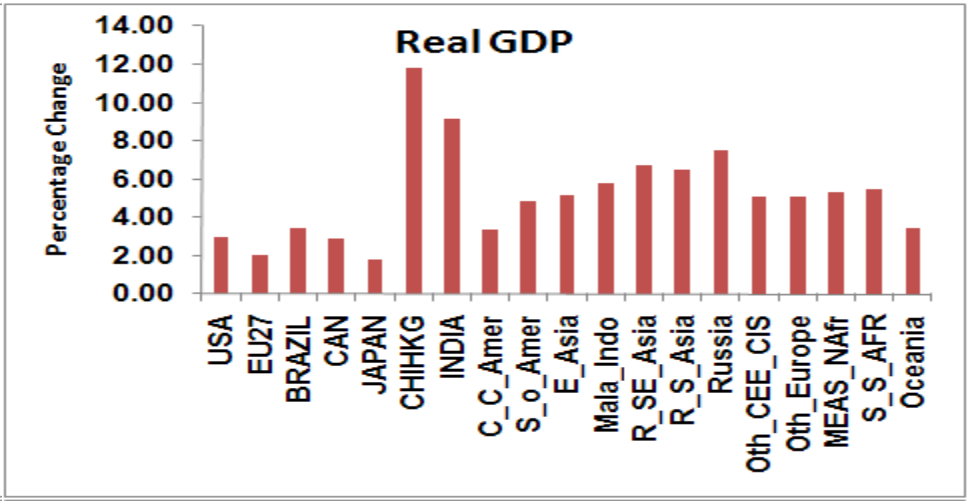
- *Group 1*- Simulations with 2001 database:
  - Ethanol production from 2001 to 2006 level.
  - Ethanol production from 2006 level to 7 B gallons,
  - Ethanol production from 7 B to 15 B gallons by increments of 2 B gallons.
- In this group we calculate land use implications of US ethanol production off of the 2001 database.
- This approach isolates impacts of US ethanol production from other changes which shape the world economy.
- It assumes that other factors such as population growth, yield improvement, and economic growth do not affect the land use implications of corn ethanol production.

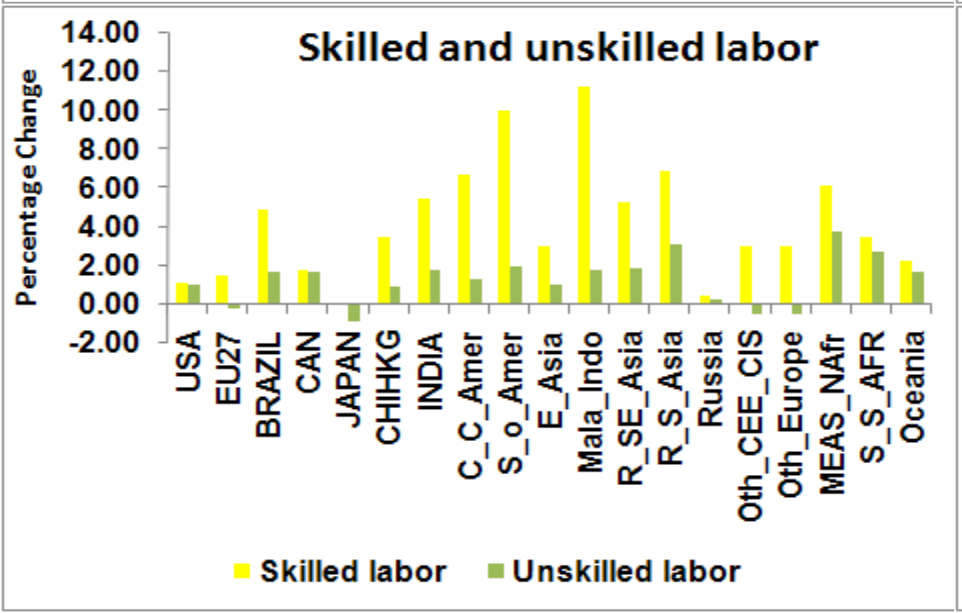
Experiments and their assumptions – Group 2

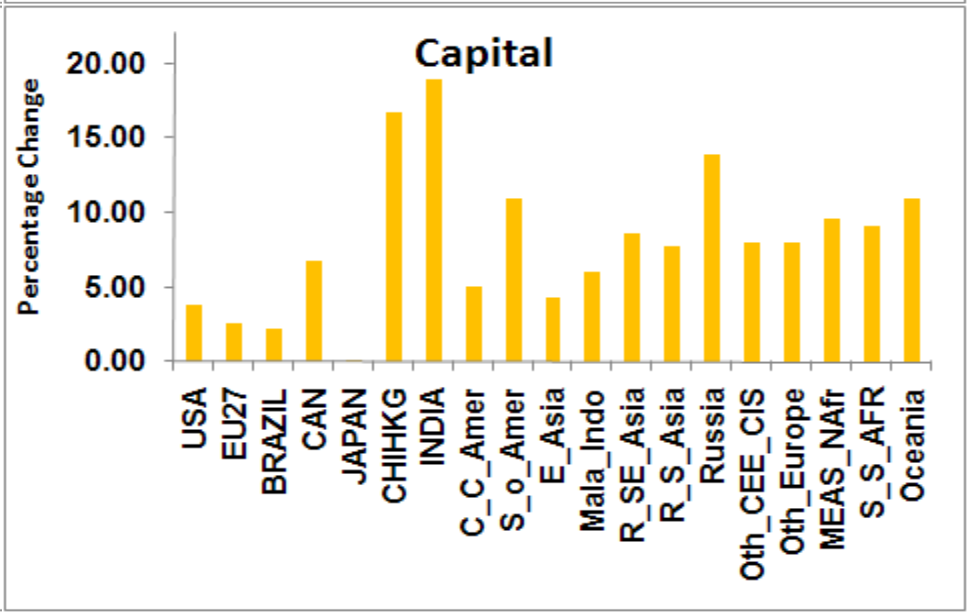
- *Group 2*- Simulations based on 2006 updated database:
  - Transition of world economy from 2001 to 2006,
  - Ethanol production from 2006 level to 7 B gallons,
  - Ethanol production from 7 B to 15 B gallons by increments of 2 B gallons.
- In this group of simulations we construct a baseline which takes into account changes in the global economy during the 2001-2006 time period.
- Then we use the updated database for other simulations of this group.
- No economic growth after 2006.

