

Global Indirect Land Use Implications of U.S. Biofuel Policies: A Review of the Evidence*

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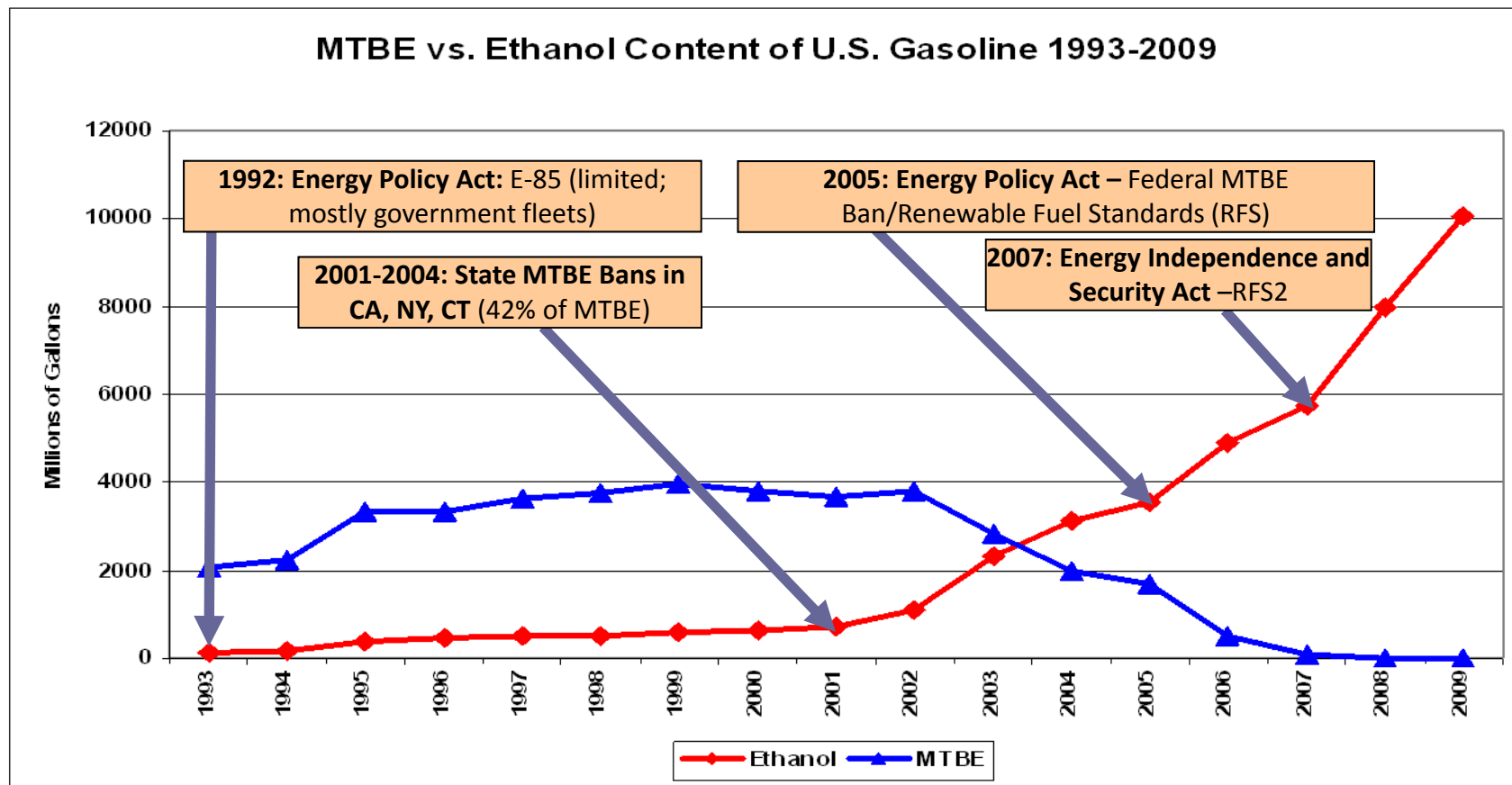
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Outline

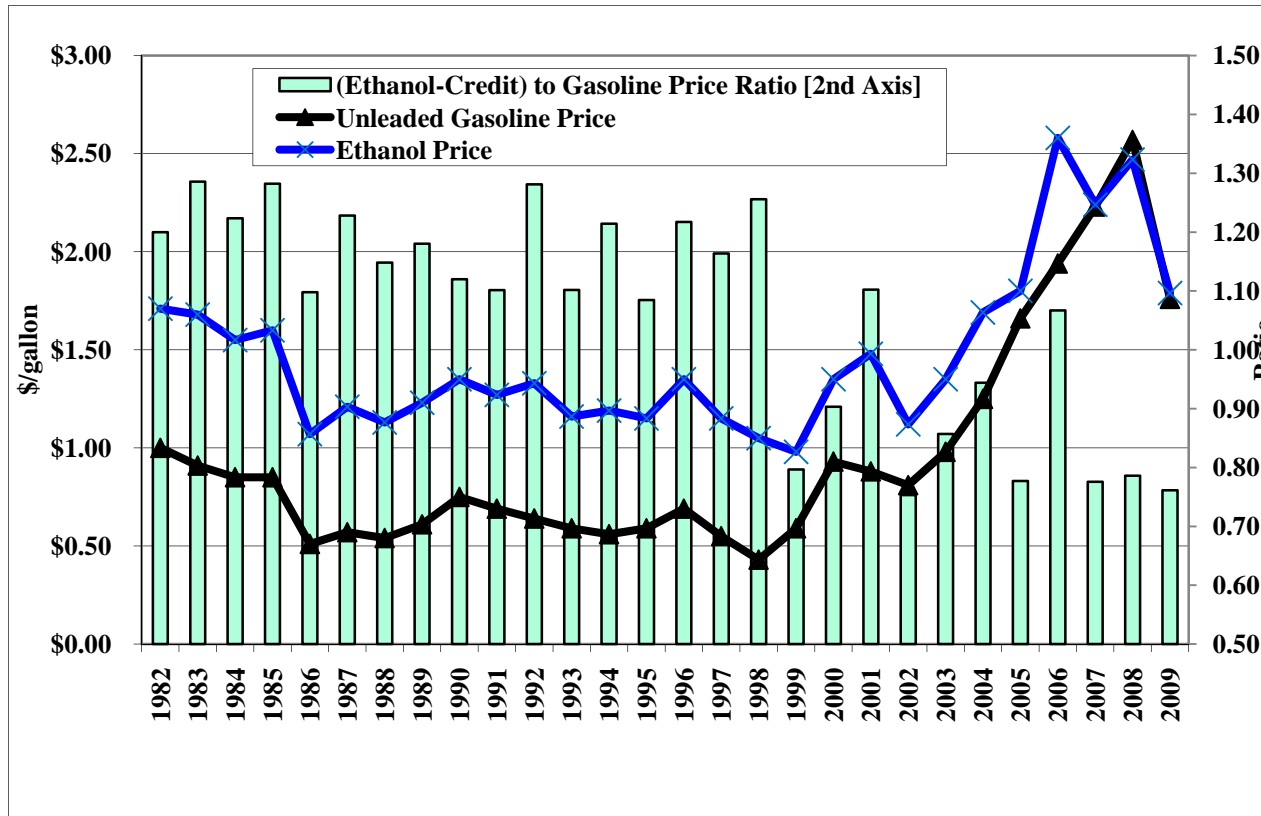
- **U.S. Biofuel Market & Policy Developments**
- **Ethanol-Related Issues**
- **Modeling the Indirect Effects of U.S. Ethanol Production**
- **Simulations of U.S. Biofuel Policy**
- **Analysis of the Empirical Corn Use for Ethanol Data**
- **Summary and Conclusions**

