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

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

- 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
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**

```
Land Supply Sub-Model

σ = -0.1

Other Land Uses
Forest
Shrub/Grass Land
Agricultural Land

Shrub/Grass/Agric. Land

Land Use Sub-Model

σ = -0.5

Agricultural Land AEZ-i

Forestry Land
Crop + Pasture Land

Crop-1 Land (e.g. Coarse Grains)
... Crop-n Land

σ = -0.75

Cropland
Dairy Land
Ruminant Land
Non-Ruminant Land

Pasture Land

σ = -0.5

Land Supply Sub-Model

σ = -0.25
```
Simulations with A Modified GTAP Model: Policy Modeling Approach

- GTAP CES function Model of Ethanol-Petroleum products Substitution

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

- 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 \( A_e \)
  - \( \sigma \) is set to 0.1 Consistent with U.S. Biofuel Market
## Simulations with A Modified GTAP Model: Scenarios Based on 2001-2006 Data

<table>
<thead>
<tr>
<th></th>
<th>Case A Blending Mandate</th>
<th>Case B Output Mandate</th>
<th>Case C Yield-Adjusted Blending/Output Mandate</th>
<th>Case D Yield-Adjusted Blending Mandate &amp; Parameter Changes</th>
<th>Case E Yield-Adjusted Output Mandate &amp; Parameter Changes</th>
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<tbody>
<tr>
<td><strong>Share Parameters</strong></td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>X X X</td>
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<tr>
<td><strong>Ethanol Output</strong></td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X X X</td>
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<tr>
<td><strong>Petroleum &amp; Ethanol Consumption Tax</strong></td>
<td>- E</td>
<td>- E</td>
<td>-</td>
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<td>E E E</td>
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<tr>
<td><strong>Petroleum &amp; Ethanol Output Tax</strong></td>
<td>- - E</td>
<td>- E</td>
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<td><strong>Change in Overall Household Tax to Income Ratio</strong></td>
<td>- X</td>
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<td>-</td>
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<td>X X X</td>
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<td><strong>Household Ethanol/Petroleum Elasticity of Substitution</strong></td>
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<td>- - -</td>
<td>-</td>
<td>X</td>
<td>X X -</td>
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<tr>
<td><strong>Land Supply Transformation Elasticities</strong></td>
<td>- - -</td>
<td>- - -</td>
<td>-</td>
<td>X</td>
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Simulations with A Modified GTAP Model: Case A – Blending Mandate

