Biotechnology and Climate Change

David Zilberman and Steven Sexton
UC Berkeley ARE

Berkeley Bioeconomy Conference

Outline

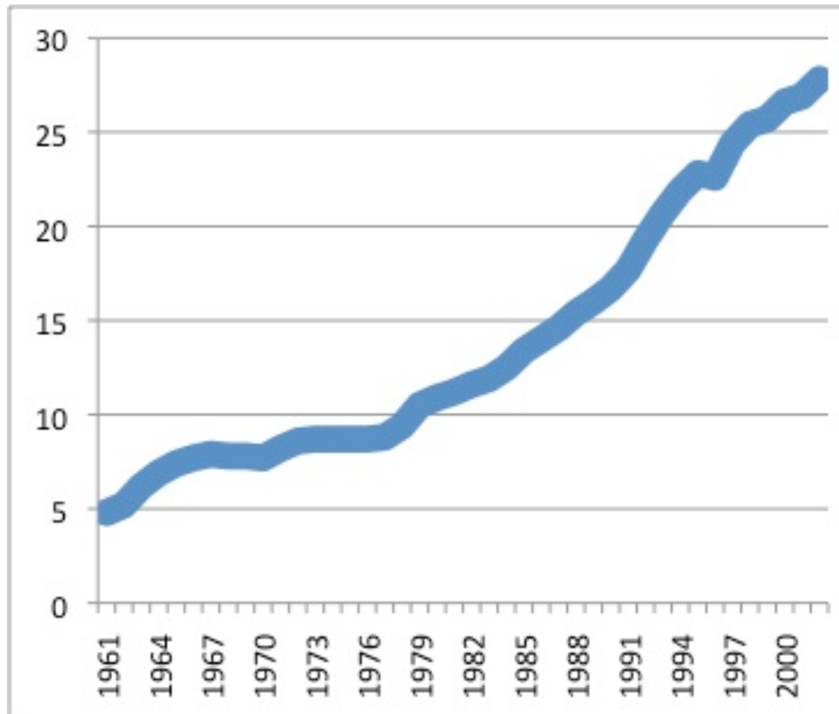
- Big challenges ahead
- How agricultural biotechnology mitigates climate change
- Offsetting effects
- Policy

Big Challenges: Rising Food Demand

- World pop will grow 30% by 2050
- Rising incomes cause per capita demand to grow too
- And diets are becoming more land intensive

- **Food production must grow faster than population**

Per Capita Meet Consumption (in kg) in Asia (1962-2002)

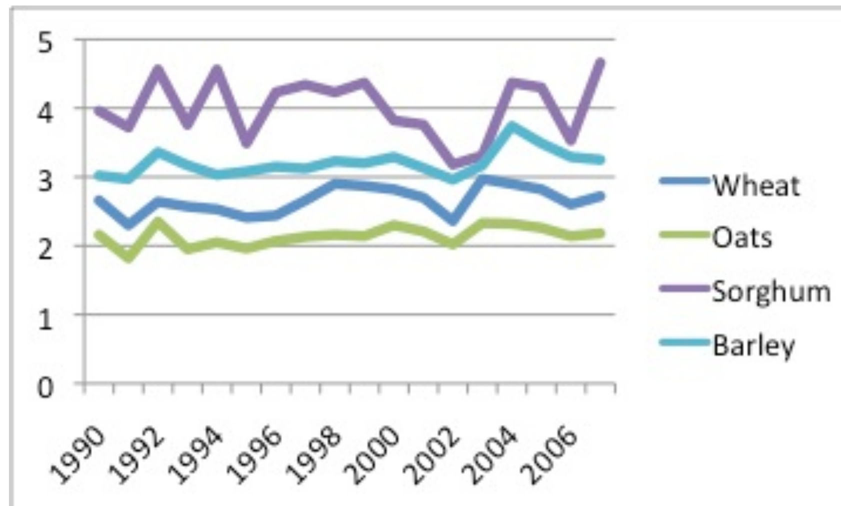


Big Challenges: Falling yield growth

- The Green Revolution allowed production to double as world pop doubled to 6 bn from 1940-1990

- **But productivity growth is slowing and stalling in staple crops w/o biotech**