Major Policy & Market Developments: Rapid Increase in Ethanol Use from 2001 - 2009



➤ **Corn Ethanol Production was about 10.5 billion gallons in 2009 (25% Annual Growth Rate between 2001 and 2009)**

Major Policy & Market Developments: Markets and Infrastructure Limit Price-Based Substitution



- Ethanol-Gasoline Price Gap Has Closed Since 2007
- Tax Credit Adjusted Ethanol to Gasoline Price Ratio Dropped Below 1 in 1999
- Ratio Was 75 to 107 Percent Between 1999-2009

- Ethanol & Gasoline Prices Move Together
- Limited U.S. Biofuel Infrastructure & Vehicle Market
- With small changes in price differentials and infrastructure constrains price-based substitution is limited

Focus of U.S. Ethanol Issues Has Evolved Over Time

➤ Net Energy

- Does Ethanol Production Consume More Energy Than It Contains?
- Resolved → No

➤ Energy Security Implications

- Would Energy-Agriculture Link Enhance Supply Security?
- Would Displaced Oil be Consumed Elsewhere Due to Lower Prices?

➤ Indirect Social and Environmental Global Impacts

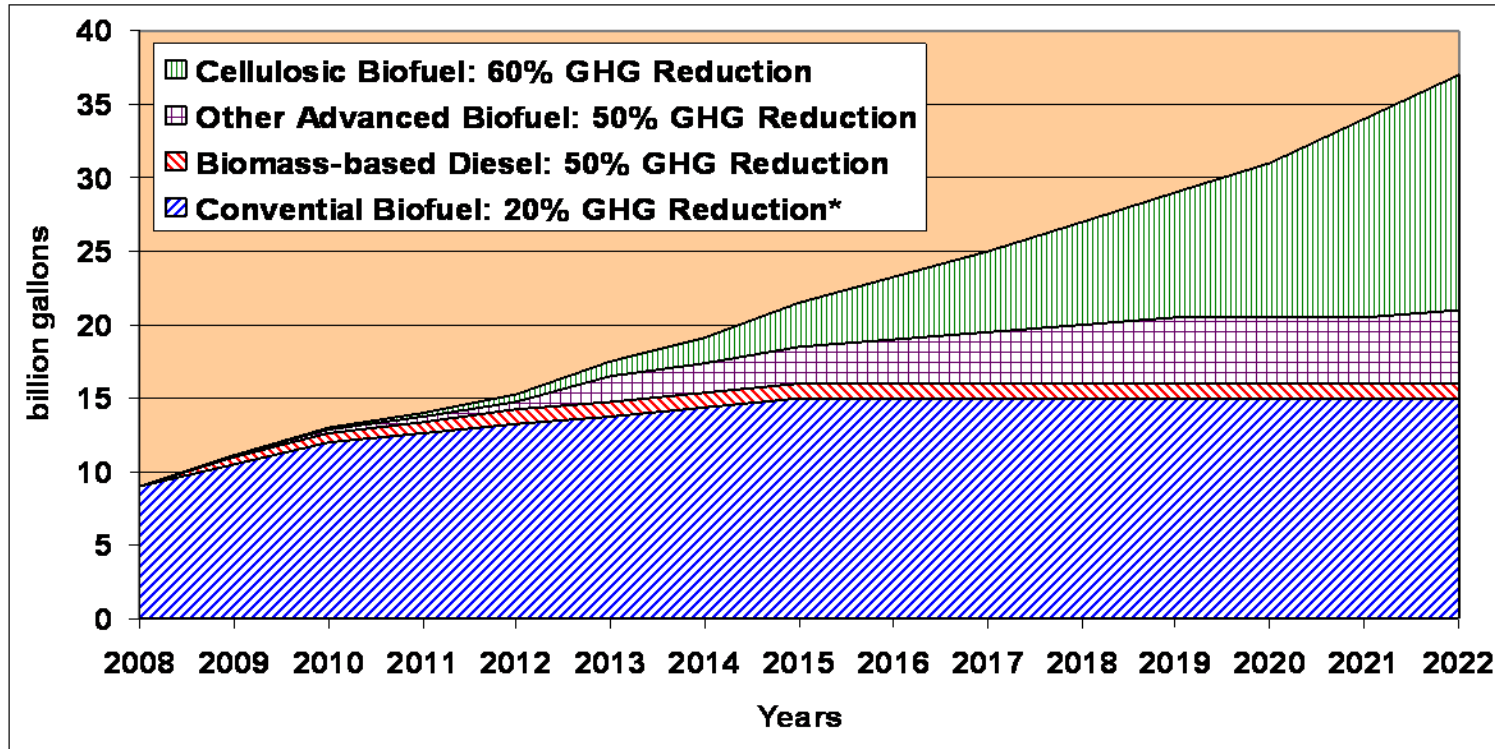
➤ Food vs. Fuel

- Are Recent Agricultural Price Changes Due to Biofuels?

➤ Net Sink or Source of GHGs

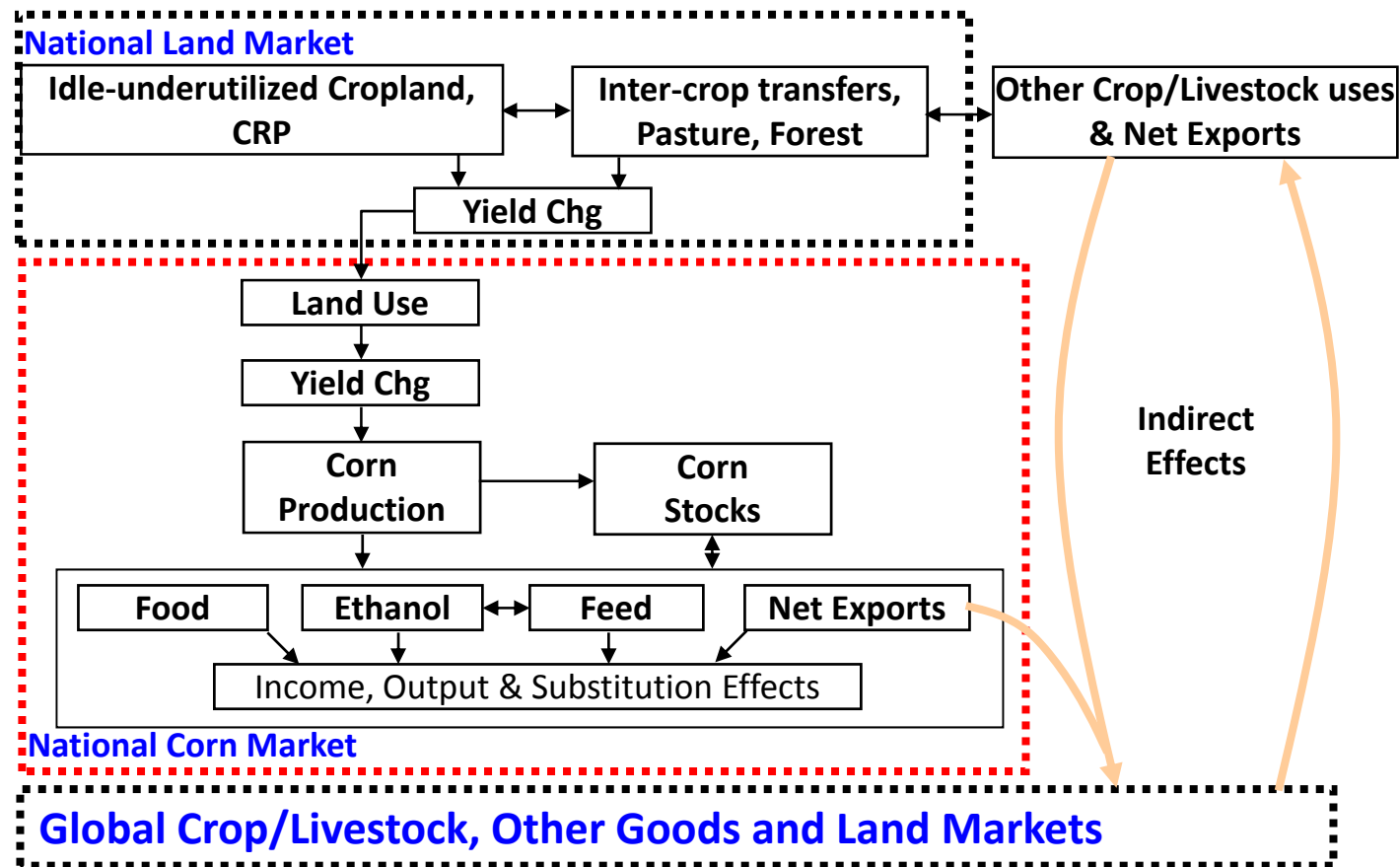
- What are the GHG Implications of Indirect Land Use Change (ILUC)?
- ILUC: Global Land Cover Changes Due to Biofuel