Experiments and their assumptions – Group 2: Annual percentage changes in global economy 2001-2006

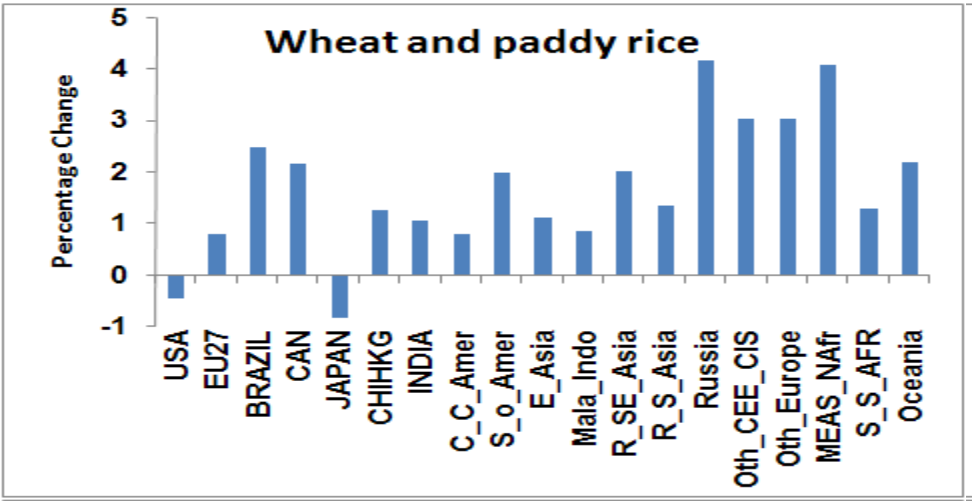


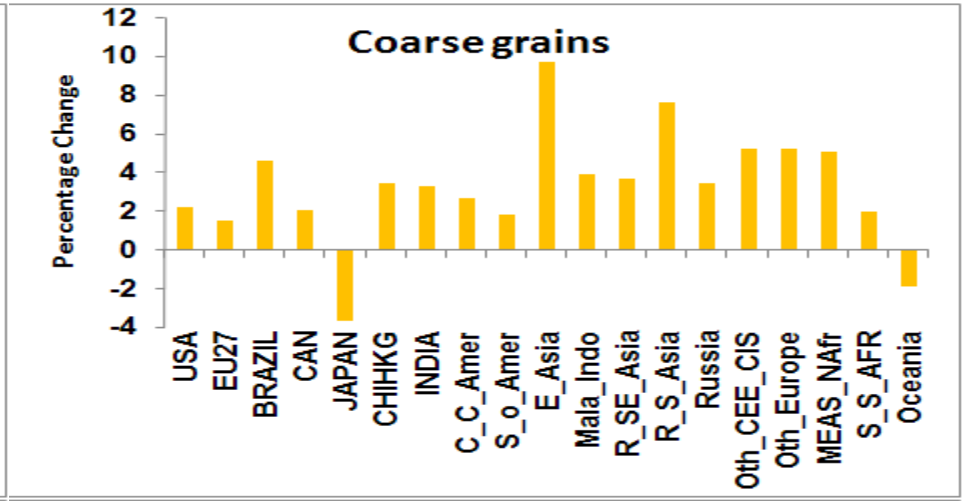


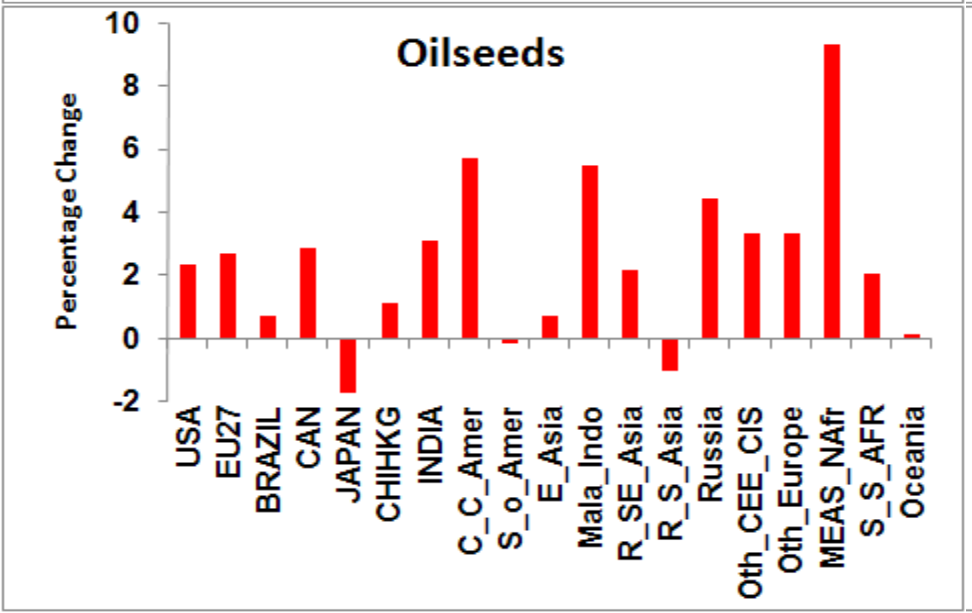


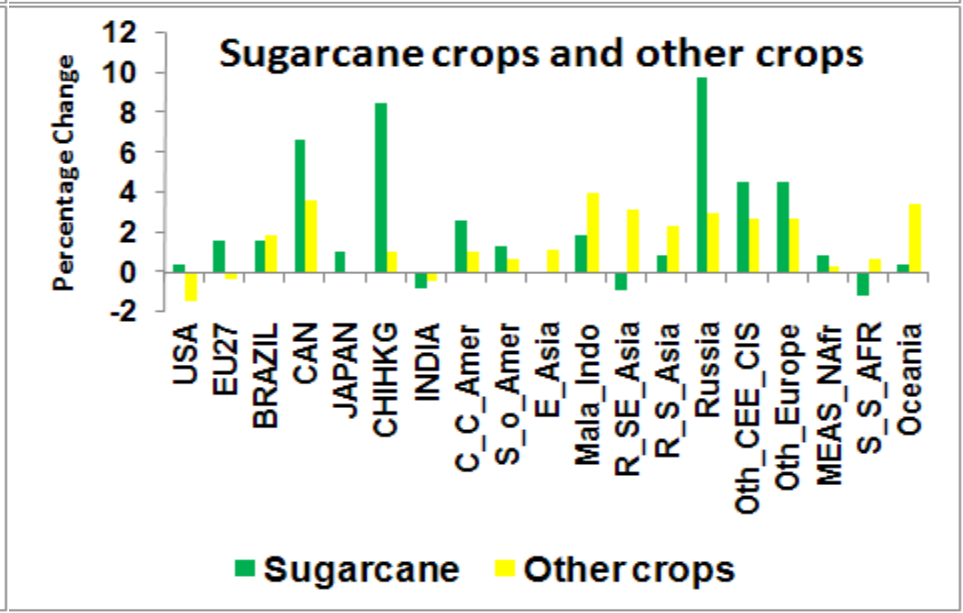


Experiments and their assumptions – Group 2: Annual percentage changes in crop yields 2001-2006