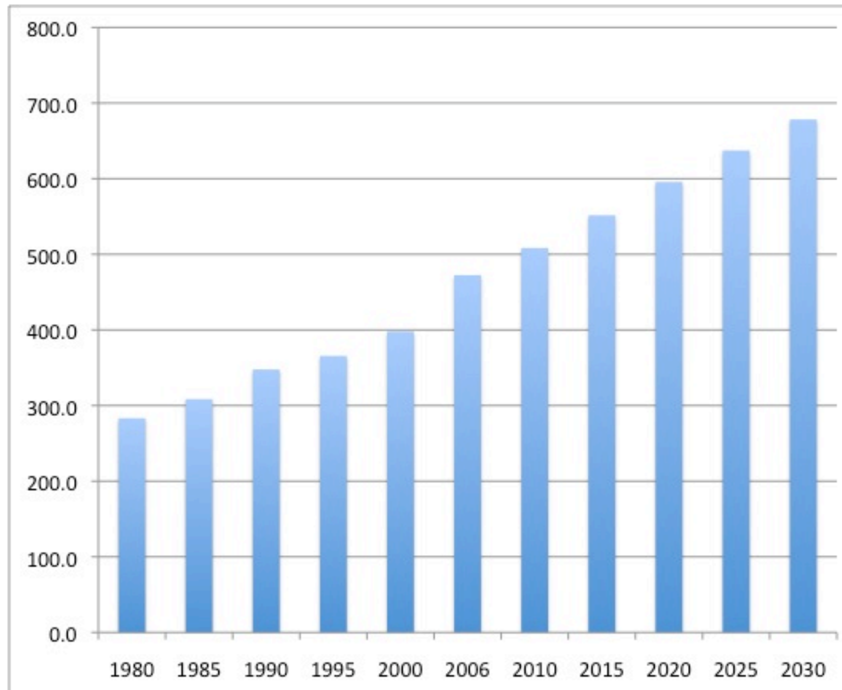
U.S. Staple field crop yields (MT/Ha) 1990-2002



Big Challenges: Energy Demand Rising

- 6% of China pop owned car in 2007. 80% in UK and 90% in US.
- Demand in non-OECD economies will grow 104% from 2006-30

World Marketed Energy Consumption (Qbtu) 1980-2030



Big Challenges: Oil is harder to get

- New supplies are harder to reach (e.g. deep sea oil wells)
- And dirtier (e.g. deep sea oil wells, tarsands, CTLs, etc.)

Big Challenges: Climate Change

- Mitigation requires less carbon emissions and more carbon sequestration

- **Agriculture must do more (food <u>and biofuel</u>) with less (emissions and land)**

Ag Biotech Can Help

- Avoids agricultural expansion
- Reduces demand for some inputs
- Boosts carbon sequestration
- Improves “performance measures” for existing and future biofuels

- But, there are offsetting effects

GE seeds reduce crop damage

- Effective output = potential output * damage abatement
  - Potential yield: $f(\mathbf{z})$
    - **z** are "directly-productive" inputs, e.g. fertilizer
  - Damage abatement: $g(\mathbf{x}, n)$
    - **x** are "damage-control" inputs, e.g. insecticides
    - *n* is effective pest pressure
  - Effective output: $y = g(\mathbf{x},n)f(\mathbf{z})$

And boost potential output

- As crop damage declines, MP of "directly-productive" inputs increases. *Ceteris paribus*, use of fertilizer, water, labor, etc. increases.

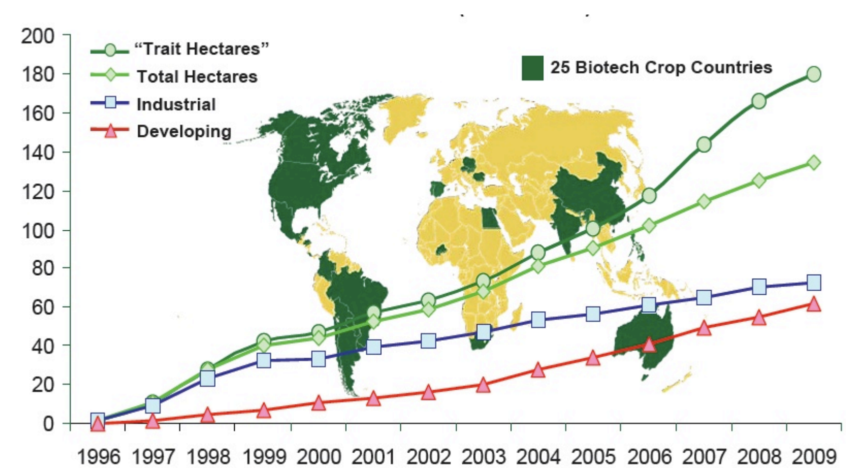
- So GE seed adoption effect on yields exceeds the "gene" effect. We call this total effect (reducing damage and boosting potential output) the "aggregate adoption" effect

Estimated yield effect of GE seed varies by trait, region (from Qaim '09)

