# Analysis of Global Land Use Impacts of Corn Ethanol

**Presentation to the Technical Advisory Committee on Biomass Research and Development**

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**And Andy Jones, Michael O'Hare, Rich Plevin and Dan Kammen, UC Berkeley**

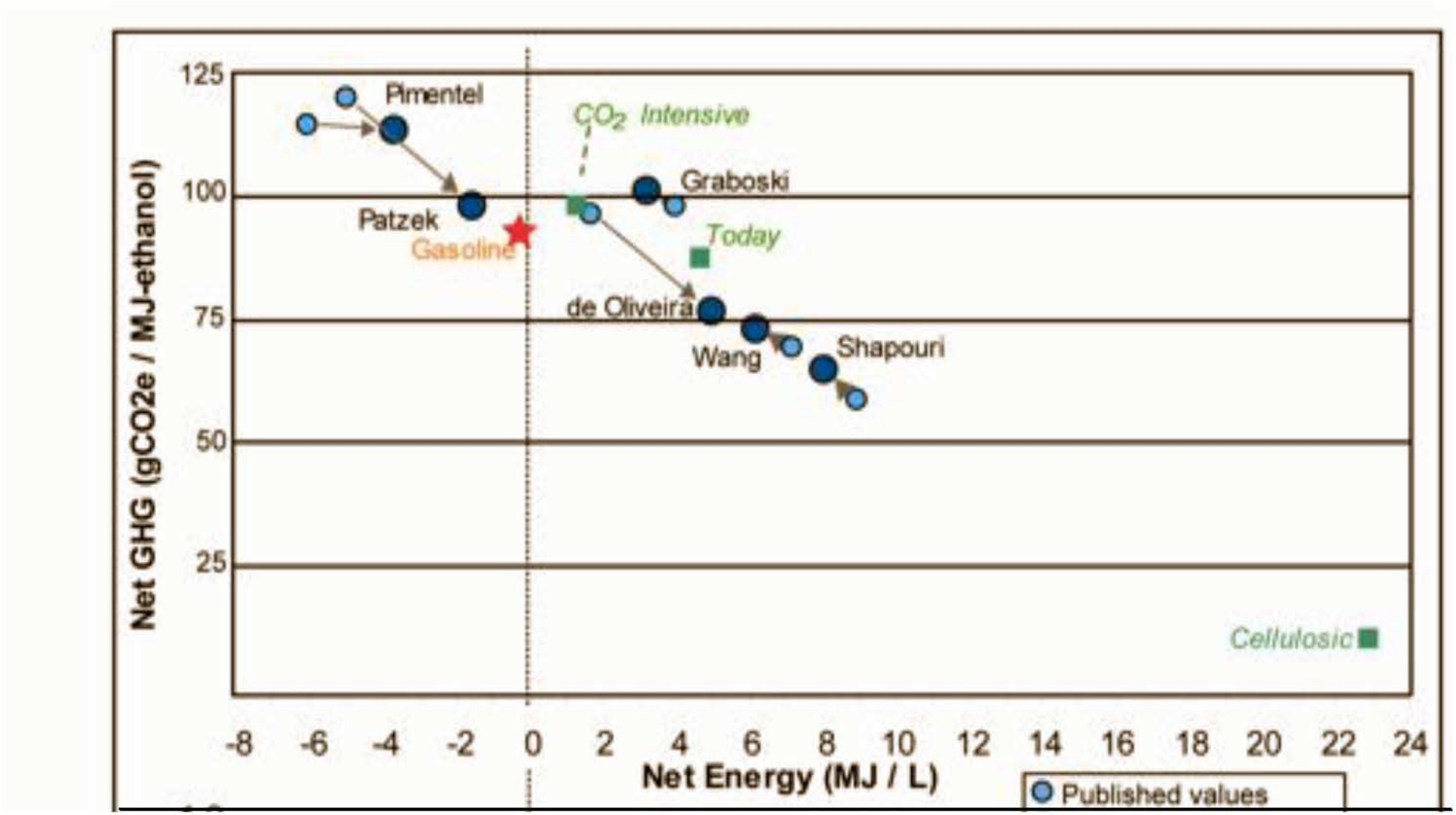
# Outline of Talk

- Background to debate over "Indirect" Land Use Change (iLUC)
- Key role for market-mediated effects
- Areas of greatest economic uncertainty:
  - Where additional research likely to pay off
  - And Areas where progress will be more difficult
- Guiding principles to ensure maximum impact from publicly funded research
- Concluding remarks

# Background (1)

- Prior to 2007, the general consensus was that corn ethanol reduced greenhouse gasses a bit more than 20% after considering all the direct effects related to growing the crop, transporting, processing, and consuming the ethanol.
- That is probably why the EISA of December 2007 included the 20% requirement for corn.