<table>
<thead>
<tr>
<th>Ethanol production and import change (%)</th>
<th>U.S.</th>
<th>Canada</th>
<th>Brazil</th>
<th>EU-27</th>
<th>Rest of World</th>
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<tr>
<td>Corn ethanol output</td>
<td>171.07</td>
<td>18.83</td>
<td>0.01</td>
<td>0.20</td>
<td>0.09</td>
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<td>Corn ethanol import</td>
<td>179.98</td>
<td>-0.51</td>
<td>0.00</td>
<td>0.19</td>
<td>-0.16</td>
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<tr>
<td>Sugarcane ethanol output</td>
<td>173.40</td>
<td>0.39</td>
<td>2.36</td>
<td>0.26</td>
<td>0.16</td>
</tr>
<tr>
<td>Sugarcane ethanol import</td>
<td>182.47</td>
<td>0.14</td>
<td>0.51</td>
<td>0.06</td>
<td>0.11</td>
</tr>
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<table>
<thead>
<tr>
<th>Coarse grains output, export and land use change (%)</th>
<th>Coarse grains output</th>
<th>Coarse grains export</th>
<th>Coarse grains export share</th>
<th>Coarse grains ethanol</th>
<th>Coarse grains land</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>4.69</td>
<td>-1.90</td>
<td>-6.30</td>
<td>171.07</td>
<td>3.12</td>
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<tr>
<td></td>
<td>0.49</td>
<td>-0.06</td>
<td>0.61</td>
<td>0.27</td>
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<td>0.25</td>
<td>0.86</td>
<td>0.27</td>
<td>0.20</td>
<td>0.14</td>
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<td>0.08</td>
<td>0.34</td>
<td>0.52</td>
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<table>
<thead>
<tr>
<th>Land use change (%)</th>
<th>Coarse grains</th>
<th>Other grains</th>
<th>Forestry</th>
<th>Oil seeds</th>
<th>Other agriculture</th>
<th>Sugarcane</th>
<th>Dairy farms</th>
<th>Ruminant cattle</th>
<th>Non-Ruminants</th>
<th>Forest</th>
<th>Agricultural land</th>
<th>Shrub/Grass land</th>
<th>Other land</th>
<th>Oil import change (%)</th>
<th>Real GDP Change (Smillion)</th>
<th>Equivalent Variation (Smillion)</th>
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<tbody>
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<td></td>
<td>3.12</td>
<td>-0.80</td>
<td>-0.04</td>
<td>-0.80</td>
<td>-0.58</td>
<td>-0.32</td>
<td>-0.32</td>
<td>-0.38</td>
<td>-0.38</td>
<td>-0.075</td>
<td>0.187</td>
<td>-0.425</td>
<td>-0.045</td>
<td>-3.80</td>
<td>-111</td>
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<td>0.00</td>
<td>0.16</td>
<td>-0.02</td>
<td>-0.07</td>
<td>-0.08</td>
<td>0.02</td>
<td>-0.08</td>
<td>0.030</td>
<td>0.038</td>
<td>-0.085</td>
<td>-0.001</td>
<td>-1.25</td>
<td>-4</td>
<td>-90</td>
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<td>0.14</td>
<td>-0.12</td>
<td>0.00</td>
<td>0.03</td>
<td>-0.06</td>
<td>0.73</td>
<td>-0.03</td>
<td>-0.08</td>
<td>-0.08</td>
<td>-0.002</td>
<td>0.038</td>
<td>-0.034</td>
<td>-0.005</td>
<td>0.90</td>
<td>2</td>
<td>79</td>
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<td>0.03</td>
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<td>0.00</td>
<td>0.07</td>
<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.004</td>
<td>0.009</td>
<td>-0.032</td>
<td>-0.004</td>
<td>0.25</td>
<td>516</td>
<td>1484</td>
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<td></td>
<td>0.01</td>
<td>0.19</td>
<td>0.26</td>
<td>0.06</td>
<td>0.20</td>
<td>-0.02</td>
<td>0.02</td>
<td>-0.01</td>
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<td>-0.004</td>
<td>0.009</td>
<td>-0.032</td>
<td>-0.005</td>
<td>-0.02</td>
<td>188</td>
<td>-191</td>
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</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th>Ethanol production and import change (%)</th>
<th>U.S.</th>
<th>Canada</th>
<th>Brazil</th>
<th>EU-27</th>
<th>Rest of World</th>
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</thead>
<tbody>
<tr>
<td>Corn ethanol output</td>
<td>177.00</td>
<td>-9.96</td>
<td>0.00</td>
<td>0.04</td>
<td>0.01</td>
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<tr>
<td>Corn ethanol import</td>
<td>-94.66</td>
<td>-0.76</td>
<td>0.00</td>
<td>0.04</td>
<td>-0.17</td>
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<tr>
<td>Sugarcane ethanol output</td>
<td>-22.36</td>
<td>0.04</td>
<td>-1.60</td>
<td>0.05</td>
<td>0.04</td>
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<tr>
<td>Sugarcane ethanol import</td>
<td>-100.00</td>
<td>0.10</td>
<td>-0.08</td>
<td>0.16</td>
<td>0.04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coarse grains output, export and land use change (%)</th>
<th>U.S.</th>
<th>Canada</th>
<th>Brazil</th>
<th>EU-27</th>
<th>Rest of World</th>
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<tbody>
<tr>
<td>Coarse grains output</td>
<td>4.87</td>
<td>0.21</td>
<td>0.36</td>
<td>0.08</td>
<td>0.14</td>
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<tr>
<td>Coarse grains export</td>
<td>-1.93</td>
<td>0.02</td>
<td>1.09</td>
<td>0.37</td>
<td>0.91</td>
</tr>
<tr>
<td>Coarse grains export share</td>
<td>-6.48</td>
<td>-0.19</td>
<td>0.73</td>
<td>0.29</td>
<td>0.53</td>
</tr>
<tr>
<td>Coarse grains ethanol</td>
<td>177.00</td>
<td>-9.96</td>
<td>0.01</td>
<td>0.04</td>
<td>0.18</td>
</tr>
<tr>
<td>Coarse grains land</td>
<td>3.23</td>
<td>0.08</td>
<td>0.23</td>
<td>0.03</td>
<td>0.10</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Land use change (%)</th>
<th>U.S.</th>
<th>Canada</th>
<th>Brazil</th>
<th>EU-27</th>
<th>Rest of World</th>
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</thead>
<tbody>
<tr>
<td>Coarse grains</td>
<td>3.23</td>
<td>0.08</td>
<td>0.23</td>
<td>0.03</td>
<td>0.10</td>
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<tr>
<td>Other grains</td>
<td>-0.81</td>
<td>0.03</td>
<td>0.03</td>
<td>0.01</td>
<td>0.00</td>
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<tr>
<td>Forestry</td>
<td>-0.04</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Oil seeds</td>
<td>-0.83</td>
<td>0.14</td>
<td>0.14</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>Other agriculture</td>
<td>-0.60</td>
<td>0.04</td>
<td>0.05</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>-0.34</td>
<td>-0.06</td>
<td>-0.54</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>Dairy farms</td>
<td>-0.34</td>
<td>-0.07</td>
<td>-0.01</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>Ruminant cattle</td>
<td>-0.39</td>
<td>0.03</td>
<td>0.01</td>
<td>-0.01</td>
<td>-0.01</td>
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<tr>
<td>Non-Ruminants</td>
<td>-0.40</td>
<td>-0.08</td>
<td>0.02</td>
<td>-0.02</td>
<td>-0.01</td>
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<table>
<thead>
<tr>
<th>Land-cover change (%)</th>
<th>U.S.</th>
<th>Canada</th>
<th>Brazil</th>
<th>EU-27</th>
<th>Rest of World</th>
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</thead>
<tbody>
<tr>
<td>Forest</td>
<td>-0.079</td>
<td>-0.002</td>
<td>-0.002</td>
<td>-0.005</td>
<td>-0.002</td>
</tr>
<tr>
<td>Agricultural land</td>
<td>0.198</td>
<td>0.029</td>
<td>0.014</td>
<td>0.011</td>
<td>0.010</td>
</tr>
<tr>
<td>Shrub/Grass land</td>
<td>-0.449</td>
<td>-0.082</td>
<td>-0.015</td>
<td>-0.027</td>
<td>-0.014</td>
</tr>
<tr>
<td>Other land</td>
<td>-0.048</td>
<td>-0.001</td>
<td>-0.006</td>
<td>-0.007</td>
<td>-0.001</td>
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<tr>
<td>Oil import change (%)</td>
<td>-1.00</td>
<td>-0.31</td>
<td>0.22</td>
<td>0.07</td>
<td>0.06</td>
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<table>
<thead>
<tr>
<th>Real GDP Change (Smillion)</th>
<th>U.S.</th>
<th>Canada</th>
<th>Brazil</th>
<th>EU-27</th>
<th>Rest of World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent Variation (Smillion)</td>
<td>-4705</td>
<td>-46</td>
<td>-1</td>
<td>338</td>
<td>-332</td>
</tr>
</tbody>
</table>