RFS2 Targets: Ethanol Categories Must Meet GHG Reduction Thresholds



➤ **Corn Ethanol Meets GHG Threshold Without Indirect Land Use Change**

Indirect Land Use Change Estimation: Complicated by Multi-Market, Local, National and Global Dimensions



- ILUC Cannot Be Observed – Must Be Estimated by Models
- Need to isolate indirect land use effects from other processes
- Model Structure, Assumptions, Policy Specifications and Data Crucial to Model Results

Simulations with A Modified GTAP Model: General Structure

- **GTAP can be used for simulating biofuel policy**
 - **May require complementary models to fully model biofuel policy e.g. spatial land use change model**

- **Model Structure**
 - **Structure is Similar to Hertel et al (2010)**
 - **GTAP 6 Database with 2001 Base Year**
 - **Corn Ethanol By-Product Incorporated**

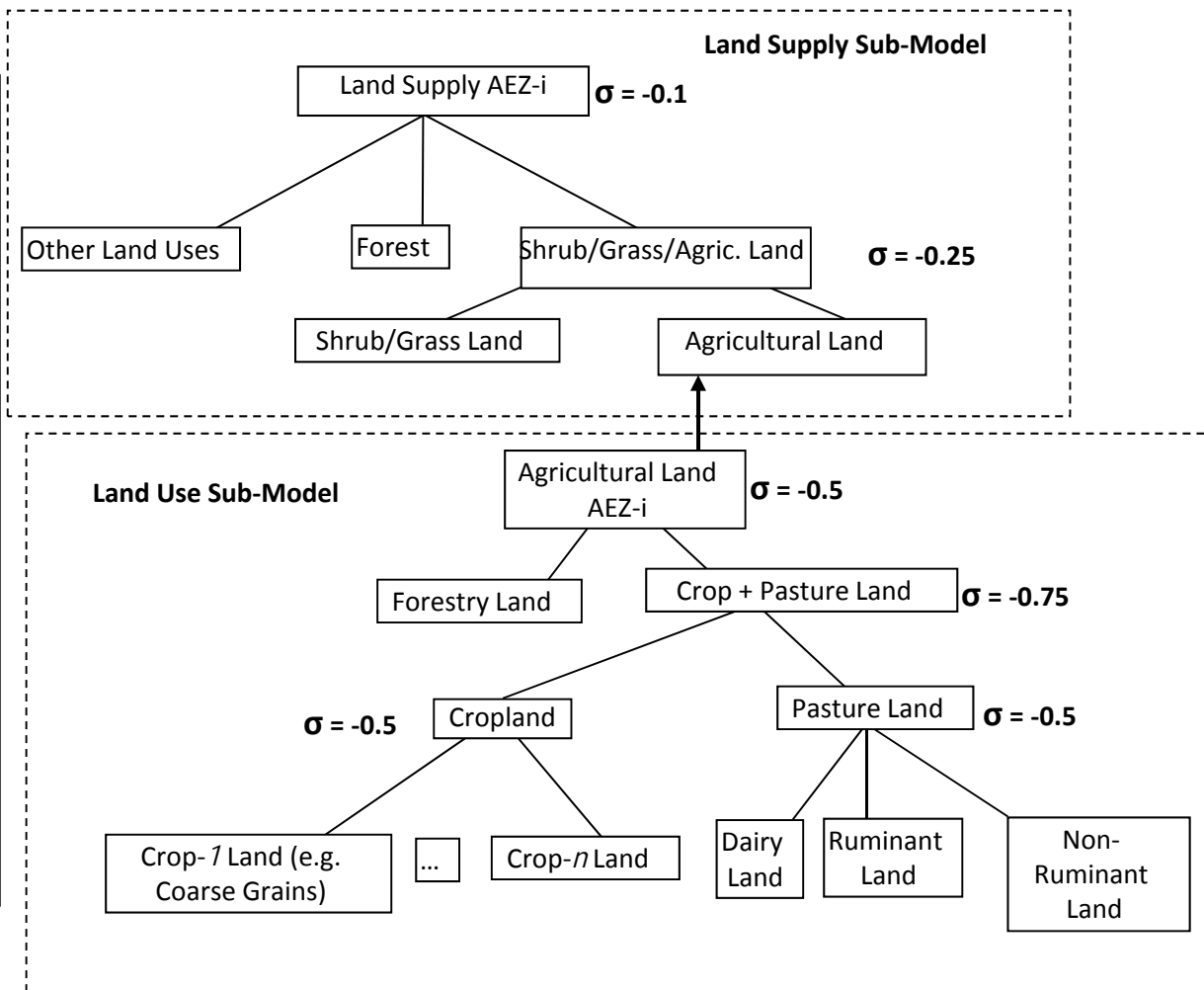
- **Main Differences:**
 - **Different Land Supply/Use Model**
 - **Different Parameterization of Biofuel Use**
 - **Mandate Policy Specification**

Simulations with A Modified GTAP Model: Land Supply/Use Model

➤ Land Supply Sub-Model Makes Unused Land Available for Agriculture

➤ Supply & Use Model Linked Through Percentage Change in Agricultural Land

➤ Generates an Upward Sloping Supply Curve for Agricultural Land



Simulations with A Modified GTAP Model: Policy Modeling Approach

➤ GTAP CES function Model of Ethanol-Petroleum products Substitution

$$\frac{Q_e}{Q} = A_e \left(\frac{P}{P_e} \right)^\sigma$$

Q_e, P_e = Ethanol use and price, respectively; Q, P = Total liquid fuel use and price, respectively; A_e = CES Share parameter; σ = Elasticity of substitution between biofuels and petroleum products

$$q_e = q + a_e - \sigma(p_e - p)$$

➤ *Share Parameter A_e*

- Technology Parameter - Usually Constant in CES Simulations
- Recent U.S. Policies Represent Changes in A_e
- Current Study Implements Policy Simulation as Changes in A_e
- σ is set to 0.1 Consistent with U.S. Biofuel Market