# Net GHG contributions of corn ethanol (vs. net energy contribution) *in absence of iLUC*




Source: Energy Resources Group, U.C. Berkeley

# Presence of iLUC may greatly increase GHG emissions

U.S. corn farmer switches from corn/soy to corn/corn

U.S. soy exports go down and world soy prices rise

Additional land in Brazil (for instance) is put into soy production

Soy farmers everywhere use more inputs to increase yields

Indirect LUC emissions

Indirect process emissions

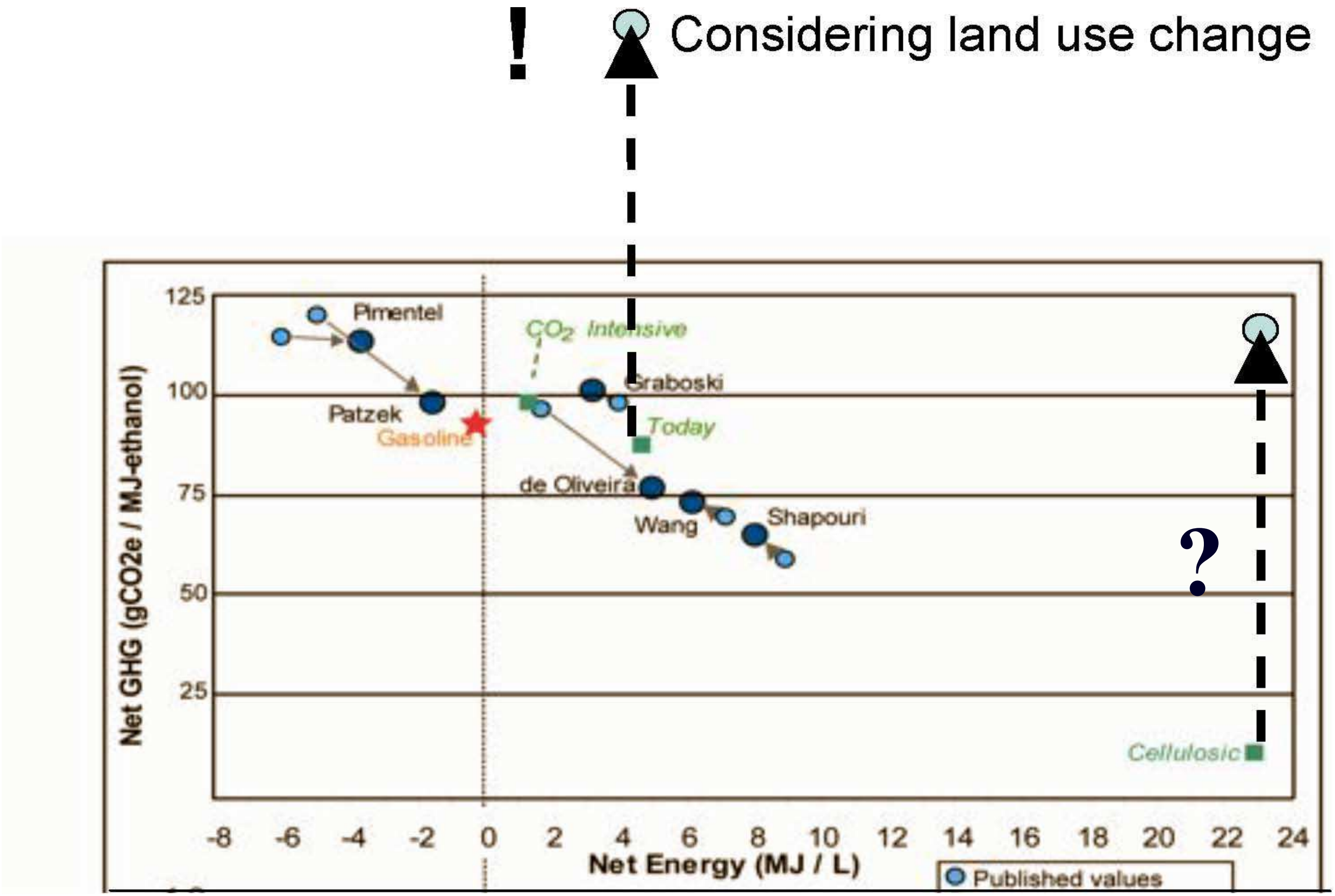
Process emissions

Source: Energy Resources Group, UC Berkeley

# Background (2)

- **By the second half of 2007, the importance of indirect land use change induced emissions was circulating among professionals in the area**
- **The EISA included a requirement that indirect land use changes be considered in estimating total GHG impacts for biofuels**
- **In February 2008, *Science* published a paper by Searchinger, Heimlich (USDA), Fabiosa, El'Obeid, Lu, Tokoz, Hayes and Du (Iowa State University) estimating the size of these effects; greatly altered the GHG landscape for biofuels**

