# BioComplexities: Equilibrium Modeling and Carbon Leakages

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# Motivation

In order to start to understand some of the most pressing sustainability questions (from Climate Change Mitigation to the expansion of renewable energy markets), one needs to:

- Develop frameworks that explicit consider the behavior of multiple agents, their interactions and how the 'systems' – Human and Ecological - evolve over time -This requires careful Equilibrium Models
- Carefully consider the SCALE of the problem – to be able to capture potential leakages that (domestic) public policies can create throughout the system

# Key Features of Equilibrium Models

- Some – perhaps those who really never build such large scale models – seem to be concerned with 'unrealistic' convexity assumptions needed to assure uniqueness and stability of equilibrium

- Economists, atmospheric scientists and other modelers often argue that to represent long run equilibrium, convexity assumptions may not be so bad after all. (e.g. fixed costs that break convexity disapear in the long run)

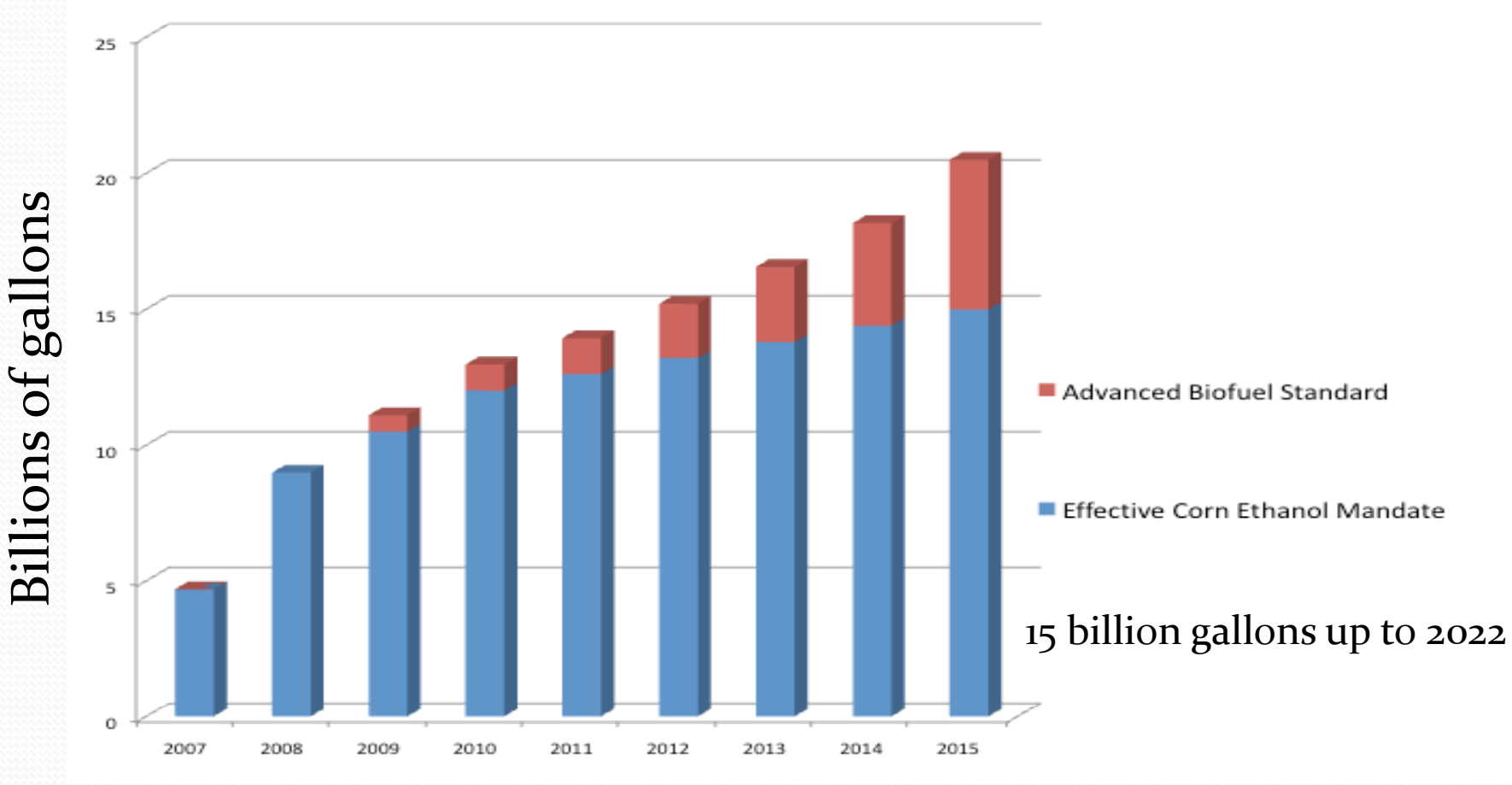
# Two Important Sustainability Public Policy Questions