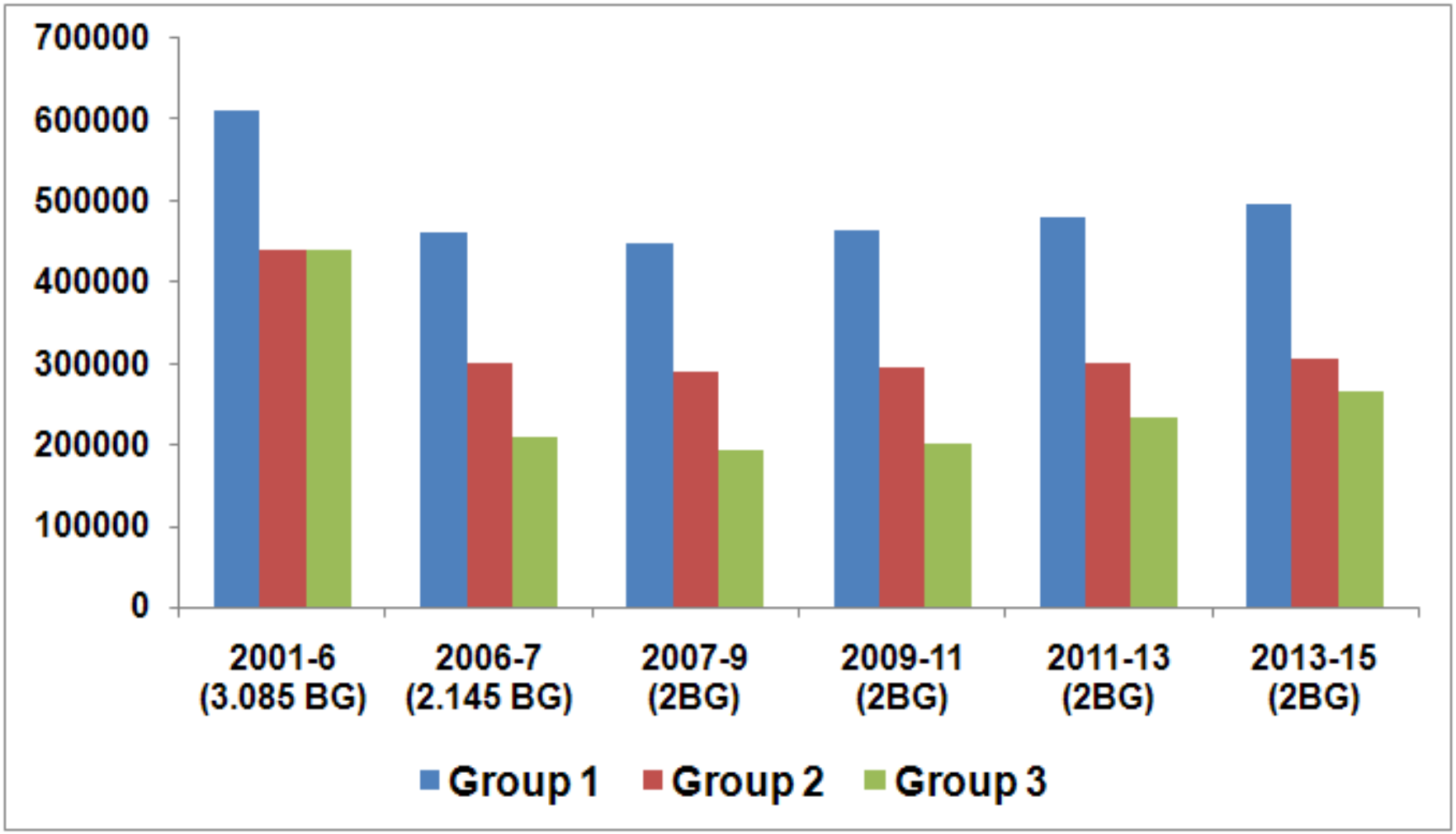




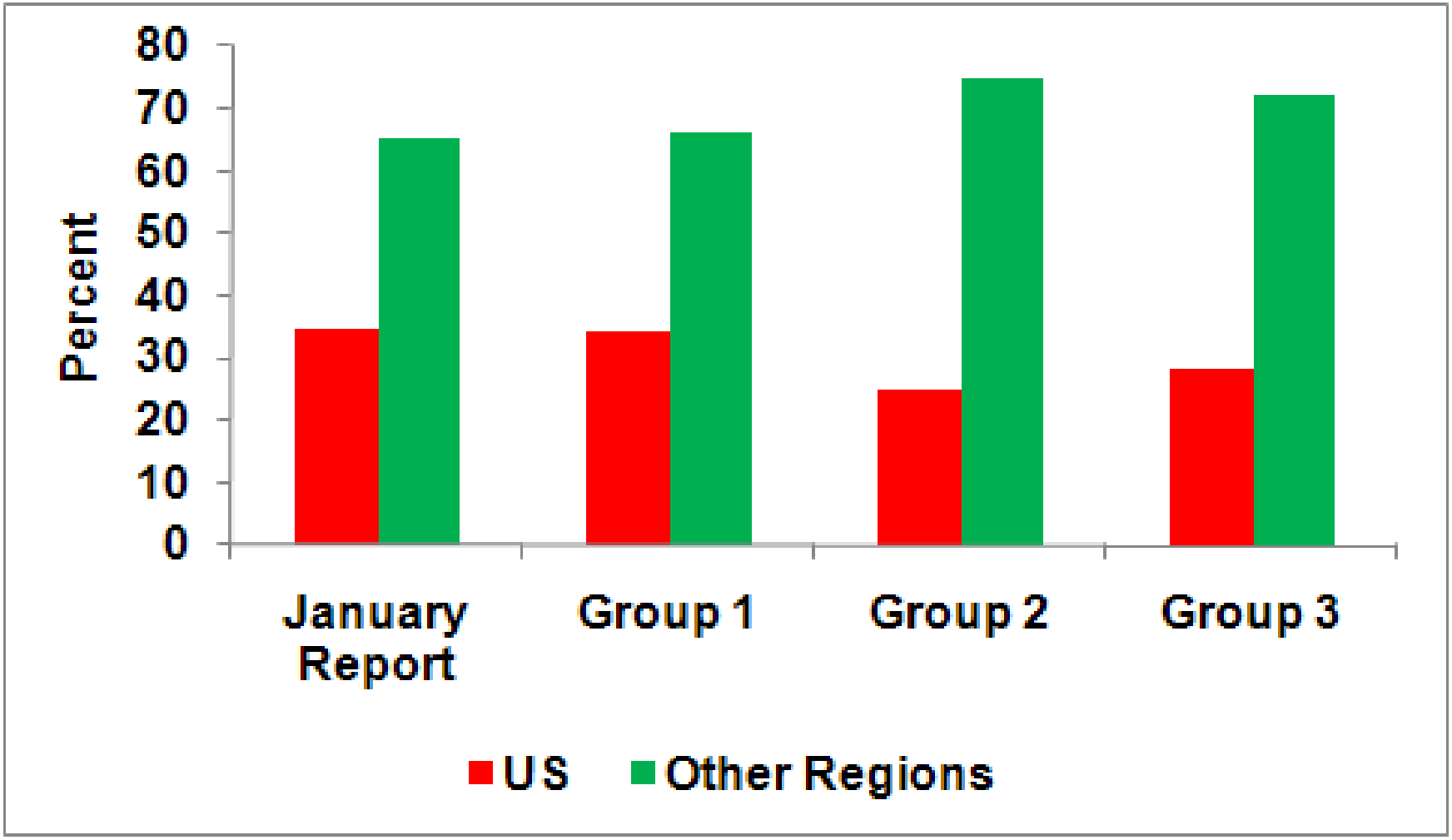
Experiments and their assumptions – Group 3

- *Group 3*- Simulations based on 2006 updated database and growth in crop yield and population:
  - Transition of world economy from 2001 to 2006,
  - Ethanol production from 2006 level to 2007 with 7 B gallons ethanol,
  - Ethanol production from 2007 to 2015 level with increase in ethanol by 2 B gallons every two years.