# Net GHG contributions in presence of iLUC (Searchinger et al. estimates)



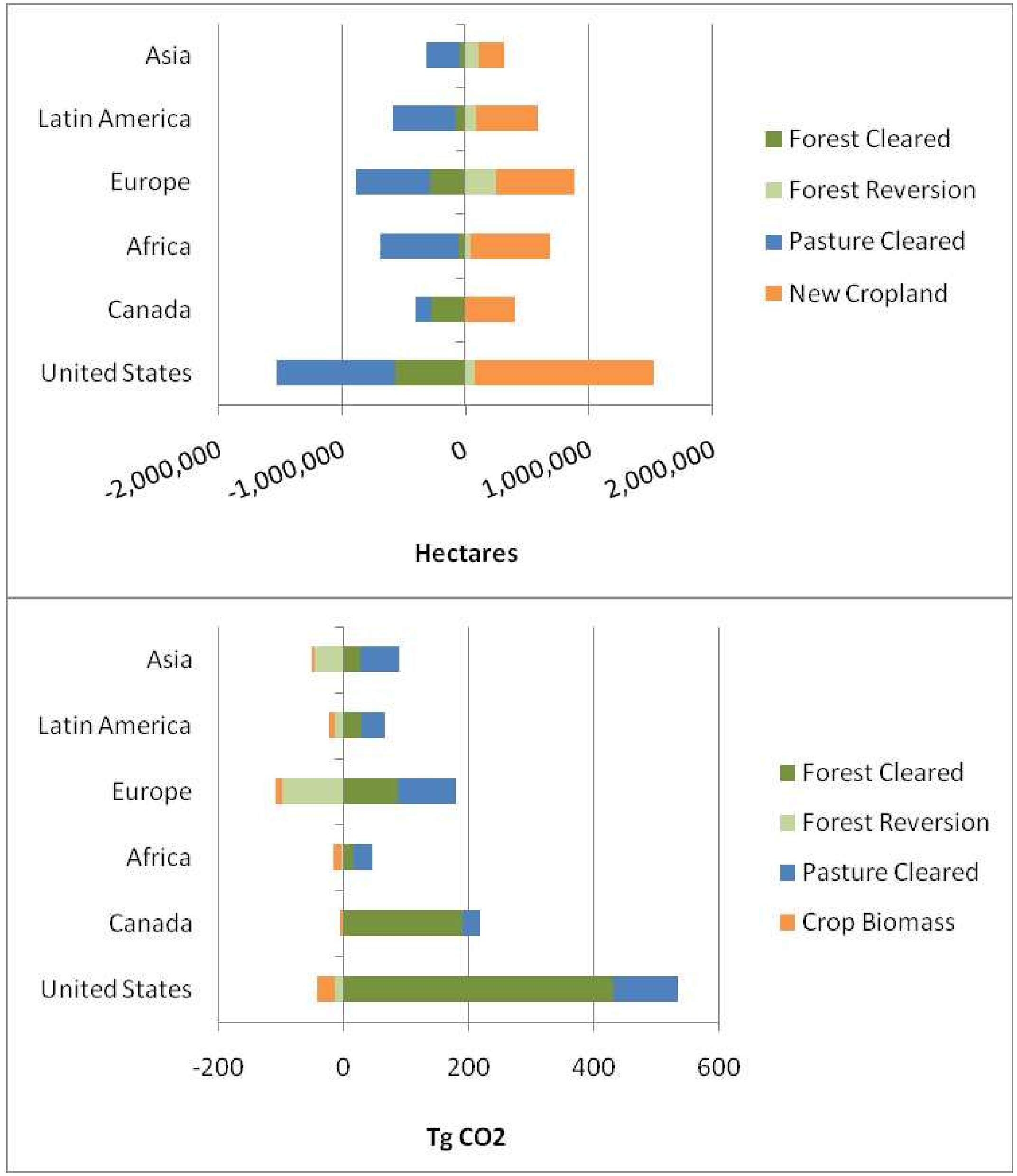

Source: Energy Resources Group, U.C. Berkeley

# Background (3)

- Publication of Searchinger et al. has precipitated a series of studies aimed at sharpening estimates of iLUC; unfortunately FAPRI model not publicly available
- California Air Resources Board and UC Berkeley approached Purdue to undertake a joint study of iLUC for use in CARB's LCFS; use GTAP model since publicly available; used by 6000+ worldwide
- In April 2009, CARB passed the LCFS, inclusive of iLUC estimates; the latter are based on GTAP analysis, undertaken at Purdue University
- Model is publicly available for replication/critique
- Subsequent analysis based on this work
- Later discuss limitations/need for further research

# Land Conversion (Ha) and Emissions (TgCO2) due to increased US corn ethanol production

- Estimate cropland expansion into accessible forest land and pastures
- Greatest portion of land conversion occurs in US
- Land cover elasticities based on US land use change: 1985 – 1997
- Emissions factors based on Woods Hole estimates




Source: CARB analysis, as documented in Hertel, Golub, Jones, O'Hare, Plevin and Kammen, 2009

# What is the bottom line?

- To play a meaningful role, corn ethanol's emissions must be significantly below gasoline:
  - Gasoline = 94-96 $gCO_2e/MJ$
  - Direct emissions of US corn ethanol = 60-65g/MJ, according to CARB; lower values are possible with new technologies (possibly 45g/MJ)
  - Indirect emissions (with 30 year time horizon):
    - Searchinger et al = 100g/MJ
    - Purdue-Berkeley estimate for CARB = 27g/MJ with std deviation of 12g/MJ
- Corn ethanol looks unlikely to make it:
  - California: need to reduce to 46g/MJ if going to achieve desired 10% reduction based on 20% blend
  - US-EPA: need 77g/MJ (20% of gasoline); but mostly grandfathered in already; implementation may be delayed for 5 years given recent deal on climate change bill

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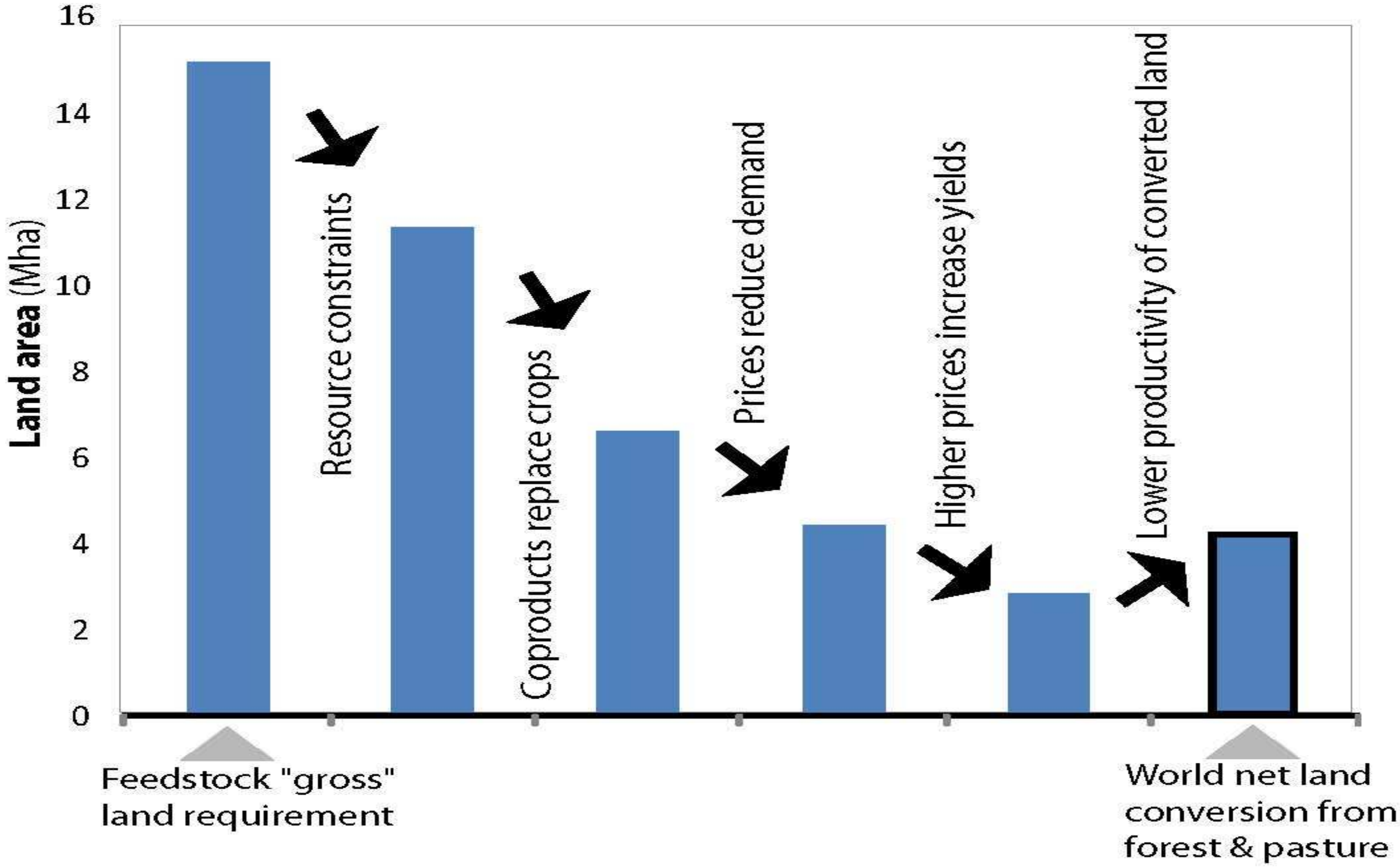
# GTAP estimates of iLUC are only ¼ of earlier estimates: market-mediated effects are key