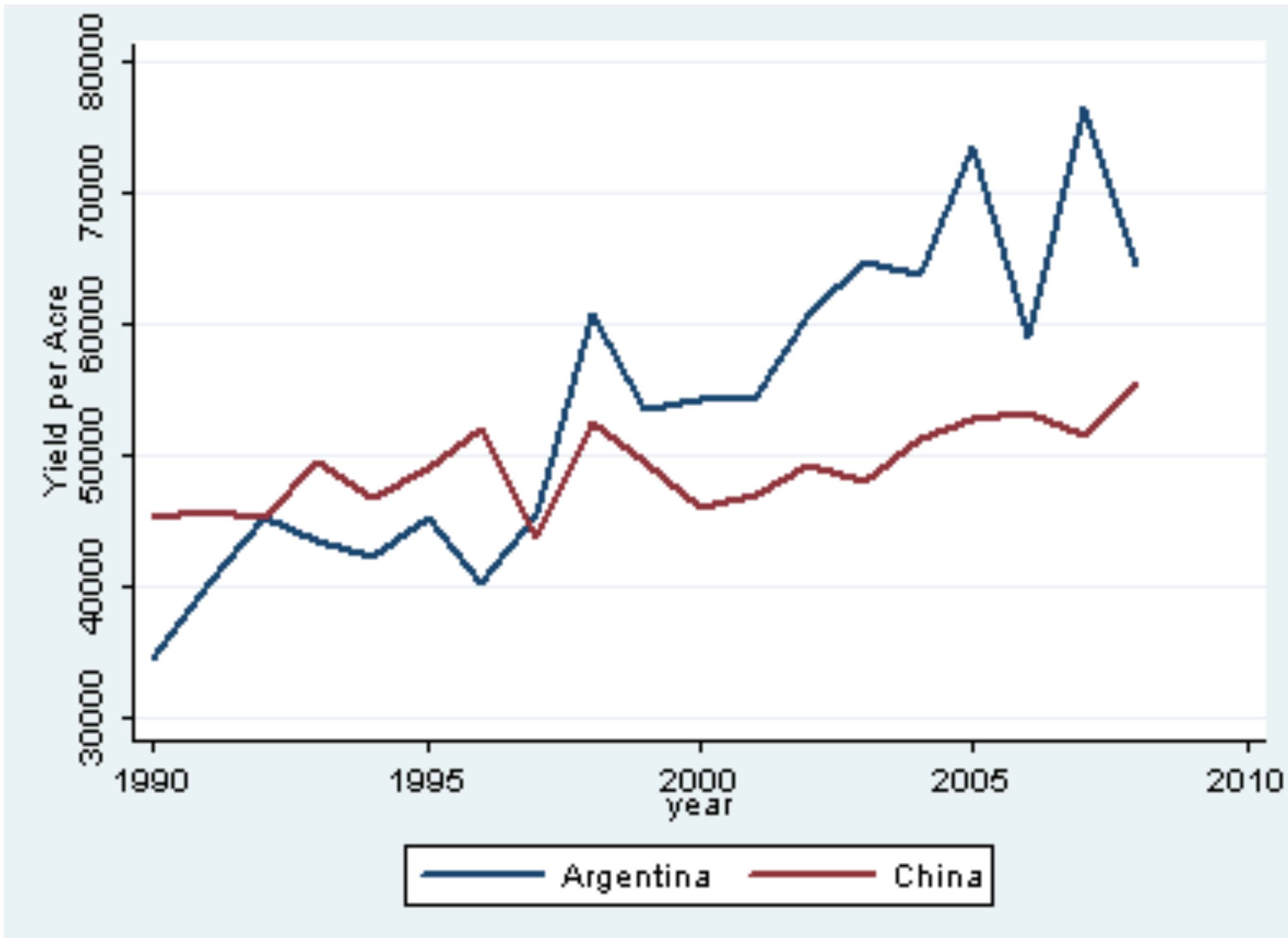
Country	Insecticide reduction (%)	Increase in effective yield (%)	Increase in gross margin (US$/ha)	Reference(s)
		Bt cotton		
Argentina	47	33	23	Qaim & de Janvry 2003, 2005
Australia	48	0	66	Fitt 2003
China	65	24	470	Pray et al. 2002
India	41	37	135	Qaim et al. 2006, Sadashivappa & Qaim 2009
Mexico	77	9	295	Traxler et al. 2003
South Africa	33	22	91	Thirtle et al. 2003, Gouse et al. 2004
United States	36	10	58	Falck-Zepeda et al. 2000b, Carpenter et al. 2002
		Bt maize		
Argentina	0	9	20	Brookes & Barfoot 2005
Philippines	5	34	53	Brookes & Barfoot 2005, Yorobe & Quicoy 2006
South Africa	10	11	42	Brookes & Barfoot 2005, Gouse et al. 2006
Spain	63	6	70	Gómez-Barbero et al. 2008
United States	8	5	12	Naseem & Pray 2004, Fernandez-Cornejo & Li 2005

What is the global impact of GE in adopting countries?