Simulations with A Modified GTAP Model: Scenarios Based on 2001-2006 Data

	Case A Blending Mandate	Case B Output Mandate		Case C Yield- Adjusted Blending/Outp ut Mandate		Case D Yield-Adjusted Blending Mandate & Parameter Changes			Case E Yield-Adjusted Output Mandate & Parameter Changes		
		A	B1	B2	C1	C2	D1	D2	D3	E1	E2
Share Parameters	X	-	-	X	-	X	X	X	-	-	-
Ethanol Output	-	X	X	-	X	-	-	-	X	X	X
Petroleum & Ethanol Consumption Tax	-	E	-	-	E	-	-	-	E	E	E
Petroleum & Ethanol Output Tax	-	-	E	-	-	-	-	-	-	-	-
Change in Overall Household Tax to Income Ratio	-	X	X	-	X	-	-	-	X	X	X
Household Ethanol/Petroleum Elasticity of Substitution	-	-	-	-	-	X	-	X	X	-	X
Land Supply Transformation Elasticities	-	-	-	-	-	-	X	X	-	X	X

Simulations with A Modified GTAP Model: Case A – Blending Mandate

	U.S.	Canada	Brazil	EU-27	Rest of World
Ethanol production and import change (%)					
Corn ethanol output	171.07	18.83	0.01	0.20	0.09
Corn ethanol import	179.98	-0.51	0.00	0.19	-0.16
Sugarcane ethanol output	173.40	0.39	2.36	0.26	0.16
Sugarcane ethanol import	182.47	0.14	0.51	0.06	0.11
Coarse grains output, export and land use change (%)					
Coarse grains output	4.69	0.49	0.25	0.08	0.14
Coarse grains export	-1.90	-0.06	0.86	0.34	0.91
Coarse grains export share	-6.30	-0.54	0.61	0.27	0.52
Coarse grains ethanol	171.07	18.83	0.01	0.20	0.25
Coarse grains land	3.12	0.27	0.14	0.03	0.10
Land use change (%)					
Coarse grains	3.12	0.27	0.14	0.03	0.10
Other grains	-0.80	-0.02	-0.12	0.00	0.00
Forestry	-0.04	0.00	0.00	0.00	0.00
Oil seeds	-0.80	0.16	0.03	0.07	0.03
Other agriculture	-0.58	0.02	-0.06	0.00	0.00
Sugarcane	-0.32	-0.07	0.73	-0.02	-0.01
Dairy farms	-0.32	-0.08	-0.03	-0.02	0.00
Ruminant cattle	-0.38	0.02	-0.08	-0.01	-0.02
Non-Ruminants	-0.38	-0.08	-0.10	-0.02	-0.01
Land-cover change (%)					
Forest	-0.075	-0.002	-0.007	-0.004	-0.002
Agricultural land	0.187	0.030	0.038	0.009	0.007
Shrub/Grass land	-0.425	-0.085	-0.034	-0.022	-0.010
Other land	-0.045	-0.001	-0.009	-0.005	0.000
Oil import change (%)	-3.80	-1.25	0.90	0.25	0.22
Real GDP Change (\$million)	-111	-4	2	516	188
Equivalent Variation (\$million)	764	-90	79	1484	-191

- **All Sources of U.S. Ethanol Increased. Little Change in Rest of World Except for Canada and Brazil**
- **U.S. Coarse Grain Export Decline by 1.9%**
- **Coarse Grain Output 4.7% (Land: 3.12; Intensive Yield: 1.54%)**
- **U.S. Oil Imports: -3.8%; Increases in Most of Other Regions**
- **U.S. Real GDP: -\$110 million**
- **U.S. Equiv. Var: +\$764 million**
- **Economic Effects Mixed in Other Regions.**

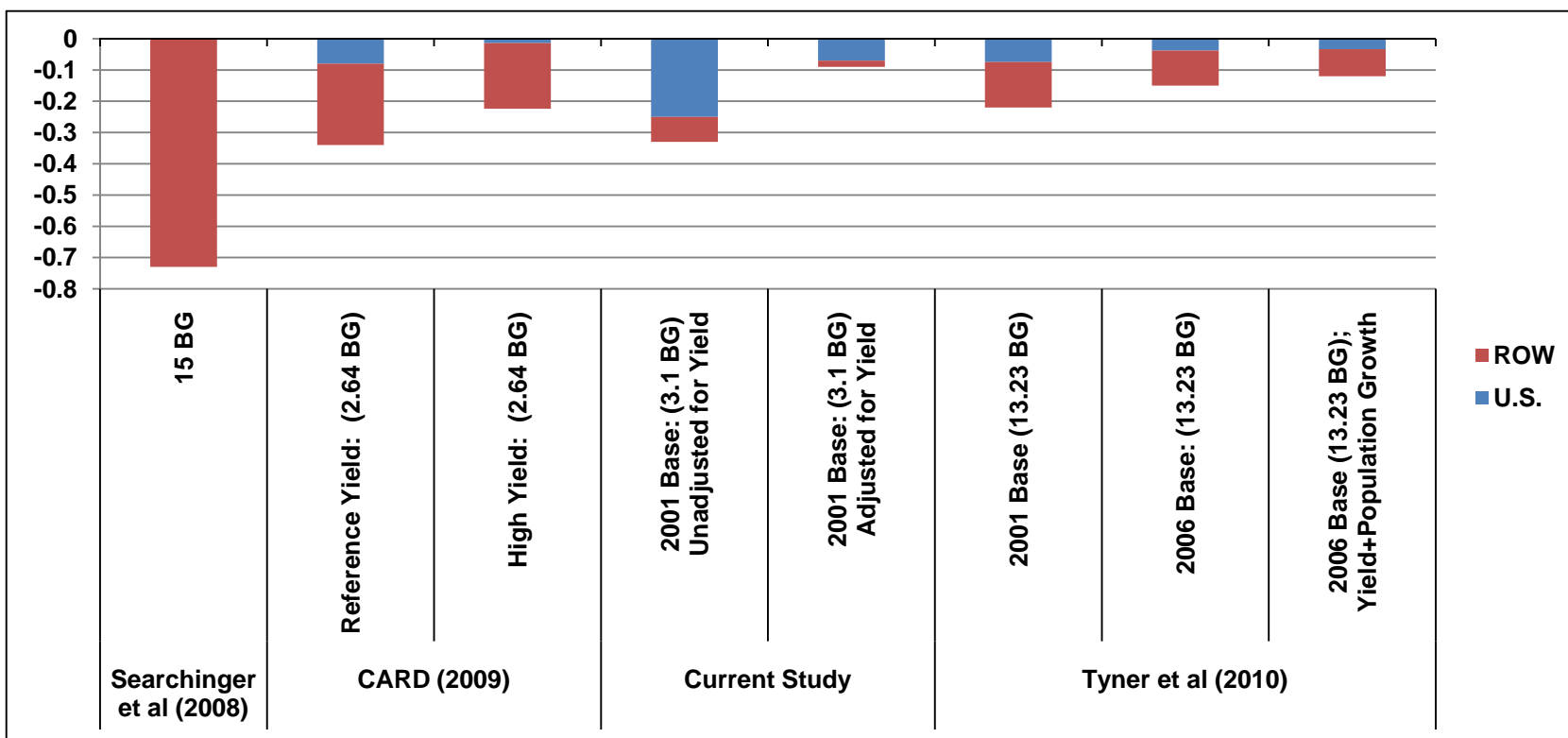
Simulations with A Modified GTAP Model: Case B1 – Output Mandate