Source: Hertel, Golub, Jones, O'Hare, Plevin and Kammen, 2009

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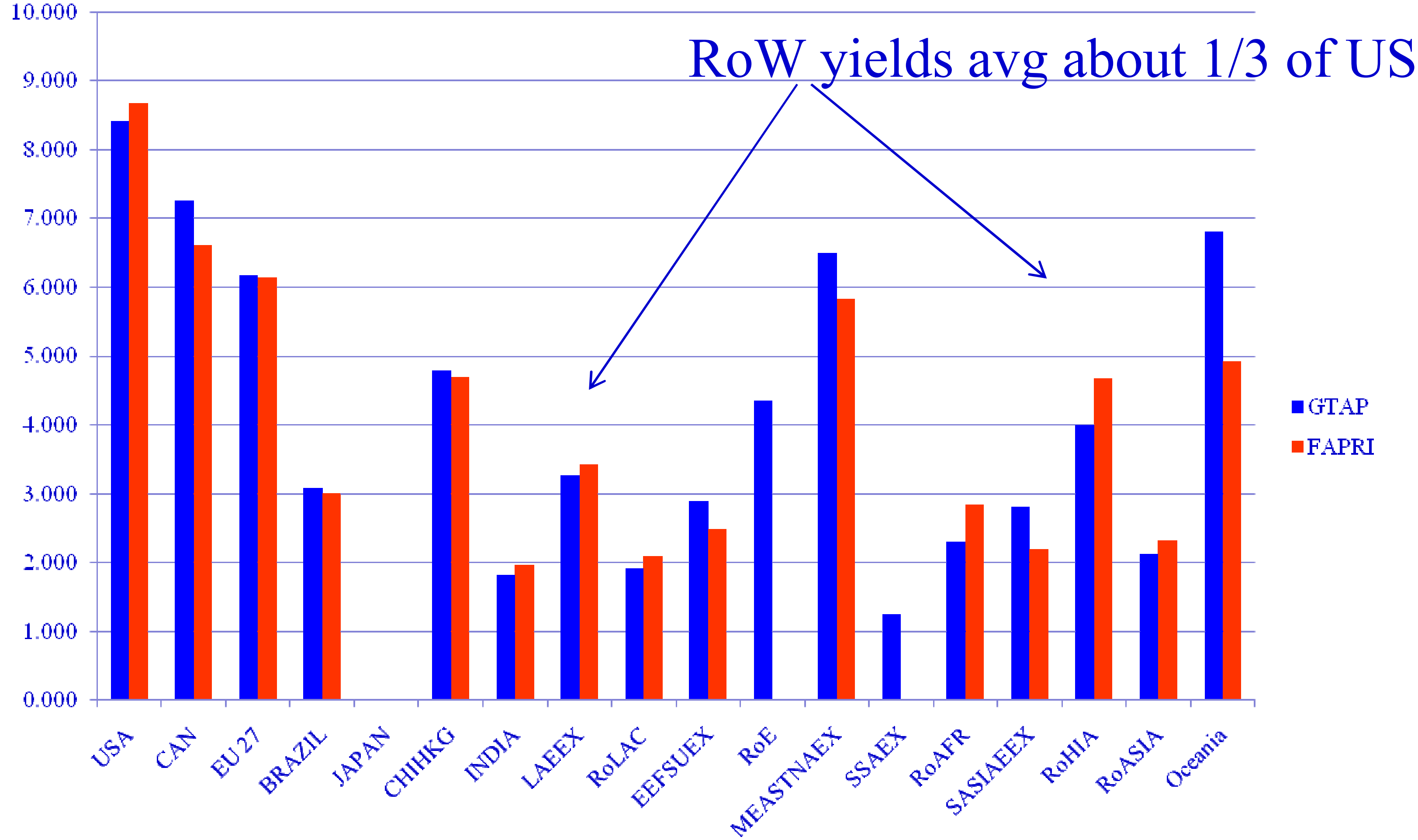
# Uncertainty about crop yields and distribution of production response