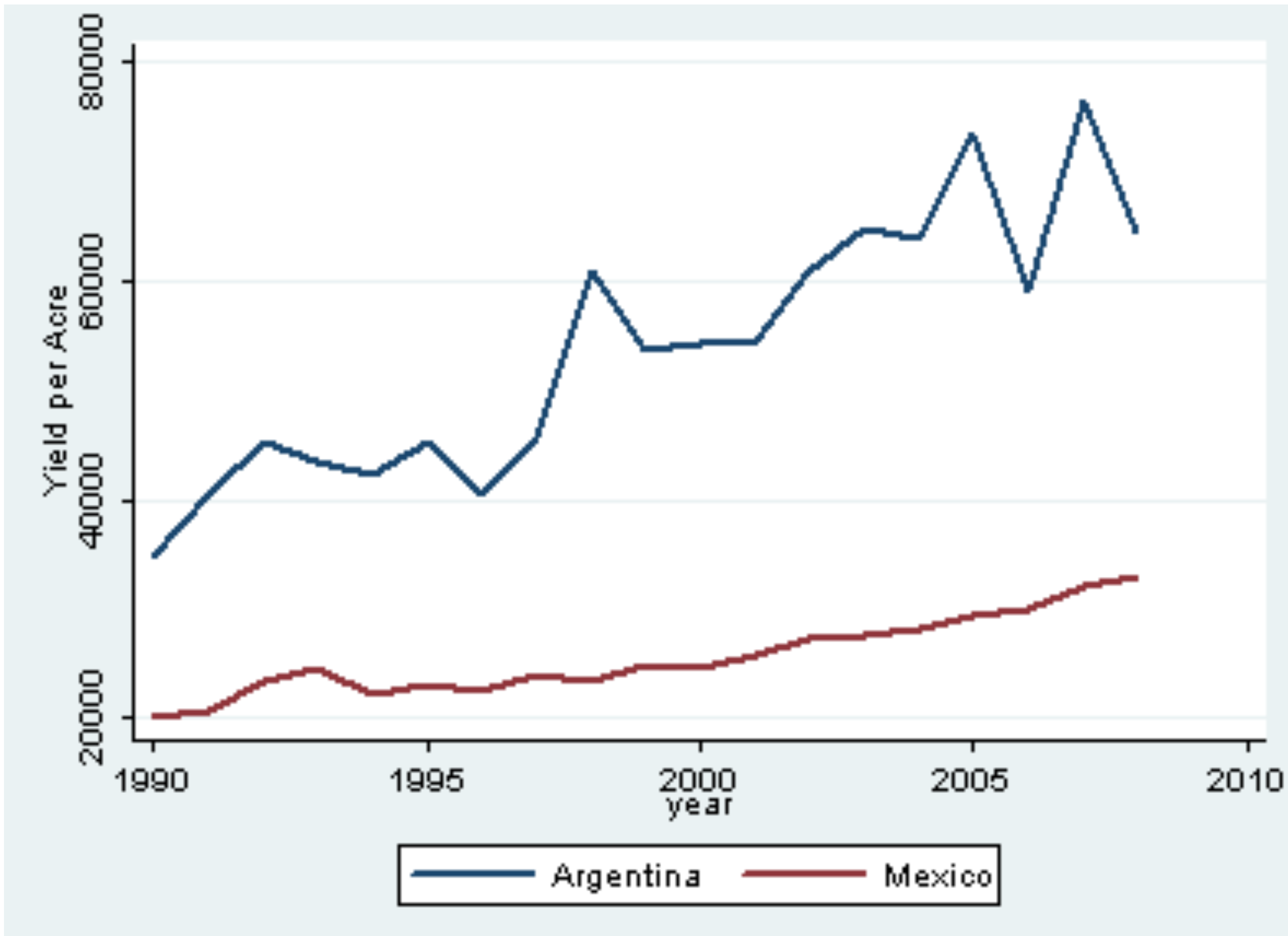
- Spatial variation in adoption
- Temporal variation in adoption
- 8 crops (**cotton, maize, rapeseed, soybean**, wheat, sorghum, oats, and rice)
- 100 "top" producing countries
- 1990-2008
- By crop-country-year: total area (HA), total GE area, total production (MT)