	U.S.	Canada	Brazil	EU-27	Rest of World
Ethanol production and import change (%)					
Corn ethanol output	177.00	-9.96	0.00	0.04	0.01
Corn ethanol import	-94.66	-0.76	0.00	0.04	-0.17
Sugarcane ethanol output	-22.36	0.04	-1.60	0.05	0.04
Sugarcane ethanol import	-100.00	0.10	-0.08	0.16	0.04
Coarse grains output, export and land use change (%)					
Coarse grains output	4.87	0.21	0.36	0.08	0.14
Coarse grains export	-1.93	0.02	1.09	0.37	0.91
Coarse grains export share	-6.48	-0.19	0.73	0.29	0.53
Coarse grains ethanol	177.00	-9.96	0.01	0.04	0.18
Coarse grains land	3.23	0.08	0.23	0.03	0.10
Land use change (%)					
Coarse grains	3.23	0.08	0.23	0.03	0.10
Other grains	-0.81	0.03	0.03	0.01	0.00
Forestry	-0.04	0.00	0.01	0.00	0.00
Oil seeds	-0.83	0.14	0.14	0.05	0.02
Other agriculture	-0.60	0.04	0.05	0.00	0.01
Sugarcane	-0.34	-0.06	-0.54	-0.02	-0.01
Dairy farms	-0.34	-0.07	-0.01	-0.02	-0.01
Ruminant cattle	-0.39	0.03	0.01	-0.01	-0.01
Non-Ruminants	-0.40	-0.08	0.02	-0.02	-0.01
Land-cover change (%)					
Forest	-0.079	-0.002	-0.002	-0.005	-0.002
Agricultural land	0.198	0.029	0.014	0.011	0.010
Shrub/Grass land	-0.449	-0.082	-0.015	-0.027	-0.014
Other land	-0.048	-0.001	-0.006	-0.007	-0.001
Oil import change (%)					
	-1.00	-0.31	0.22	0.07	0.06
Real GDP Change (\$million)					
	-5372	-2	2	117	-2
Equivalent Variation (\$million)					
	-4705	-46	-1	338	-332

- **Other Sources of U.S. Ethanol Reduced Due To Output Mandate**
- **Coarse Grain Export Loss More Pronounced**
- **Non-Land Results Differ Sharply From Case A**
- **U.S. Oil Imports: -1% vs. -3.8%;**
- **U.S. Real GDP & Equiv. Var. Both Decrease By Almost \$5 billion**
- **Economic Effects Small But Almost All Negative in Other Regions.**

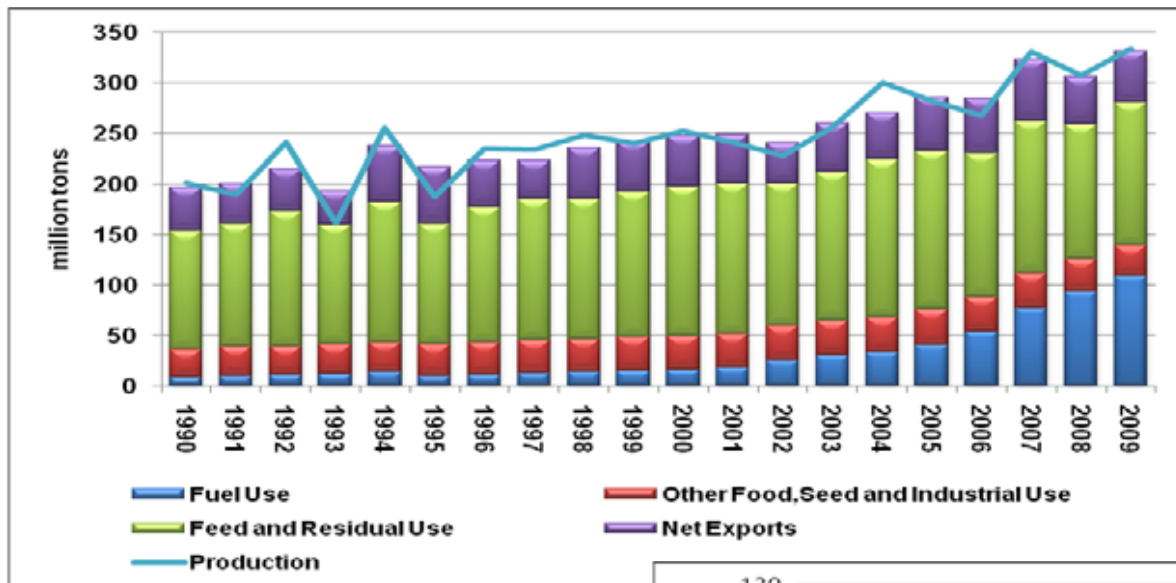
Summary and Conclusions: Land Use Change Modeling Still Remains Inadequate

➤ Indirect Land Cover Loss Estimates Depend on Both Model Structure and Assumptions



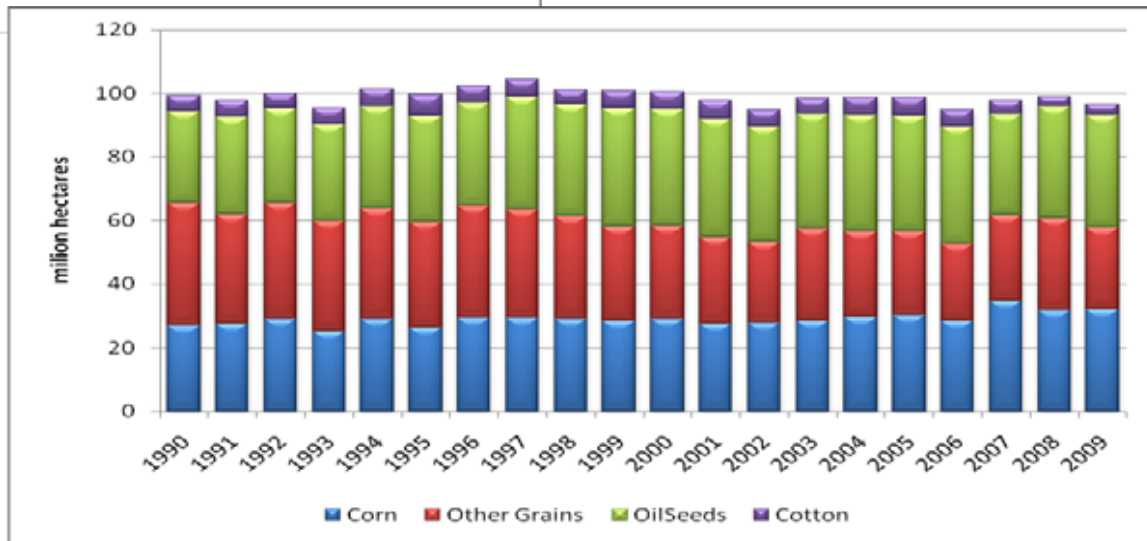
➤ Many Crucial Land Use Change Drivers Remain Uncounted

Empirical Corn Data: Corn Use for Ethanol Quintupled and Exports Increased By 50% from 2001-2009



- Production and Export Surged as Corn Use for Ethanol Quintupled in Recent Years
- Corn Exports Reached Record Levels in 2007 Only for The Third Time in The Last Two Decades