- In this group of simulations the base line for 2001-2006 is similar to group 2.
- We assume population will continue to grow following its past trend after 2006.
- We assume yield will grow at annual rate of 1% across all types of crops and regions after 2006.

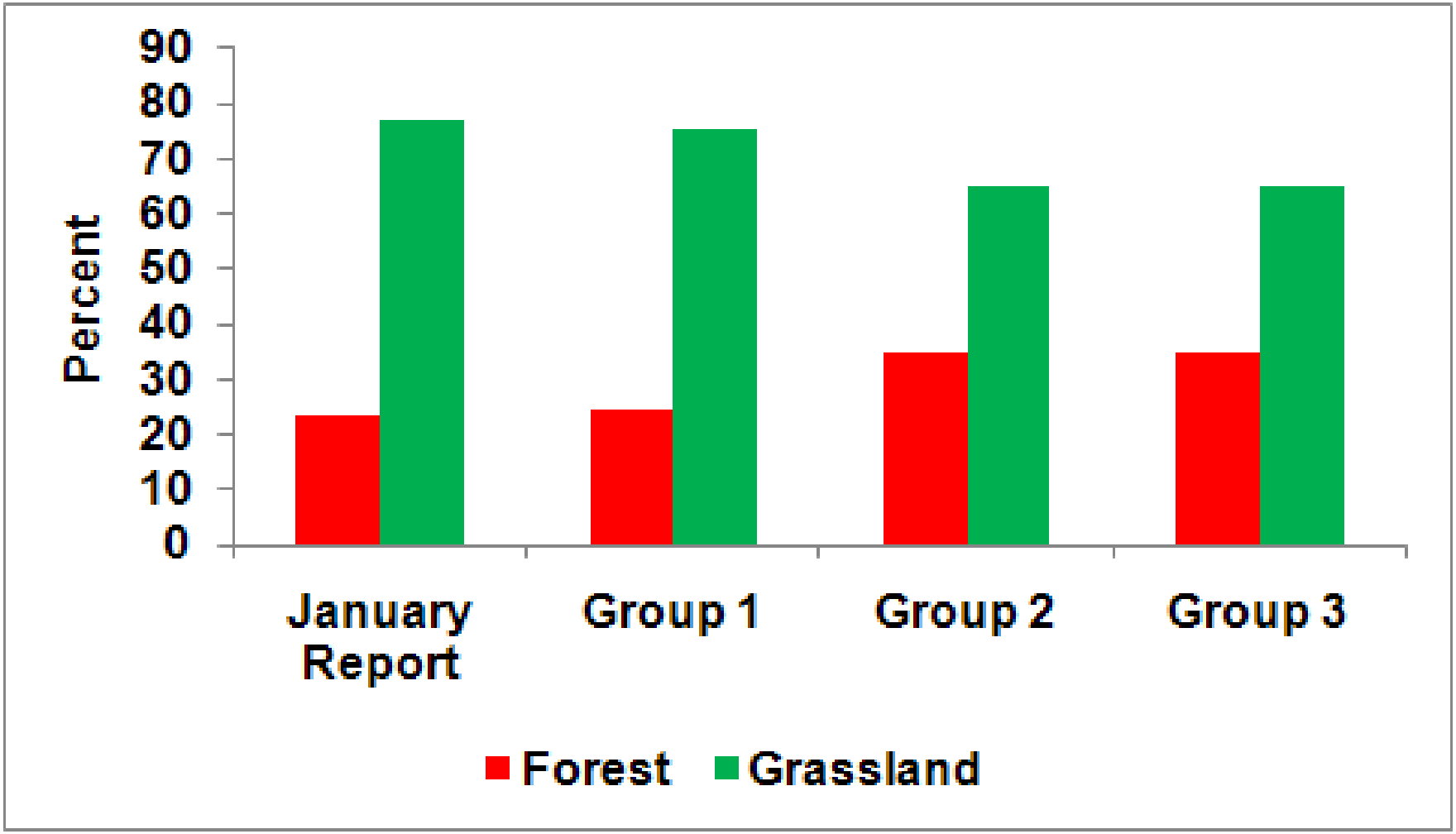
Land use implications due to US ethanol (Hectares)