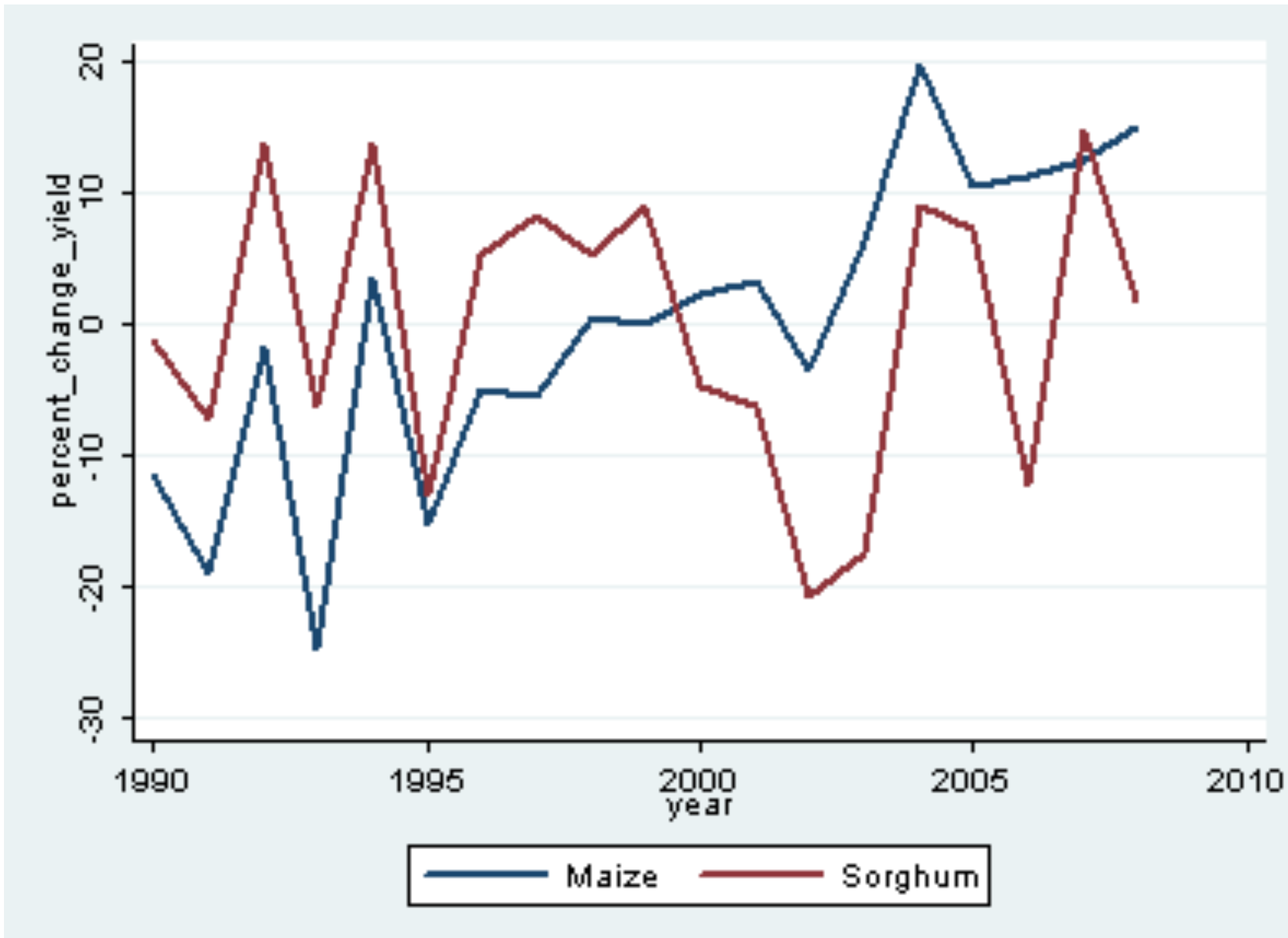
Visual Diff-in-Diff: Maize yield



Visual Diff-in-Diff: maize yield



Visual Diff-in-Diff: Yield percent deviation from mean (USA)



Visual Diff-in-Diff: Yield percent deviation from mean (Argentina)