- Harvested Total Cropland & Corn Land Has Changed Little Since 1990
- Most of the Recent Increase in Corn Land is Within the Grain Category
- 2007 Was an Outlier



Index Decomposition Analysis of Empirical Corn Data: Logarithmic Mean Divisia Index (LMDI I)

➤ Index Decomposition Analysis

➤ Allocates Changes in an Aggregate Variable to Each Contributing Component If All Other Components Were Held Constant

➤ Especially Useful for Relationships of the Form:

$$y(x_1, x_2, \dots, x_n) = x_1 \cdot x_2 \cdot \dots \cdot x_n$$

➤ Decomposition based on the total differential:

$$dy = \sum_{i=1}^n \prod_{j=1, j \neq i}^n x_j dx_i$$

➤ Application to Discrete Data Leads to Different IDA Formulations

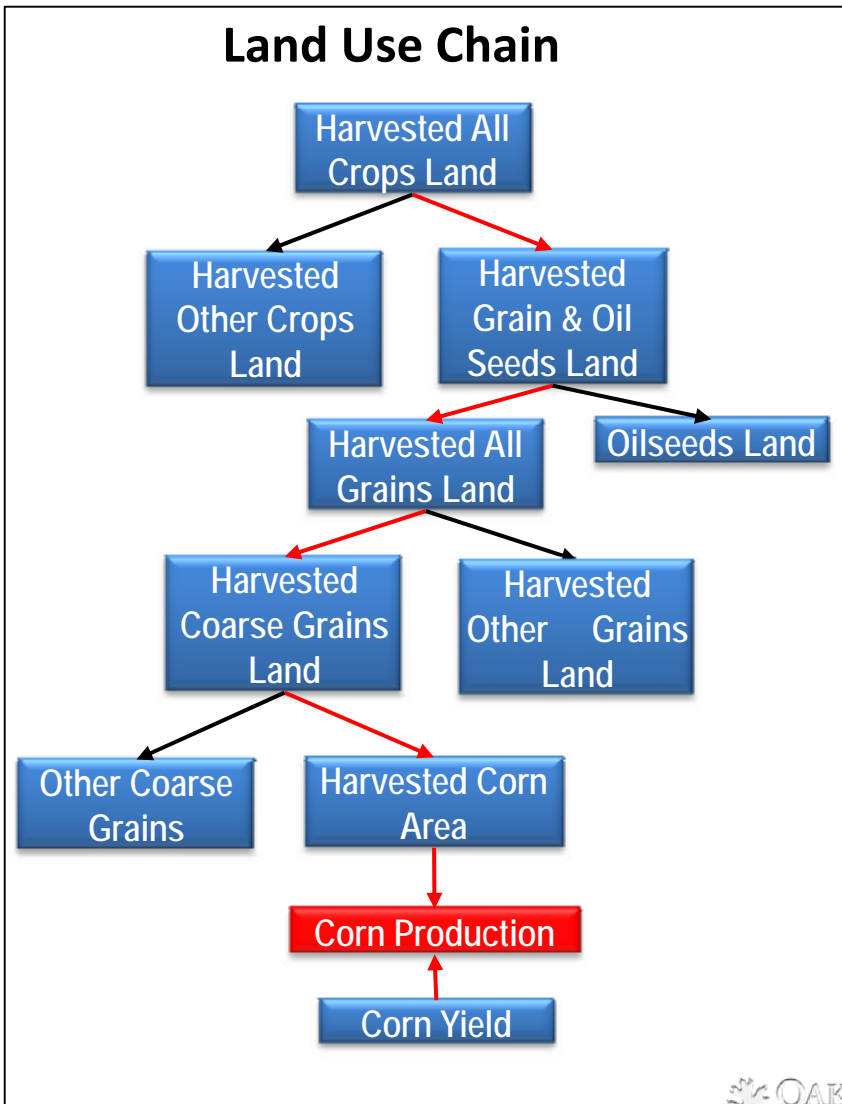
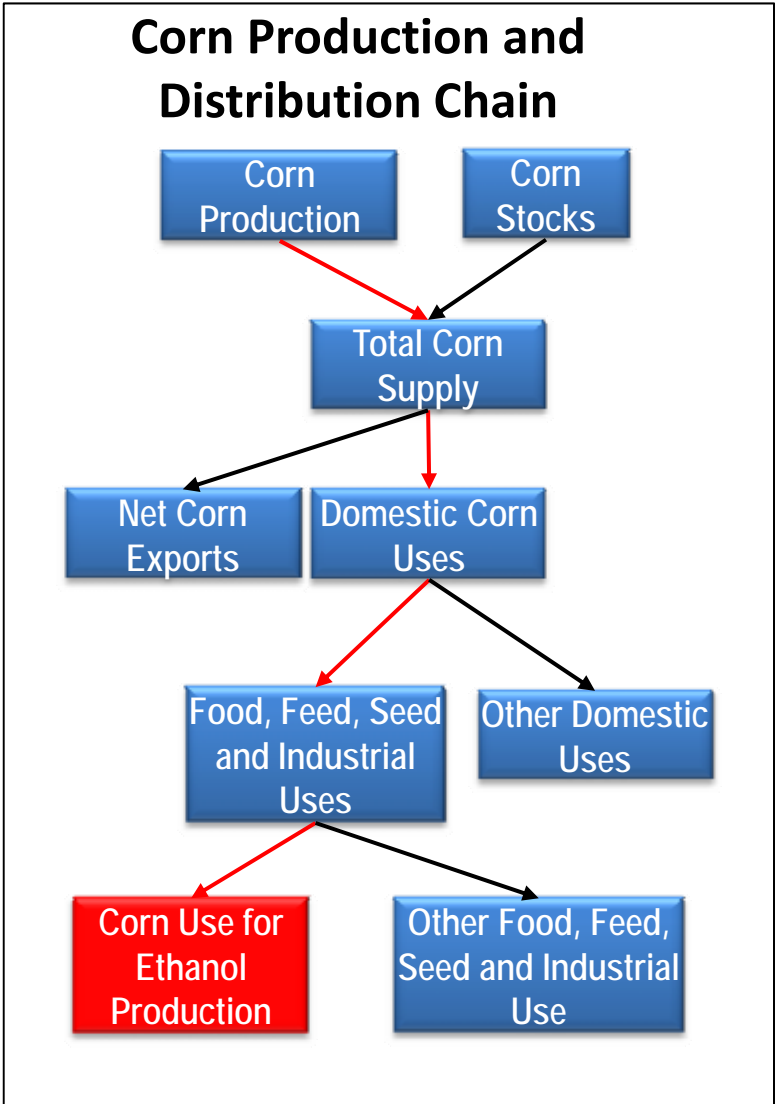
➤ Depending on How the Integral is Approximated

➤ The Logarithmic Mean Divisia Index (LMDI I) Uses the Approximation:

$$\Delta y^D = \sum_{i=1}^n \left(\frac{(y_{t1} - y_{t0})}{\ln\left(\frac{y_{t1}}{y_{t0}}\right)} \right) \ln\left(\frac{x_{i,t1}}{x_{i,t0}}\right) = \sum_{i=1}^n \Delta y \frac{g_{xi}}{g_y}$$

➤ Similar to the GTAP Linearization (Percentage Change) Solution Approach

Decomposition Analysis of Empirical Corn Use for Ethanol Data with LMDI I: Linkages in the Chain