- How does the provision of carbon offsets affects the overall costs of cap-and-trade programs?
  - Require modeling of the interactions between regulated sectors and sectors – like agriculture and forestry - that can reduce GHG emissions voluntarily
  - Requires modeling of the diffusion of cleaner technologies in regulated sectors
  - Requires attention to potential carbon leakages and the modeling of the path of carbon accumulation over time

# Two Important Sustainability Public Policy Questions

- What are the GHG emissions, Land Use Effects and overall costs of renewable fuel standards?
- Today I am going to focus on this project
- Outreach Component: Currently this model is one of the models – together with GTAP, FASOM, and FAPRI – that the office of air quality at the EPA is using to alter rule making related to biofuels mandates.

# Corn-Based Ethanol Mandates




15 billion gallons up to 2022

# Questions Addressed

- What are the economy-wide (gross) costs of increases in the mandates of biofuels production?
  - Effects of the pre-existing volumetric tax credit
  - Effects of the pre-existing gasoline tax
- What are the impacts of the mandates on car use (VMT) and the fuel economy of the automobile fleet?
- What are the impacts of the mandates on crude oil dependence and crude oil expenditures?

# Questions Addressed

- What are the impacts of the mandates on land use change:
  - crop acreage, rotation and tillage
  - Allocation of land to the conservation reserve program (CRP)
- What are the impacts of the mandates on the volume of crop exports?

# Key Features of our Study

| Feature | Capability |
|---|---|
| Integrated treatment of agricultural and fuel markets | Establish a relationship between the prices of corn, ethanol, food and blended fuel |
| Attention to detail of agricultural practices and Land Use Allocation | Consider adjustments in acreage, rotation systems and tillage practices and land in CRP |
| Integrated treatment of trade in crops and crude oil | Measure changes in crop exports and potential unintended land use effects<br>Measure changes in crude oil prices |
| Ability to capture important dynamic effects | Allow agricultural yields, fuel economy, efficiency of ethanol production, income and external demand for crops to evolve over time. |

# Overview of the Numerical Model: Economic Agents

- The Economic agents in the model are:
  - Households
  - Producers of agricultural crops
  - Producers of ethanol
  - Producers of Food
  - Suppliers of Regular Gasoline
  - Suppliers of Blended Fuel
  - Government
- Trade with the rest of the world: Crude Oil and Crops

# Elements of the Simulation Model: Representative Agent

- Representative Agent:
  - Decides total VMT, Food Consumption and composite good consumption
  - Produces VMT by investing in Fuel Economy and purchasing Blended Fuel (allow for a non-proportional relation between blended fuel and VMT)
  - Households do not distinguish regular gasoline from E10
  - Endowed with the 3 fixed factors in the economy: Labor, Land and Capital
  - Faces a blended fuel tax

# Elements of the Simulation Model: Allocation of Land

- Maximizes the returns to Land by deciding:
  - Combination of acreage, rotation and tillages
  - 4 Crops: Corn, Soybeans, Wheat, Hay
  - 6 Rotations:
    - Single Crop Rotations: Continuous Corn; Continuous Soybeans; Continuous wheat and Continuous hay
    - Multi-crop Rotations: Corn-Soybeans; Corn-Soybeans-Wheat
  - 4 Tillages: Conventional, Mulch, Reduced, No-Till

# Elements of the Simulation Model: Land Allocation (cont.)

- Challenge to integrate rotation and tillage decisions into a non-linear returns maximization function
  - Max Net Returns:
    - Yields of each crop*Land allocated to each crop*price
    - Returns to CRP land

    Net of costs of production – these vary by tillage (inputs are: labor, capital, energy and fertilizers)

  Model constraints that reflect how farmers substitute across different rotations using CES functions (2 stages)

# Elements of the Simulation Model: Supply of Ethanol

- Multi-output production process
  - Ethanol
  - 4 Co-products:
    - DDGS
    - Corn Gluten meal
    - Corn Gluten feed
    - Corn Oil
- Model Ethanol Production using fixed proportion technology; Inputs: Corn, Labor, Capital and Energy

# Elements of Simulation Model: Regular Gasoline and Blended Fuel

- Regular gasoline producers combine:
  - Labor
  - Capital
  - Crude Oil
- Blended Fuel Producers:
  - Seek to mix ethanol and regular gasoline to produce blended fuel
  - Face a constraint that mandates a quantity of ethanol to be blended
  - For every gallon of ethanol blended , blender receives a tax credit