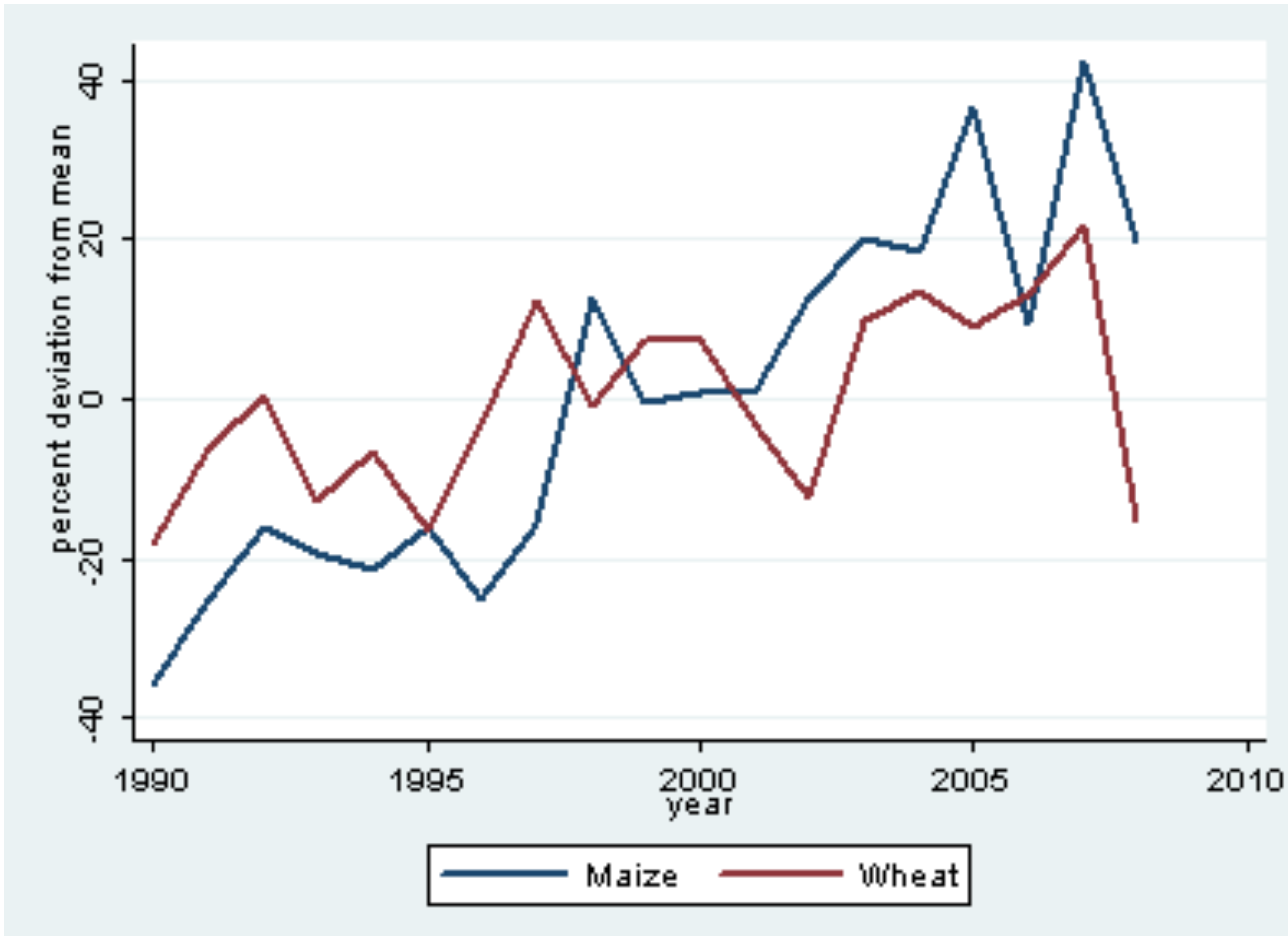


Table: Effects of GM Seed in *Developed* Countries

CROPS	(1) Total Area	(2) GM Area
Cotton	1.407***	0.322***
	(0.267)	(0.105)
Maize	12.44***	1.890***
	(2.867)	(0.485)
Rapeseed	1.538***	0.370***
	(0.126)	(0.0994)
Soybean	2.784***	0.196
	(0.624)	(0.164)
Oats	2.149***	
	(0.115)	
Rice	5.381***	
	(1.154)	
Sorghum	4.572***	
	(0.366)	
Wheat	2.189***	
	(0.222)	
Constant	-453968*	
	(262868)	
Observations	2208	
Number of groups	150	
R-squared	0.848	

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table: Yield Gain from GM Seed as Percent of Non-GM Yield

VARIABLES	(1) Cotton	(2) Maize	(3) Rapeseed	(4) Soybean
All Countries	65.042	45.607	25.484	12.475
Developed Countries	22.886	15.193	24.057	7.040
Developing Countries	109.510	56.403	-	30.189

Econometric Results

- GM yield effects are significant—both in statistical and economic senses
- These estimates present an estimate of the "average treatment effect on the treated"
  - Selection controlled only at country level, not farmer level; this is an upper bound of the "population average treatment effect"
- We estimated an "aggregate adoption" effect, not a "gene" effect

Econometric Results

- Yield effect is greater in developing countries than in developed countries.
- Theory: yield effect will be greater where:
  – Pest pressure is higher
  – Chemical use was low / ineffective