- 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:**
  \[ y(x_1, x_2, \ldots, x_n) = x_1 \cdot x_2 \cdots x_n \]
- **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:**
  \[ \Delta y^D = \sum_{i=1}^{n} \left( \frac{y_{i+1} - y_{i-1}}{\ln \left( \frac{y_{i+1}}{y_{i-1}} \right)} \right) \ln \left( \frac{x_{i+1}}{x_{i-1}} \right) = \sum_{i=1}^{n} \Delta y \frac{g_{xi}}{g_y} \]
- **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

**Corn Production and Distribution Chain**
- Corn Production
- Corn Stocks
  - Total Corn Supply
    - Net Corn Exports
    - Domestic Corn Uses
      - Food, Feed, Seed and Industrial Uses
      - Other Domestic Uses
        - Corn Use for Ethanol Production
        - Other Food, Feed, Seed and Industrial Use

**Land Use Chain**
- Harvested All Crops Land
- Harvested Grain & Oil Seeds Land
  - Harvested All Grains Land
    - Harvested Coarse Grains Land
      - Other Coarse Grains
      - Harvested Corn Area
        - Corn Production
          - Corn Yield

- Other Food, Feed, Seed and Industrial Use
- Other Domestic Uses

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

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

\[ Q_{prd} = Y_{\text{corn}} \frac{A_{\text{corn}}}{A_{cgrn}} \frac{A_{cgrn}}{A_{grn}} \frac{A_{grn}}{A_{grn+oilsd}} \frac{A_{grn+oilsd}}{A_{\text{all}}} A_{\text{all}} \]

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)
- \( Y_{\text{corn}} \) = Annual corn yield in (tons/ha)
- \( A_{\text{corn}} \) = Annual corn harvested area (ha)
- \( A_{cgrn} \) = Annual coarse grain harvested area (ha)
- \( A_{grn} \) = Annual all grain harvested area (ha)
- \( A_{grn+oilsd} \) = Annual all grain plus oilseed harvested area (ha)
- \( A_{\text{all}} \) = 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
References