# Simulation Model: Other Sectors

- Model considers the production of natural gas (the energy input used in the production of ethanol and agriculture);
- Model considers the production of food:
  - Combine crops, ethanol co-products, labor, capital and energy to produce food
  - Do not consider livestock sector
- Consider the demand for Corn, Soybeans and Wheat from the rest of the world
- Consider rest-of the world net supply of crude oil

# Simulation Model: Government

- Government expenditures are financed by:
  - Tax on labor, capital and blended fuel
  - Provides a volumetric tax credit to blenders
  - Provides CRP payments
  - Provides a lump-sum transfer to households

# Simulation Model Solution and Dynamics

- Solution:
  - Solve for a sequence of market equilibria at one-year intervals (2003-2015), choosing a vector of prices that clears ALL markets (prices of crops and crude oil and amount of government return)
  - Consider pre-existing gasoline tax and tax credit for ethanol
- Dynamics:
  - Exogenous changes yields for crops, fuel economy of the automobile fleet, efficiency of ethanol conversion, adjustments in income, crop demand from the rest of the world

# Baseline and Mandated Ethanol (Billion Gallons)

| | 2003 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|
| Ethanol Baseline Quantities | 2.75 | 4.29 | 6.53 | 9.41 | 10.98 | 12.40 | 13.05 | 14.42 | 14.93 |
| Ethanol EISA 2007 Mandate Quantities | 0.00 | 9.00 | 10.50 | 12.00 | 12.60 | 13.20 | 13.80 | 14.40 | 15.00 |
| Ethanol Estimated Mandate Quantities | 2.75 | 9.00 | 10.52 | 12.05 | 12.68 | 13.30 | 13.92 | 14.53 | 15.13 |
| Difference in Estimated Mandate Relative to Baseline | 0.00 | 4.71 | 3.99 | 2.64 | 1.70 | 0.91 | 0.87 | 0.11 | 0.20 |
| Does the Mandate Bind? | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

# Baseline and Change in Crop Prices

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|
| Baseline Price of Corn ($/bushel) | $2.66 | $3.05 | $3.45 | $3.85 | $4.24 | $4.43 | $4.87 | $5.03 |
| % Change | 28.72% | 24.52% | 22.80% | 14.41% | 7.56% | 7.25% | 0.92% | 1.68% |
| Baseline Price of Soybeans ($/bushel) | $8.09 | $9.10 | $10.44 | $11.46 | $12.48 | $12.99 | $14.13 | $14.58 |
| % Change | 27.11% | 23.75% | 18.46% | 11.80% | 6.24% | 6.00% | 0.77% | 1.40% |
| Baseline Price of Hay ($/ton) | $95.95 | $108.90 | $123.62 | $136.65 | $149.81 | $156.57 | $171.22 | $177.22 |
| % Change | 26.31% | 22.65% | 19.57% | 12.44% | 6.55% | 6.29% | 0.80% | 1.46% |
| Baseline Price of Wheat ($/bushel) | $3.50 | $3.90 | $4.39 | $4.76 | $5.13 | $5.32 | $5.73 | $5.89 |
| % Change | 24.14% | 20.55% | 16.34% | 10.55% | 5.64% | 5.45% | 0.70% | 1.29% |

# Baseline and Change in Crops and CRP (Million Acres)

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|
| Baseline Corn | 78.11 | 78.95 | 83.39 | 83.57 | 83.72 | 83.78 | 83.91 | 83.94 |
| % Change | 6.79% | 5.87% | 0.44% | 0.28% | 0.15% | 0.14% | 0.02% | 0.03% |
| Baseline Soybeans | 72.44 | 72.54 | 69.37 | 69.42 | 69.47 | 69.48 | 69.54 | 69.55 |
| % Change | -4.21% | -4.27% | 0.17% | 0.11% | 0.07% | 0.07% | 0.01% | 0.02% |
| Baseline Hay | 63.13 | 62.79 | 62.83 | 62.54 | 62.30 | 62.21 | 62.02 | 61.97 |
| % Change | -0.43% | -0.34% | -0.84% | -0.51% | -0.25% | -0.23% | -0.03% | -0.05% |
| Baseline Wheat | 52.63 | 52.12 | 50.86 | 51.03 | 51.17 | 51.21 | 51.33 | 51.35 |
| % Change | -3.33% | -2.09% | 0.65% | 0.40% | 0.20% | 0.19% | 0.02% | 0.04% |
| Baseline CRP | 33.66 | 33.57 | 33.51 | 33.41 | 33.31 | 33.29 | 33.17 | 33.17 |
| % Change | -0.68% | -0.69% | -0.87% | -0.61% | -0.35% | -0.35% | -0.05% | -0.09% |