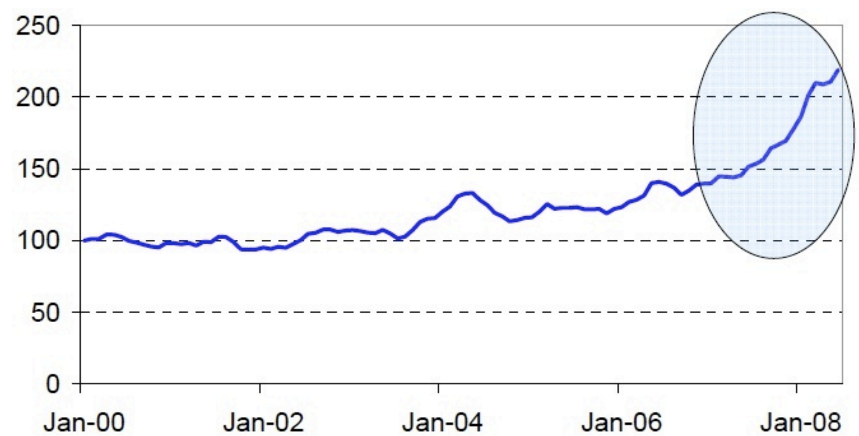
Implications for Land use

- Gene revolution allows us to meet growing food demand without relying on farmland expansion alone
- Without GE yield gains in '08, would have needed:
  - 8.6 million HA more land to produce maize crop
  - 11 million HA more land for soybean crop
  - **An area of additional land equal to state of Kansas or total area planted to wheat in U.S. in 2008.**

Implications for food security

- GE lessens competition for land between food and (bio) fuel.
- Biofuels were blamed for as much as 45% increase in food prices during the *last* food crisis in 2008 (when prices rose 56%)
- Without biotech, the food crisis would have been worse

World Food Price Index in 2000 dollars (World Bank)



Simulating the crisis without GE seeds

Table: Simulation Scenarios

	Scenario 1	Scenario 2	Scenario 3
Own-price elasticity of demand	-0.30	-0.5	-0.30
Own-price elasticity of supply	0.30	0.30	0.30
Cross-price elasticities of demand	0.05	0.05	0.05
Cross-price elasticities of supply	-0.10	-0.10	-0.075

Simulating the crisis without GE seeds

Figure: Simulated 2008 world commodity prices ($/ton)

	2008 Price	No biofuel	No biotech	%Change No biofuel	%Change No biotech
Scenario 1: Base					
Corn	223.13	133.28	300.24	-40.27	34.56
Soybean	474.74	337.96	676.55	-28.81	42.51
Wheat	268.59	197.87	342.25	-26.33	27.42
Rapeseed	604.92	385.7	802.32	-36.24	32.63
Scenario 2: Elastic demand					
Corn	223.13	178.7	256.4	-19.91	14.91
Soybean	474.74	337.96	575.33	-28.81	21.18
Wheat	268.59	197.87	293.51	-26.33	9.27
Rapeseed	604.92	385.7	685.91	-36.24	13.38
Scenario 3: Increased substitutability					
Corn	223.13	157.19	274.76	-29.55	23.14
Soybean	474.74	390.711	623.64	-17.70	31.36
Wheat	268.59	227.95	310.92	-15.13	15.76
Rapeseed	604.92	451.37	732.85	-25.38	21.15

If there were broader adoption of GE

- If top-10 producing countries had all adopted GE at the rate of the US . . .
  - maize production would have been 75 million tons higher just from yield gains
    - Biofuels recruited 86 million tons
  - Vegetable oils production would have been 37 million tons higher
    - Biofuels recruited 8.6 million tons

If there were broader adoption of GE

- And if GE wheat were introduced in top-10 countries and yield gains mirrored those in soybean . . .
  - Production would have been 12 million tons higher
    - Biofuels recruited 26 million tons