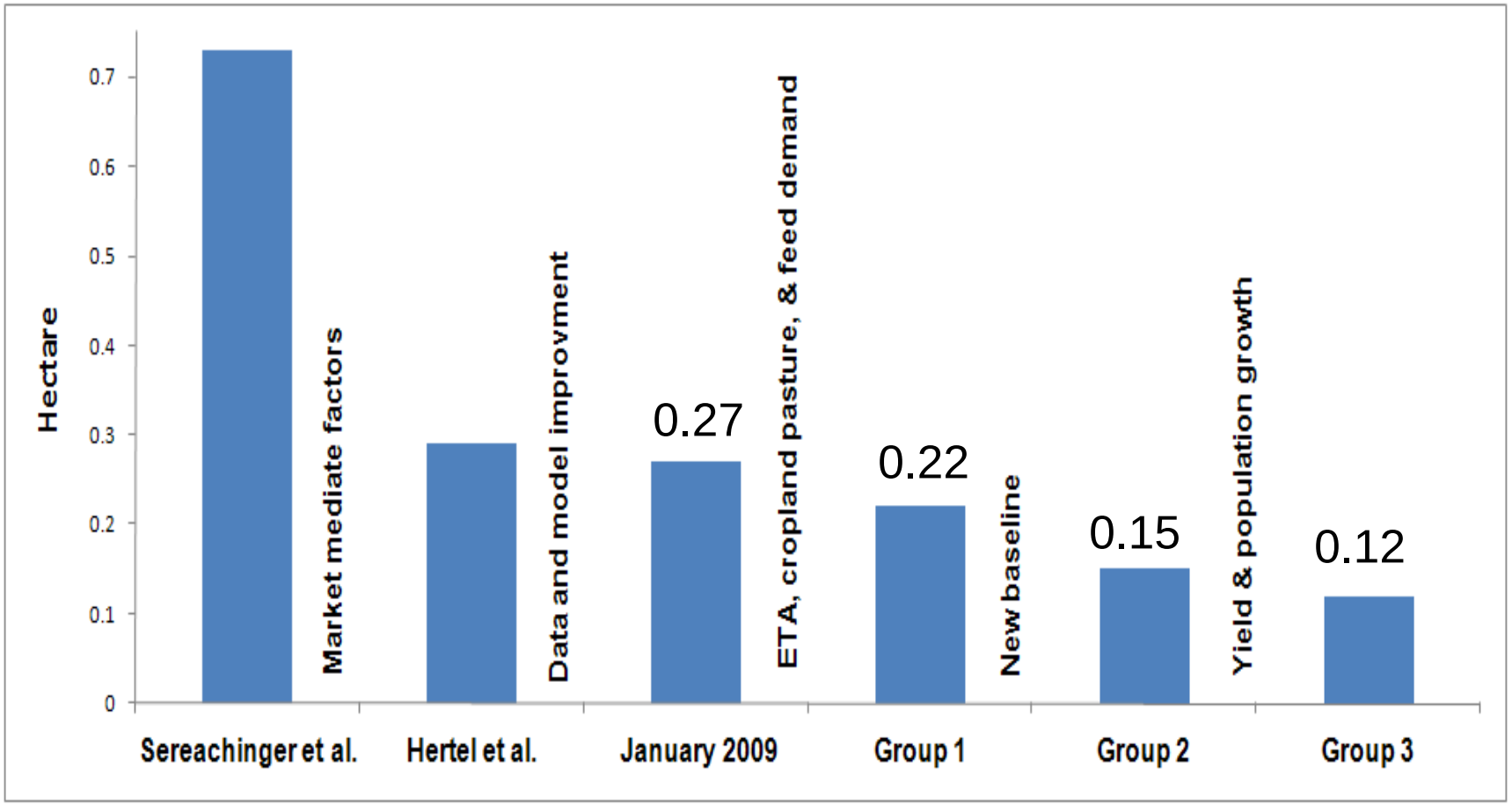
Land use implications due to US ethanol: Distribution of required land between US and other regions