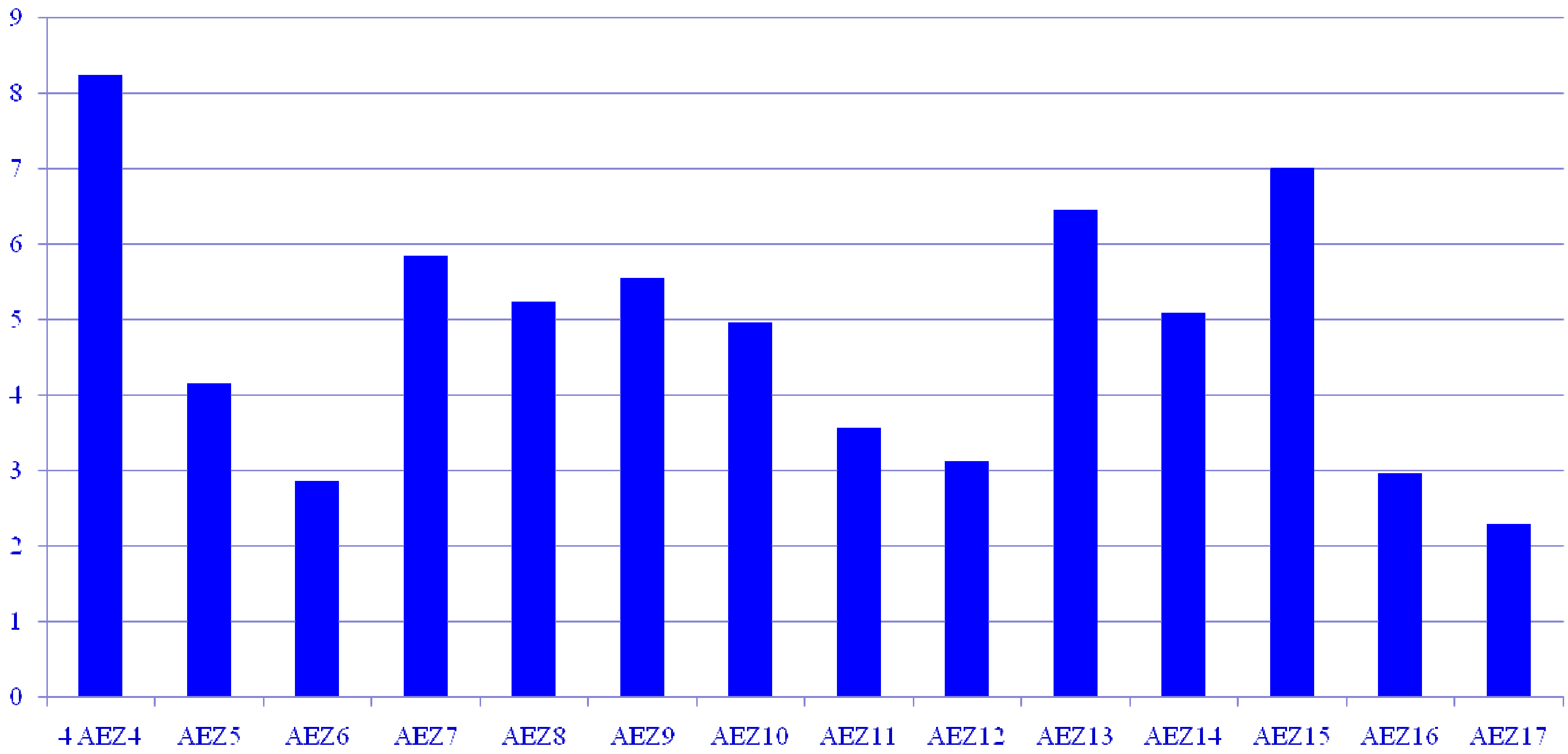
- The amount of new cropland which must be converted to plug the gap in supply due to diversion of crops to biofuel feedstock depends critically on yields
- Yields vary greatly:
  - Across countries: where is production response likely to occur?
  - Within countries: determines land cover change
  - Over time:
    - Baseline growth (independent of biofuel programs)
    - Endogenous response to biofuels requirements:
      - Intensive margin: higher yields on existing land
      - Extensive margin: potential yield decline as expand cropland area