Decomposition Analysis of Empirical Corn Use for Ethanol Data with LMDI: Chain Relationship of Corn Use and Ethanol Distribution/Land Use Variables

$$Q_{ce} = \left(\frac{Q_{ce}}{Q_{ffsi}}\right) \left(\frac{Q_{ffsi}}{Q_{dom}}\right) \left(\frac{Q_{dom}}{Q_{prd+stc}}\right) \left(\frac{Q_{prd+stc}}{Q_{prd}}\right) Q_{prd}$$

$$Q_{prd} = Y_{corn} \left(\frac{A_{corn}}{A_{cgrn}}\right) \left(\frac{A_{cgrn}}{A_{grn}}\right) \left(\frac{A_{grn}}{A_{grn+oilseed}}\right) \left(\frac{A_{grn+oilseed}}{A_{all}}\right) A_{all}$$

where:

Q_{ce} = Annual corn use for ethanol production (10^3 tons);

Q_{ffsi} = Annual corn use for food, feed, seed and industrial purposes (10^3 tons)

Q_{dom} = Annual total domestic corn use (10^3 tons)

Q_{prd} = Annual total corn production (10^3 tons)

$Q_{prd+stc}$ = Annual corn production plus net stock withdrawal i.e. total supply (10^3 tons)

Y_{corn} = Annual corn yield in (tons/ha)

A_{corn} = Annual corn harvested area (ha)

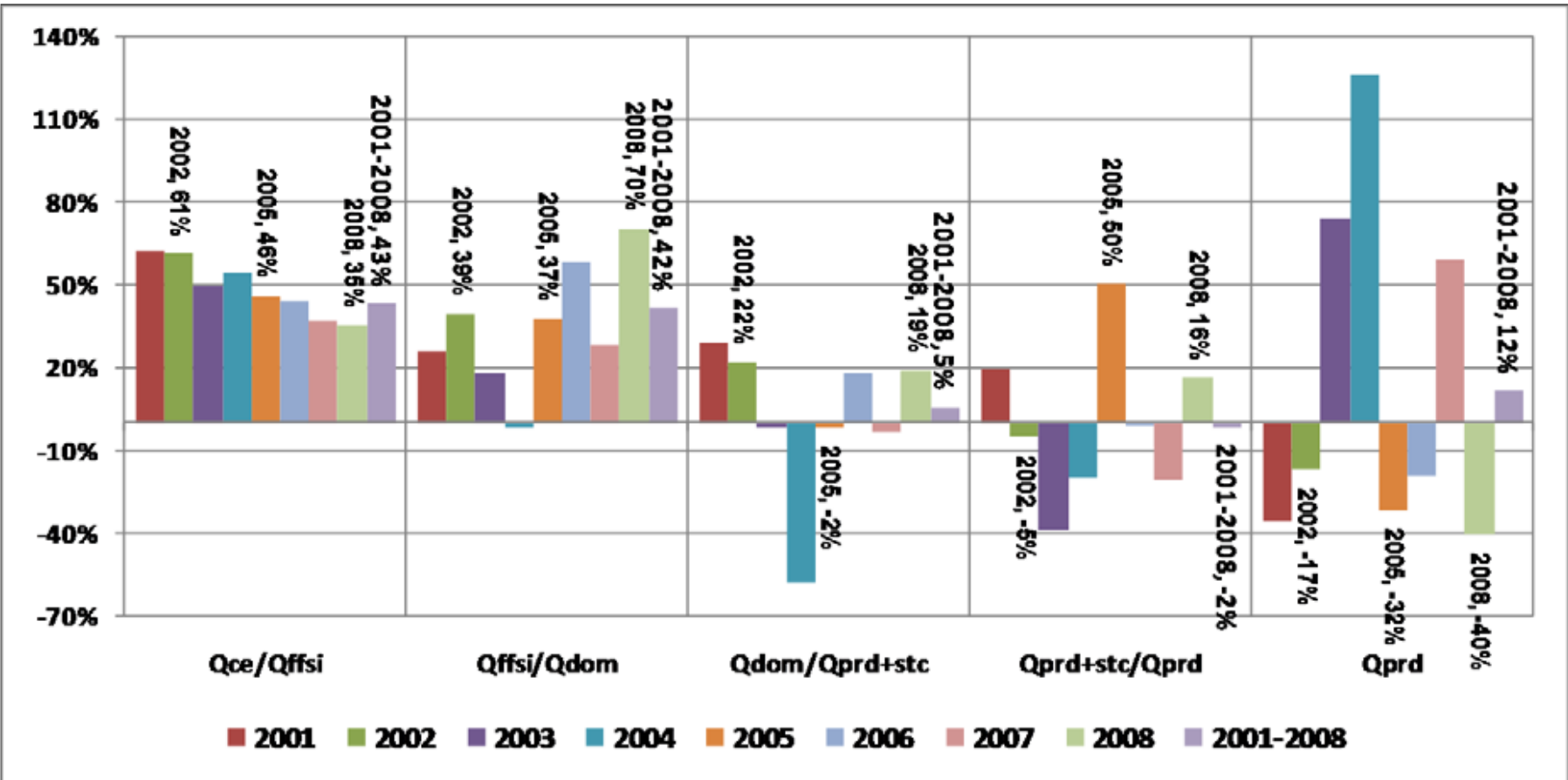
A_{cgrn} = Annual coarse grain harvested area (ha)

A_{grn} = Annual all grain harvested area (ha)

$A_{gn+oilseed}$ = Annual all grain plus oilseed harvested area (ha)

A_{all} = Annual total harvested cropland area (ha)