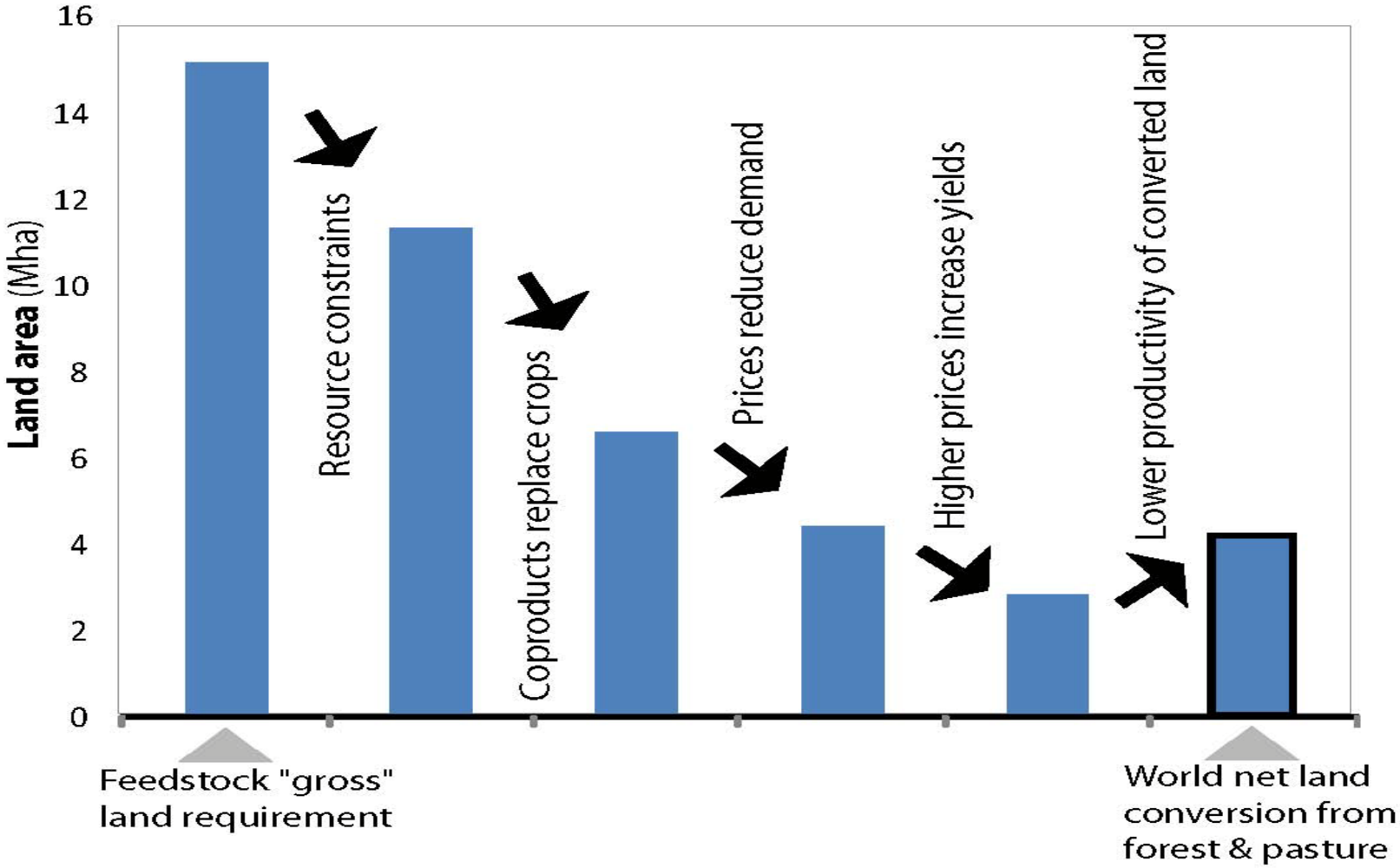
Land use implications due to US ethanol: Distribution of required land between forest and grassland



Land use implications due to US ethanol (Hectares per 1000 gallons)



Understanding the GTAP estimates of iLUC: market-mediated effects are key



Source: Hertel, Golub, Jones, O'Hare, Plevin and Kammen, *Bioscience* 2010.

Land use emissions factors: Data base and assumptions

- Datasets on land carbon profile: Woods Hole (regional data)
- Major assumptions
  - Carbon released at the time of land conversion
    - 25% of carbon stored in the soil will be released
    - 75% of carbon stored in forest vegetation will be released
    - 100% of carbon stored in grassland vegetation will be released
  - Forgone carbon sequestration; i.e., the carbon that could have been stored by non-croplands if land conversion did not occur
- Duration of ethanol production: 30 years

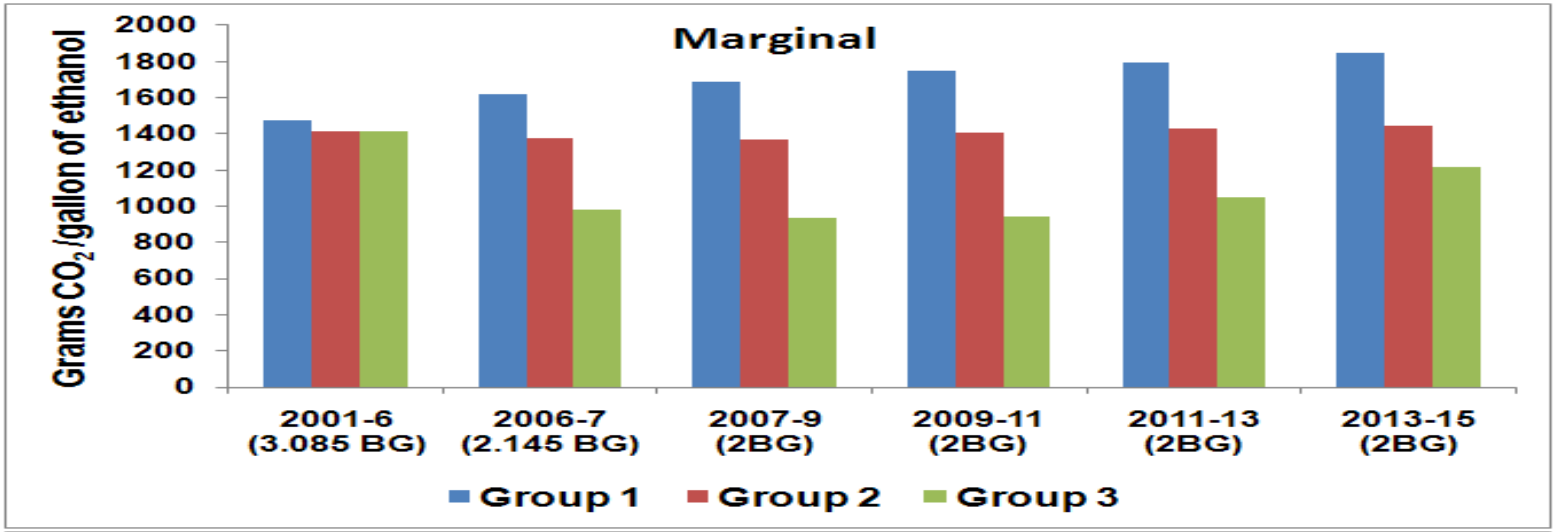
Land use emissions factors (Annual metric tons CO_2 equivalent per hectare for 30 years corn production)