# There is reasonably good agreement on historical international yields



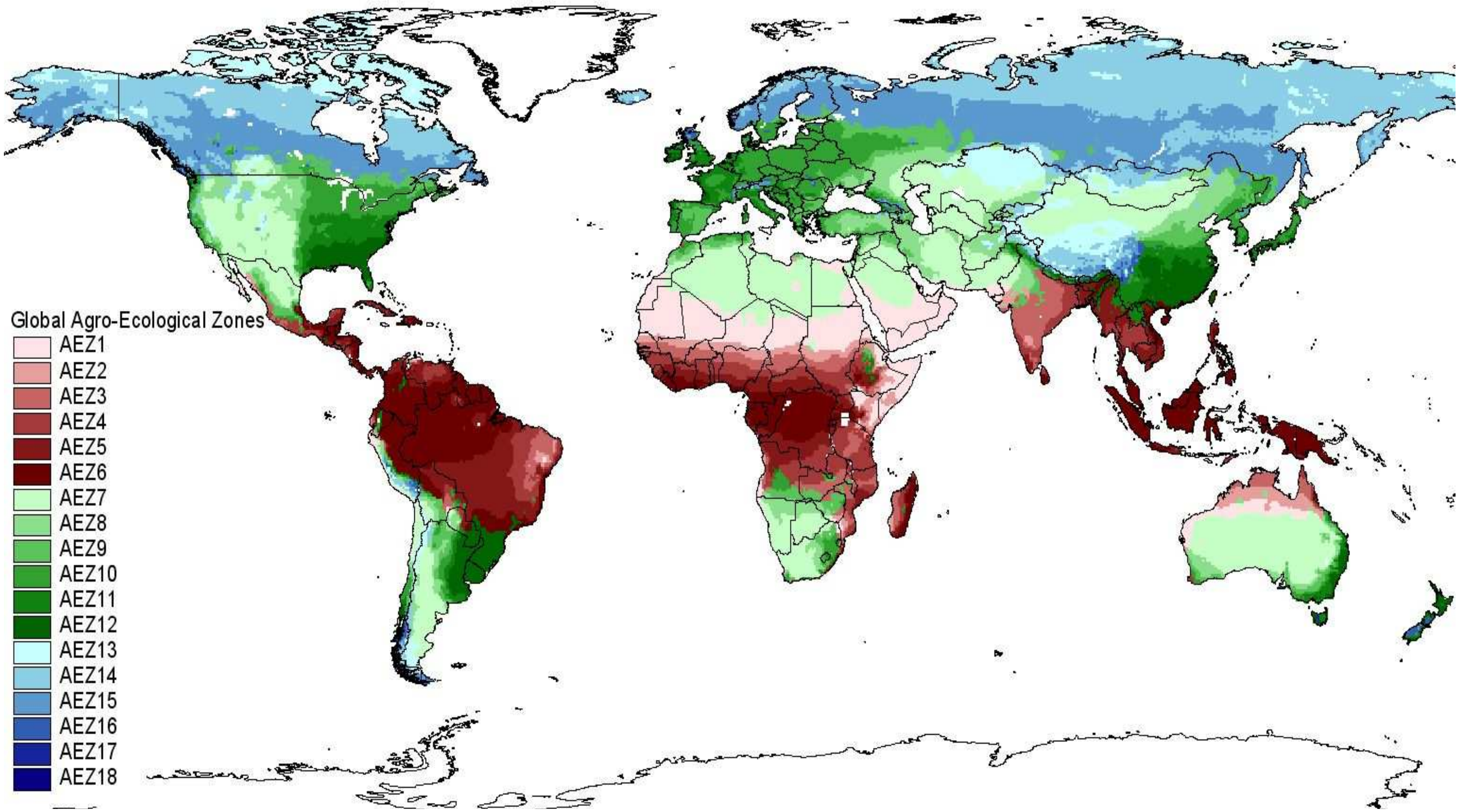

Comparison of ***corn yields*** (metric ton/ha) GTAP/SAGE is 1997-2003 average/ FAPRI is from the 2001/02 marketing year

## Intra-national variation is also important: Ignored in most global analyses, but captured by GTAP AEZs




**Corn yields** (metric ton/ha) GTAP/SAGE across AEZs for China (no corn is grown in AEZ18; no AEZs 1-3 in China)

# Global Distribution of AEZs




Source: Lee *et al*.

# The Question of Baseline Yields

- GTAP analysis is based on 2001 global economic data base – latest year for which comprehensive AEZ area/yield data are available (product of FAO, IFPRI, SAGE joint project)
- 2001 yields are lower than yields in 2009, 2017, etc
- How will this bias our results?
- Can we make a simple adjustment to capture effect of higher current yields?
- If developing a full-blown baseline with future yields, what should we look out for?

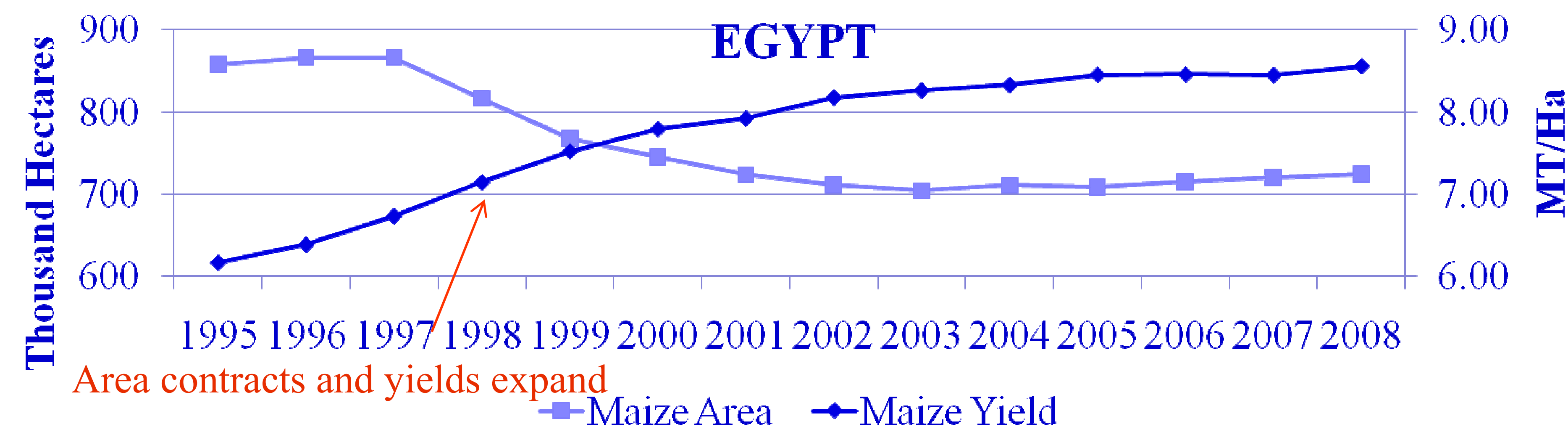
# Key to iLUC is *relative* rate of yield growth