# Change in Fuel Prices

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|
| Baseline Price of Ethanol ($/gallon) | $1.59 | $1.70 | $1.81 | $1.92 | $2.03 | $2.08 | $2.20 | $2.24 |
| % Change | 13.82% | 12.65% | 12.46% | 8.25% | 4.51% | 4.39% | 0.58% | 1.06% |
| Baseline Price of Regular Gasoline ($/gallon) | $1.59 | $1.70 | $1.81 | $1.92 | $2.03 | $2.08 | $2.20 | $2.24 |
| % Change | -0.66% | -0.54% | -0.36% | -0.22% | -0.11% | -0.11% | -0.01% | -0.02% |
| Baseline Price of Blended Fuel ($/gallon) | $1.59 | $1.70 | $1.81 | $1.92 | $2.03 | $2.08 | $2.20 | $2.24 |
| % Change | 0.30% | 0.50% | 0.82% | 0.61% | 0.36% | 0.38% | 0.05% | 0.11% |
| Baseline Price of Crude Oil ($/barrel) | $32.04 | $37.53 | $42.97 | $48.44 | $53.94 | $56.42 | $62.54 | $64.59 |
| % Change | -1.62% | -1.21% | -0.75% | -0.44% | -0.22% | -0.20% | -0.02% | -0.04% |
| Baseline Price of Miles ($/mile) | $0.19 | $0.19 | $0.20 | $0.20 | $0.21 | $0.21 | $0.21 | $0.22 |
| % Change | 0.12% | 0.21% | 0.35% | 0.27% | 0.17% | 0.17% | 0.03% | 0.05% |

# Change in Fuel and VMTs

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|
| Baseline Blended Fuel (billion gallons) | 134.96 | 133.05 | 131.37 | 129.85 | 128.47 | 128.53 | 127.08 | 127.40 |
| % Change | -0.14% | -0.23% | -0.39% | -0.29% | -0.17% | -0.18% | -0.03% | -0.05% |
| Baseline Ethanol (billion gallons) | 4.29 | 6.53 | 9.41 | 10.98 | 12.40 | 13.05 | 14.42 | 14.93 |
| % Change | 109.67% | 61.15% | 28.08% | 15.49% | 7.30% | 6.63% | 0.77% | 1.36% |
| Baseline Regular Gasoline (billion gallons) | 130.67 | 126.52 | 121.96 | 118.87 | 116.07 | 115.48 | 112.67 | 112.47 |
| % Change | -3.75% | -3.40% | -2.58% | -1.74% | -0.97% | -0.95% | -0.13% | -0.24% |
| Vehicle Miles Travelled (trillion passenger miles) | 2.79 | 2.78 | 2.77 | 2.76 | 2.76 | 2.77 | 2.76 | 2.78 |
| % Change | -0.06% | -0.09% | -0.16% | -0.12% | -0.07% | -0.07% | -0.01% | -0.02% |
| Fuel Economy (Miles Per Gallon) | 20.64 | 20.86 | 21.07 | 21.26 | 21.45 | 21.56 | 21.75 | 21.84 |
| % Change | 0.09% | 0.14% | 0.23% | 0.17% | 0.10% | 0.11% | 0.02% | 0.03% |

# Conclusions

We develop a framework that embraces supply- and demand-side responses to biofuels mandates in fuel and land markets

- On the demand side, vehicle use (fuel economy and fuel consumption) and food demand are integrated

- On the supply side, we account for the decisions of acreage-rotation-tillages and conversion of land from CRP

- Account for international trade in crops and crude oil
- Model important dynamic adjustments

# Main Findings

- The overall efficiency cost of meeting the mandate in 2008 is 2,776.19 million dollars
- The efficiency cost per gallon of increased ethanol mandates is 0.59
- Effects are mostly felt in the short run
  - - vast intensification of land use
- For Each Gallon of ethanol mandated the reduced displacement of regular gasoline is 1.04 (represents a 3.53% change in crude oil demand)

# Prospects and caveats

- Prospects:
  - Model has potential to investigate other policies aimed at reducing gasoline consumption and GHG emissions (carbon tax, fuel taxes, CAFE standards)
  - Model has the potential to extend lifecycle analysis that calculate the GHG emissions resulting from biofuels mandates
  - Model has the potential to include the second generation of biofuels