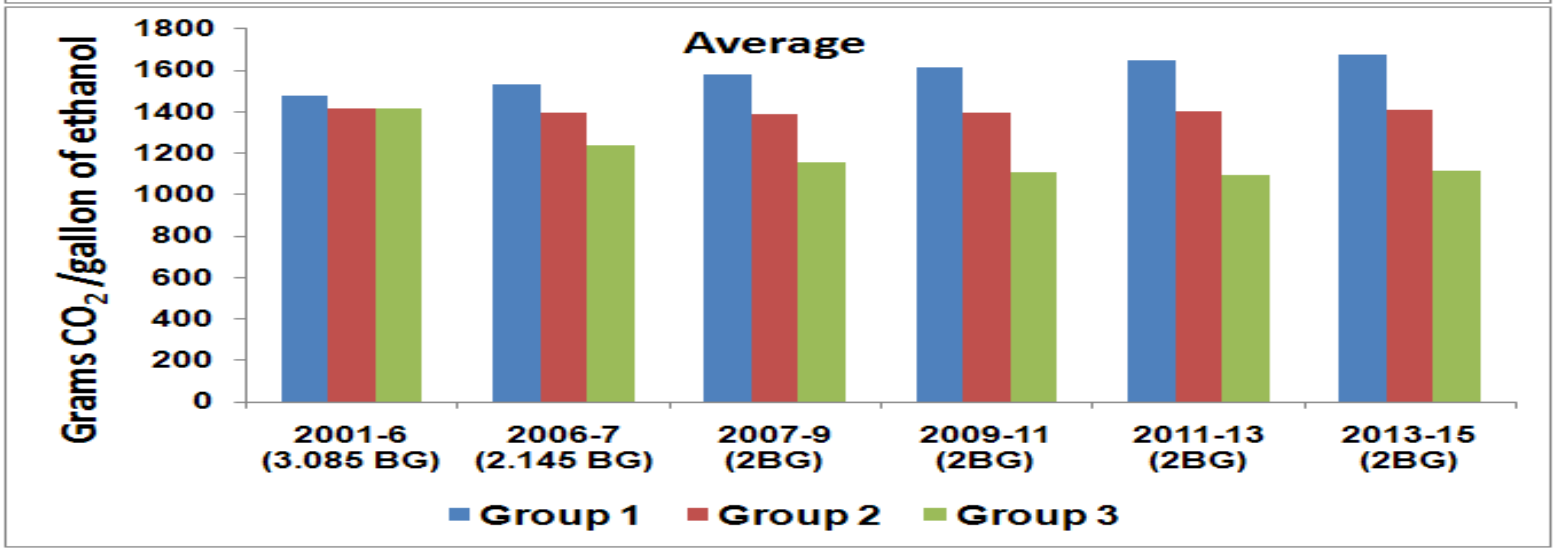
Regions	Forest emissions factors	Grassland emission factors
United States	19.6	3.7
Canada	15.3	5.7
Sub Saharan Africa	10.4	1.5
European Union 27 East Europe and Rest of Former Soviet Union Rest of European Countries	18.6	6.6
Russia	14.1	7.0
Brazil Central and Caribbean Americas South and Other Americas	16.1	2.5
Middle Eastern and North Africa	12.2	2.2
East Asia Oceania Japan	13.2	3.5
China and Hong Kong India	23.0	6.6
Rest of South East Asia Rest of South Asia Malaysia and Indonesia	23.0	6.6

Calculating land use emissions: Estimated marginal land use emissions per gallon of E100 for 13 to 15 billion gallons simulation off of 2001 data base

Total 30 year emissions from land use changes (million metric tons)	110.77
Change in ethanol production (million gallons) per year	2000
Emissions (metric tons per gallon-year of ethanol)	0.0554
Emissions (grams per gallon-year of ethanol)	55386
One year marginal emissions (grams per gallon of ethanol)	1846