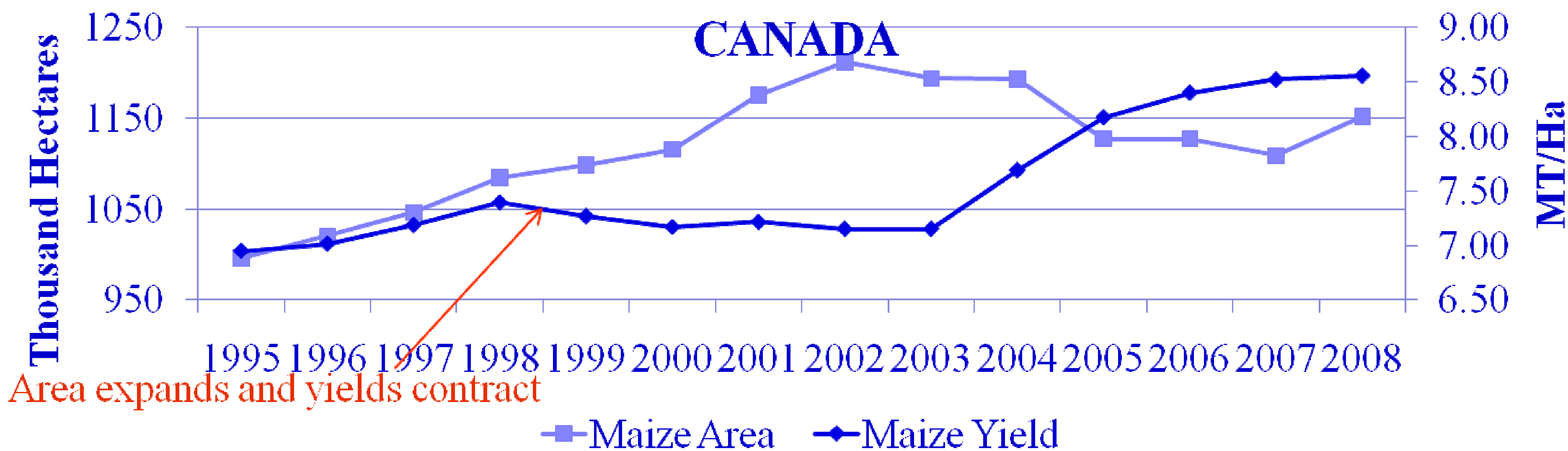
- **US corn yields grew by about 10% 2001-2007, so need 10% less land to meet given biofuel mandate; why not deflate iLUC estimate by 10%?**
- **Compare this to iLUC when update global yields and demands to 2007:**
  - **Balanced growth case (US/RoW demands and yields all grow by 10%) then same answer as above**
  - **If RoW yields grow faster, then iLUC is less**
  - **If RoW yields grow more slowly, then iLUC is larger**
  - **Key factor is *relative rate of yield growth*; to date excessive focus on US yield growth**
- ***Research Agenda: Would be valuable to update global land use data base***

# Endogenous variation in yields is very important: Can sharply alter iLUC

- **Intensive margin: producers respond to biofuels mandate by boosting yields (price-induced effect)**
  - **Historical yield response in US corn pretty high (as high as 0.7)**
  - **More recent estimates much lower (avg. 0.25 for corn)**
  - **We use 0.25 yield elasticity (Keeney and Hertel, AJAE)**
  - ***Research Agenda: Assemble estimates for other crops/countries***
- **Extensive margin: producers expand into new area, yields may decline as move onto marginal lands**
  - **Limited empirical evidence here; more work needs to be done**
  - **We assume 0.66 (need 3 ha of newly converted land to replace production lost from 2 ha of existing land)**
  - ***Research Agenda: Estimate this effect across countries/crops***

# Extensive margin illustrated: Maize Yields (moving avg) often go in opposite direction of area (Keeney et al)



## Another source of estimates for extensive margin: Production "slippage" from US set-aside programs

- **US Slippage estimates**
  - **% Change output for a 1 % change in area**

| | | | | |
|---|---|---|---|---|
| • **Corn =** ***avg*** | **0.72** | ***range*** | **[0.42, 0.95]** | **(10 estimates)** |
| • **Cotton =** | **0.73** | | **[0.65, 0.80]** | **(10 estimates)** |
| • **Wheat =** | **0.75** | | **[0.345, 1.00]** | **(10 estimates)** |
| • **Barley/oats =** | **0.87** | | **[0.83, 0.89]** | **(10 estimates)** |
| • **Sorghum =** | **0.88** | | **[0.85, 0.90]** | **(10 estimates)** |

  - **Slippage appears to be greater in "principal" crops vs. estimates for "marginal" crops**
- ***Research Agenda: Estimate slippage factors for other regions***

Source: Keeney and Hertel, AAEA organized session, August 2009

## Intensive margin dominates our CARB results for corn ethanol; yields rise worldwide; reduces area required

Decomposition of Global Crop Output (% change)

| Crop | Total | Area | TotYield | YieldInt | YieldExt |
|---|---|---|---|---|---|
| Cgrns | 6.05 | 4.94 | 1.06 | 1.54 | -0.47 |
| Oilseeds | 0.10 | -0.35 | 0.45 | 0.64 | -0.20 |
| SugarCrp | -0.17 | -0.62 | 0.45 | 0.31 | 0.14 |
| OthGrain | -0.25 | -0.57 | 0.32 | 0.27 | 0.05 |
| OthCrops | -0.25 | -0.36 | 0.12 | 0.22 | -0.10 |