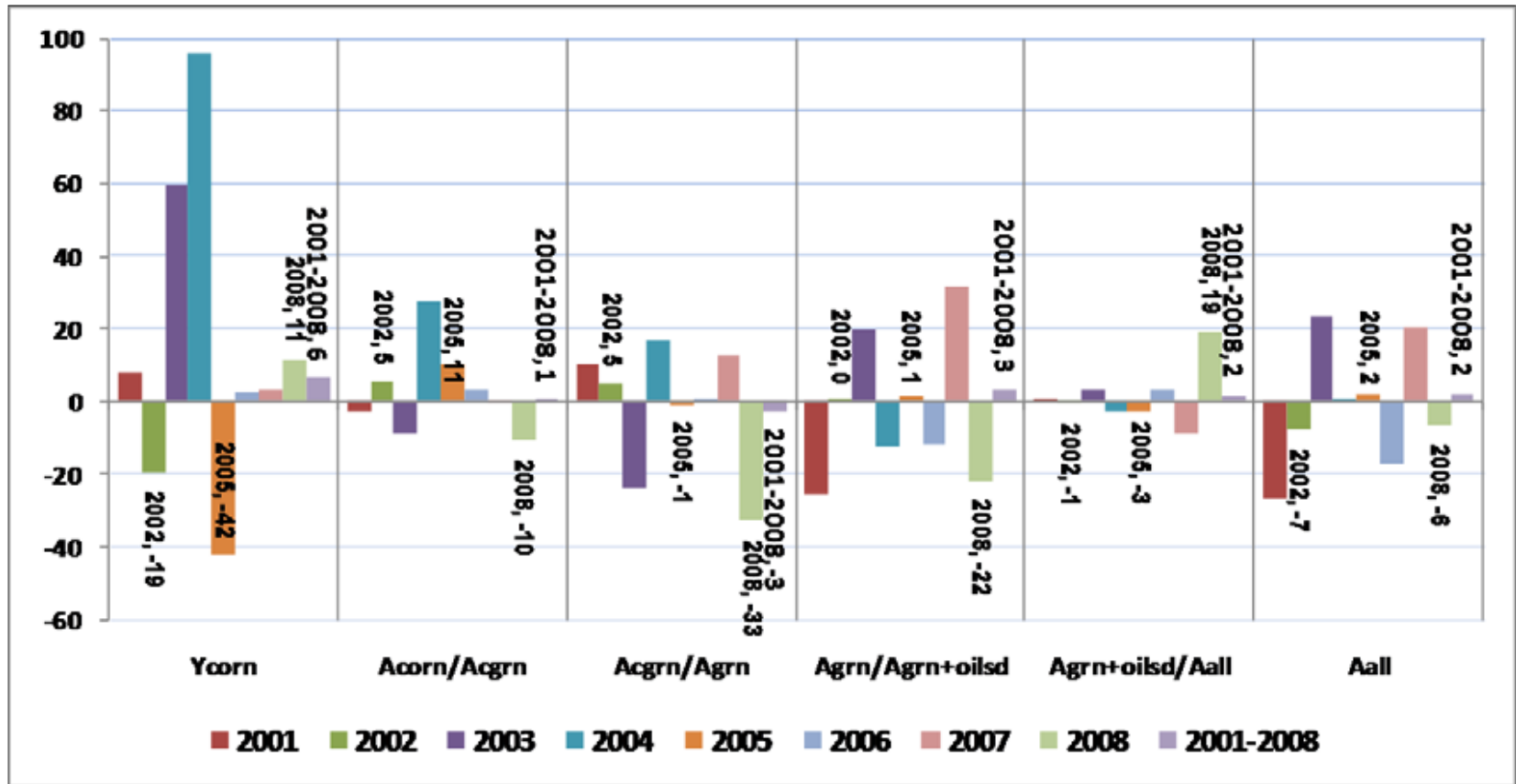
Decomposition Results of Corn Use for Ethanol Production: Domestic Adjustments Consistently Accounted for Most of the Change



➤ Net Contribution between 2001-2008

➤ Domestic Reallocation : 85%, Production: 12%; Domestic Corn Use Share: 5%; Corn Stock Withdrawals: -2%;

Decomposition of Corn Use for Ethanol Production: Yield Contributions and Land Use Change Contributions Quite Variable



➤ Net Production Contribution between 2001-2008 (12%)

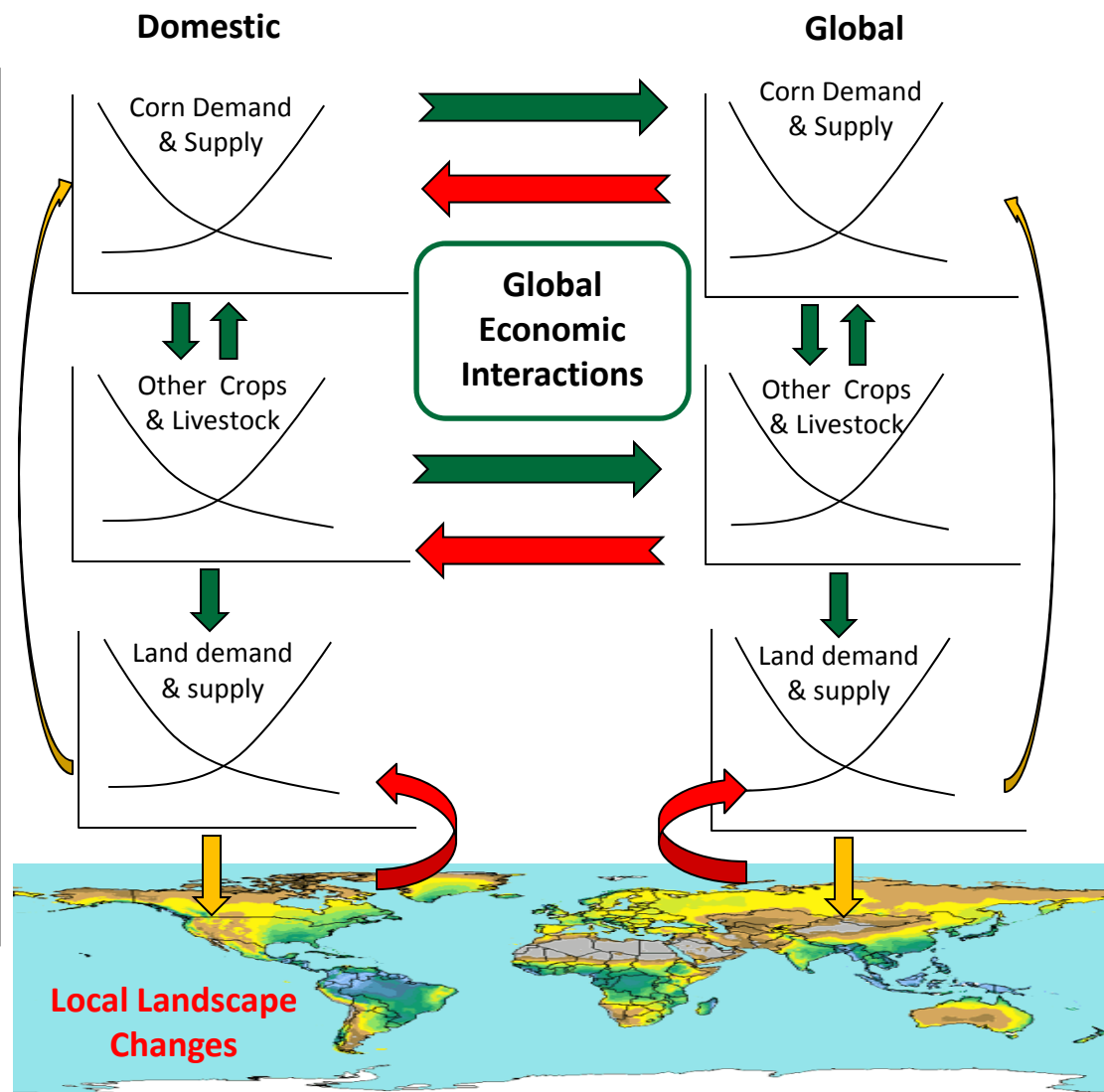
➤ Yield: 6%; Total Cropland: 2%; Others: 4%

Summary and Conclusions: Model Results Dependent on Many Factors

- **Policy Alternatives in Current Study Produce Similar LUC Impacts**
 - **Price-based Policies Produce Larger Welfare Losses**
 - **Yield Change is Crucial in Estimating Land and Welfare Effects**
 - **Increased Ethanol-Petroleum Substitution and Land Supply Elasticities Improve Welfare Effects**
 - **But Increase Land Conversion**
 - **Also Shift More of the Land Conversion to the U.S.**
- **Empirical Data Provides Little Support for Many Model Assumptions**
 - **Exports Continued to Increase to Record Levels in 2007**
 - **Domestic Re-Allocation Provided Bulk of Corn Use for Ethanol**
 - **Most of the increase in corn production due to yield change**

Summary and Conclusions: Designing New Models of Land Use Change

- **Current Models: Incorporate Some Drivers of LUC**
- **Crucial Missing Processes:**
 - Global Actions on Domestic Changes
 - Linkage Between Landscape and Land Demand/Supply Sub-Models
 - Better Coupling of Land Use and Economic Sub-models
 - Local Land Use models
- **Refine the Representation of Land Use and Biofuels in Economic Models**



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