Marginal and average land use emissions

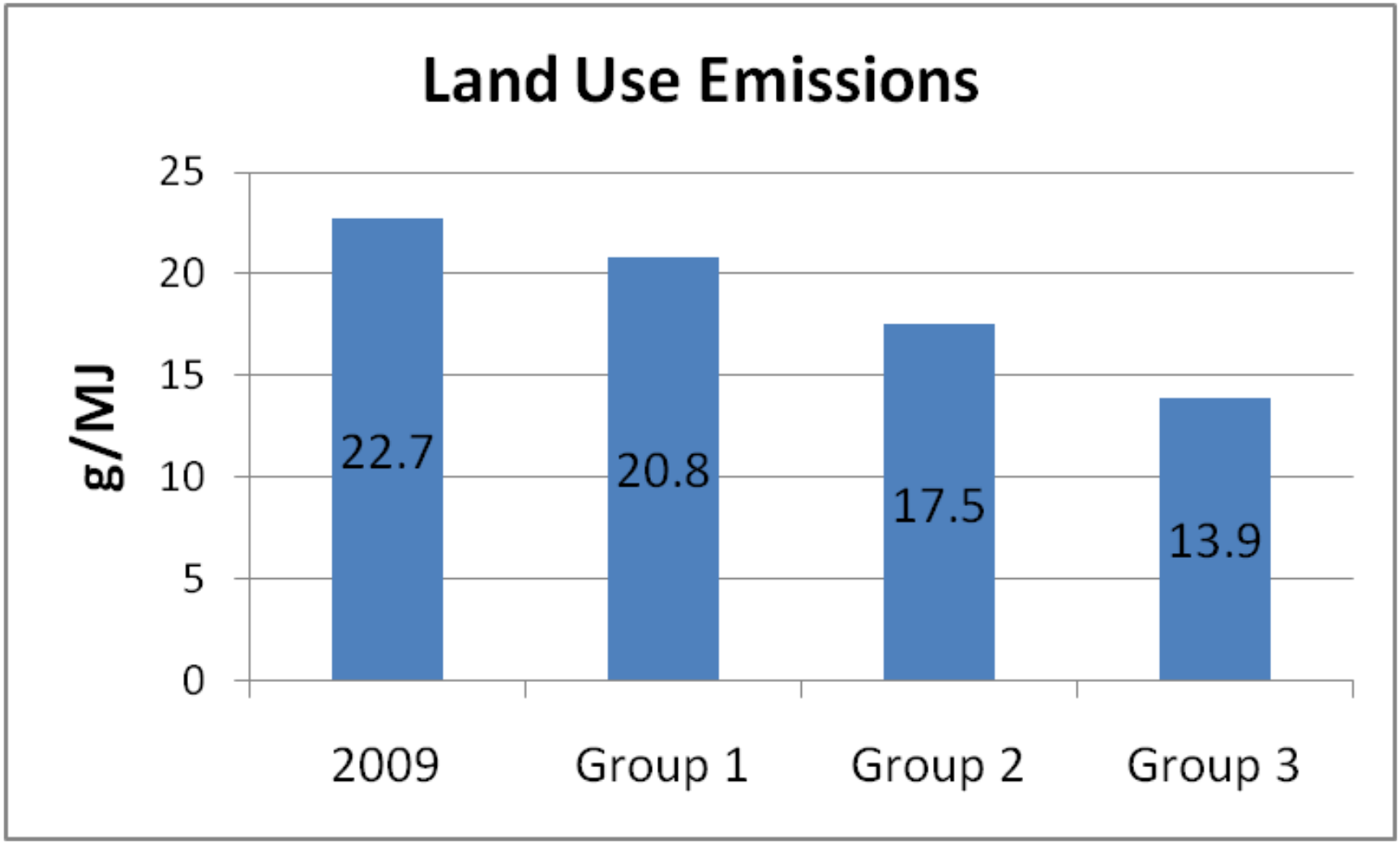




Estimated land use change emissions due to U.S. ethanol (Comparing GTAP and Searchinger et al. (2008) results)

Searchinger et al. (2008)	Total Emissions for 30 years (million metric tons)	3801
	Change in ethanol production (billion liters of ethanol)	55.92
	Total emissions for 30 years (grams per liter)	67972
	Liters per gallon	3.785
	Total emissions for 30 years (grams per gallon of ethanol)	257302
	One year emissions (grams per gallon of ethanol)	8577
GTAP results off of 2001 database	One year average emissions (gram per gallon of ethanol)	1676
	One year marginal emissions (gram per gallon of ethanol)	1846
GTAP results off of 2006 database	One year average emissions (gram per gallon of ethanol)	1407
	One year marginal emissions (gram per gallon of ethanol)	1446
GTAP results off of 2006 plus population & yield growth	One year average emissions (gram per gallon of ethanol)	1116
	One year marginal emissions (gram per gallon of ethanol)	1217

Group 3 results are 14% of Searchinger, et al.


Land Use Emissions
g/MJ
25
20
15
10
5
0
22.7
20.8
17.5
13.9
2009
Group 1
Group 2
Group 3

Estimated well-to-wheel ethanol and gasoline emissions for average land use changes

Description		Emissions in grams/MJ		
		Ethanol	Gasoline	Ethanol vs gasoline (percent)
Simulations Off of 2001	Marginal	86.3	93.3	92.2
	Average	84.4	93.3	90.5
Simulations Off of 2006	Marginal	81.3	93.3	87.1
	Average	81.1	93.3	86.9
Simulations Off of 2006 with population and yield growth	Marginal	78.4	93.3	84.1
	Average	77.5	93.3	83.0

Summary of Model Changes

- The three major biofuels have been incorporated into the model: Corn ethanol, sugarcane ethanol, and biodiesel.
- Cropland pasture in the US and Brazil and Conservation Reserve Program lands have been added to the model.
- The energy sector demand and supply elasticities have been re-estimated and calibrated to the 2006 reality. Current demand responses are more inelastic than previously.

Summary of Model Changes

- Corn ethanol co-product (DDGS) has been added to the model. The treatment of production, consumption, and trade of DDGS is significantly improved.
- The structure of the livestock sector has been modified to better reflect the functioning of this important sector.
- Corn yield response to higher corn prices has been estimated econometrically and included in the model.

Summary of Model Changes

- The method of treating the productivity of marginal cropland has been changed so that it is now based on the ratio of net primary productivity of new cropland to existing cropland in each country and AEZ.

Simulations Accomplished

- Land use implications of US ethanol off the 2001 database
- In the second group of simulations, we first construct a baseline which represents changes in the world economy during the time period of 2001-2006. Then we calculate the land use impact of the US ethanol production off of the updated 2006 database

Simulations Accomplished

- In the third group of simulations we use the updated 2006 database obtained from the second group of simulations, but we assume that during the time period of 2006-2015 population and crop yields will continue to grow.

Estimation Results

- On average 28% of the land use change occurs in the US, and 72% in the rest of the world.
- Forest reduction accounts for 35% of the change and pasture 65%.
- On average 0.12 hectares of land are needed to produce 1000 gallons of ethanol. Our January 2009 report estimated 0.27 ha, and Searchinger estimated 0.75.
- Land use emissions in group 3 are 13.9 g/MJ
- Corn ethanol emissions in the 3rd group of simulations are 83% of gasoline.

Conclusions

- Land use change and the associated GHG emissions is a very controversial topic.
- Some argue it is impossible to measure such changes. Others argue that failure to measure the land use changes and the consequent GHG emissions would lead us to incorrect policy conclusions.

Conclusions

- We come out between these extremes.
  - With almost a third of the US corn crop today going to ethanol, it is simply not credible to argue that there are no land use change implications of corn ethanol.
  - The valid question to ask is to what extent land use changes would occur.
- One cannot escape the conclusion that modeling land use change is quite uncertain.
  - Of course, all economic modeling is uncertain, but it is important to point out that we are dealing with a relatively wide range of estimation differences.

Conclusions

- Analysis such as that undertaken here is very complex and is limited by data availability, validity of parameters, and other modeling constraints.
  - Economic models, like other models, are abstractions from reality. They can never perfectly depict all the forces and drivers of changes in an economy.
  - However, the basic model used for this analysis, GTAP, has withstood the test of time and peer review. Hundreds of peer reviewed articles have been published using the GTAP data base and analytical framework.

Conclusions

- In this project, we have made many changes in the model and data base to improve its usefulness for evaluating the land use change impacts of large scale biofuels programs.
- Yet, uncertainties remain.
- We believe quite strongly that analysis of this type must be done with models and data bases that are available to others. Replicability and innovation are critical factors for progress in science. They also are important for credibility in policy analysis.

Thank you!

Questions and Comments

For more information:

http://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3288

http://www.agecon.purdue.edu/directory/details.asp?username=wtyner