Source: Hertel, Golub, Jones, O’Hare, Plevin and Kammen, 2009

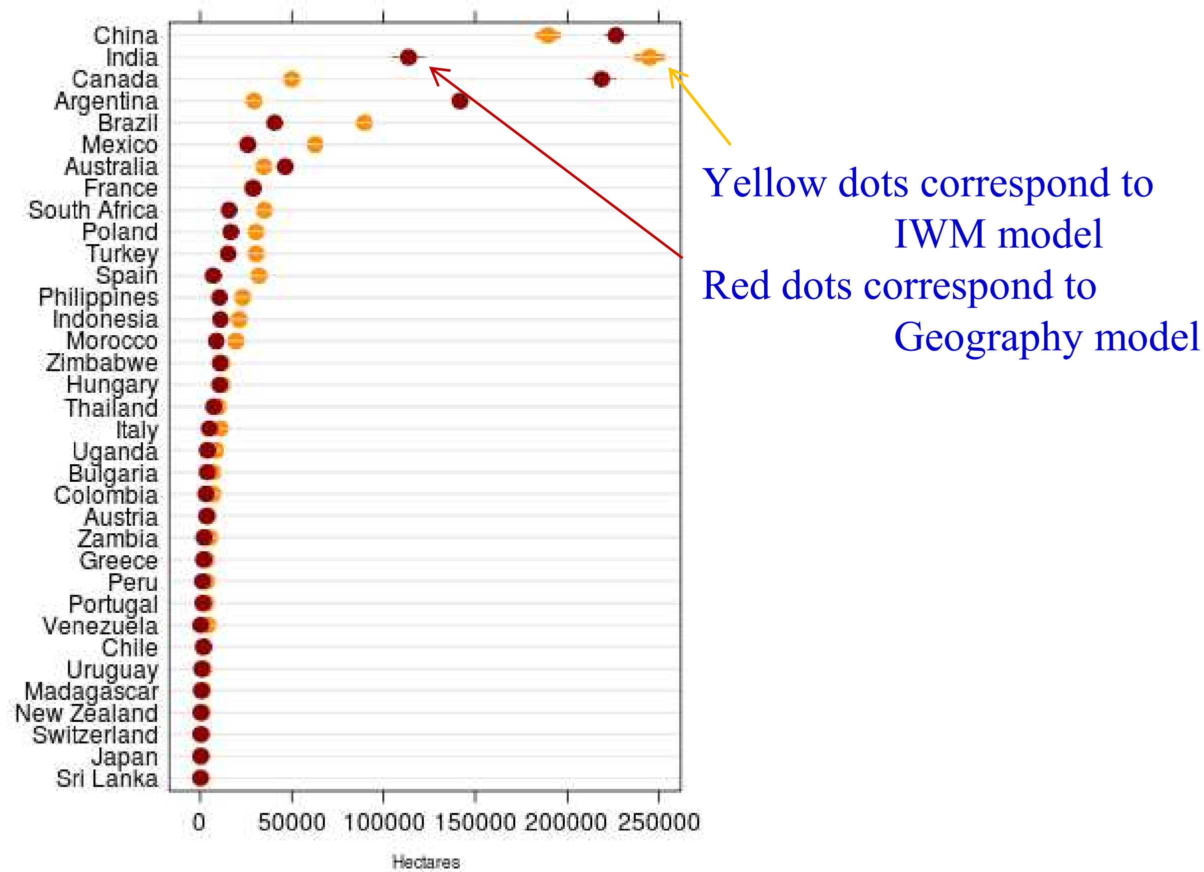
# Where will production response occur?

- **Key factor; if high yield region, then less area required; if low carbon region, then iLUC generates less GHG emissions**
- **Two competing hypotheses:**
  - **Integrated World Markets (IWM): FAPRI assumes a single market-clearing price**
  - **Geography rules: GTAP and most of empirical trade literature treats products as differentiated – exporter-specific prices**
- **Implications for global production response to biofuels:**
  - **US share of global response to US biofuels: FAPRI is one-fifth vs. GTAP: two-fifths**
  - **Relative role of India and China large in FAPRI, smaller in GTAP due to lesser participation in wld markets**
- **Which is right? Or is neither accurate? Let's turn to history and do some econometrics.**

# Estimation of area response to US price changes

- **Methodology (Villoria and Hertel):**
  - **Estimate derived demand for land/non-US regions**
  - ***Model nests two competing hypotheses***
  - **Permits estimation of area response elasticity to US prices**
- **Data:**
  - **FAO data on area harvested/36 countries, combined with data on bilateral trade, regional income, weather and real exchange rate; USDA price data on cgrns**
- **Findings:**
  - ***Reject IWM hypothesis in favor of geography model***
  - **Illustrate differences by estimating response to 1993 US drought: cgrns prod fell by 32%, US price rose by 15%**

## Mean predictions (with 95% confidence intervals) of additional harvested area, by model due to 1993 drought in USA




Villoria, N. and Hertel, T. (2009) "Understanding the Global Land Use Impacts of Biofuels: The Role of Product Differentiation". Work in progress.

# What about cropland that is not currently under cultivation?

- **Globally, cropland cover is 1.53Bha. vs. 1.27Bha. harvested area; what accounts for difference?**
  - **US relative gap larger: CRP and cropland pasture**
  - **Crop failures (plant but don't harvest) can be significant**
  - **Multi-cropping works in other direction: reduces gap between these two measures; particularly important in the tropics**
  - **Preliminary results from bringing rough estimates of cropland pasture into our model change the composition of cropland conversion – more pasture, less forest, so less GHG emissions**
  - ***Research Agenda: need to better understand this difference***
- **Unmanaged lands (2.3BHa. Globally) are lands not currently in use; why is it not in use? Limited productivity? Poor access? This is a a more difficult issue to address in economic model**
- **Inaccessible forests: Will these lands come into commercial production? Access often driven by (lack of) property rights**

# Consumption response can also be important

- Impact of reduced consumption due to higher prices plays a significant role in reducing land requirements for biofuels; but largely overlooked
- However, most price responsive demand is in low income countries, where rates of poverty and malnutrition are highest; unfortunate that most adjustment likely there
- What if prevented reduction in consumption via food subsidies? In our work with UCB-ERG:
  - We estimate twice as much forest land conversion and
  - 50% higher GHG emissions from LUC when food consumption is fixed (do not adjust to higher food prices in the wake of increased biofuels)

# Conclusions

- Estimating the global land use impacts of biofuels is a challenging task; but no more difficult than many regularly tackled in global economic analysis; we have made significant progress with limited resources
- To date, most $$ have been spent on producing more/different numbers based on questionable data and using models cannot be replicated by others; little devoted to fundamental research needed to improve iLUC estimates