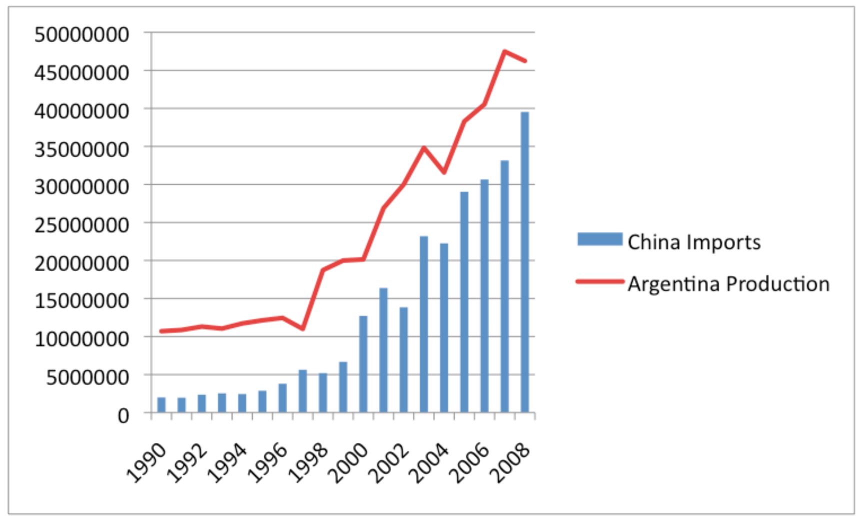
HT seeds and double cropping

- Tillage and persistence of herbicides complicate double cropping on many farms
- GE shortens fallow periods (enabling more double cropping in two ways):
  - By allowing substitution toward less toxic and persistent herbicides like glyphosates; and
  - By allowing post-emergent herbicide applications to substitute for tilling operations.

HT seeds and double cropping

- Double cropping wheat and late season soybean has created virtual land expansion of 10M acres in Argentina.
- Argentina has met fast-growing Chineese demand for soybean
- Also, wheat and sorghum in USA and Canada

Soybean production in Argentina and imports in China



Total Carbon Savings from Avoided Land-use Changes

- 12-74.8 metric tons of carbon savings per Ha avoided land conversion in US; 9-90MT in Latin America
- GE seed in 2009 saved on the order of 480-5,400 million MT of carbon
- The equivalent of savings from taking 800-9,000 million passenger cars of the road.

Boosting carbon sequestration on existing land

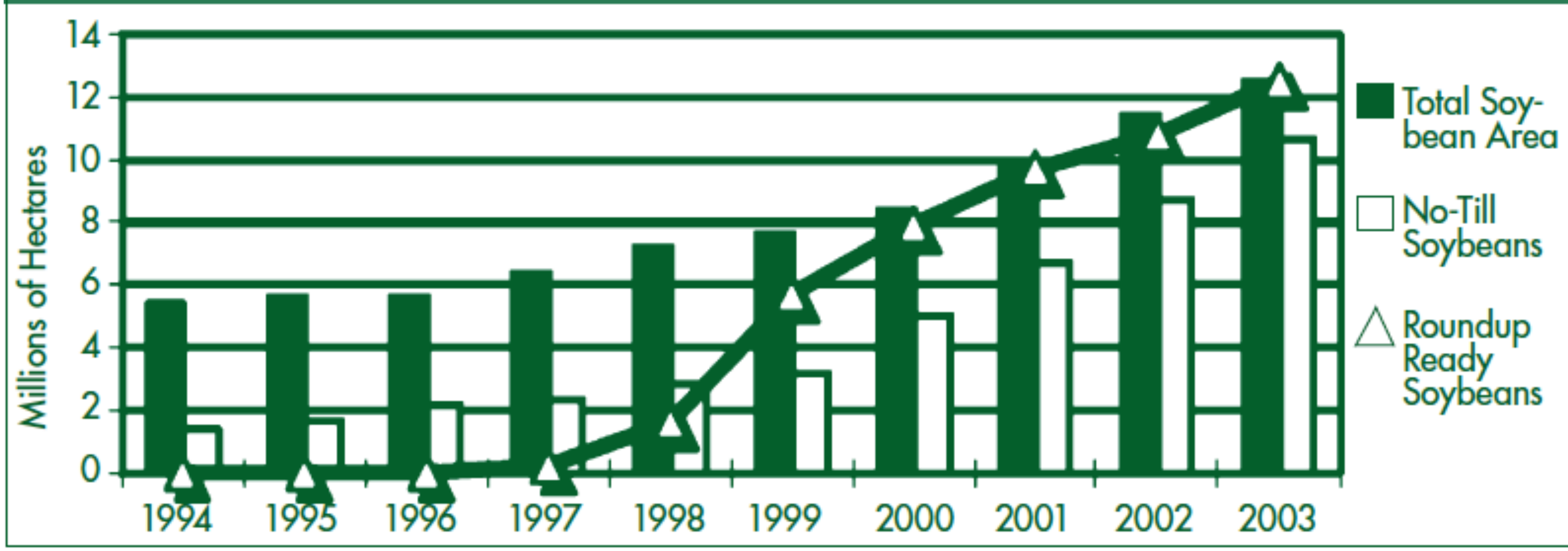
- Tilling operations degrade soil, increase chemical runoff, and reduce soil carbon sequestration.
- HT soybean, sugarbeet and rapeseed allow post-emergent herbicides to substitute for tilling operations.

Boosting carbon sequestration on existing land

- No-till soybean area has increased 69% in US since introduction of GE soybean.
  - Now constitutes 39% of total crop
- No-till area has doubled worldwide since 1999

Boosting carbon sequestration on existing land

Figure 1. Soybean Area in Argentina: Total, No-Till, and Roundup Ready



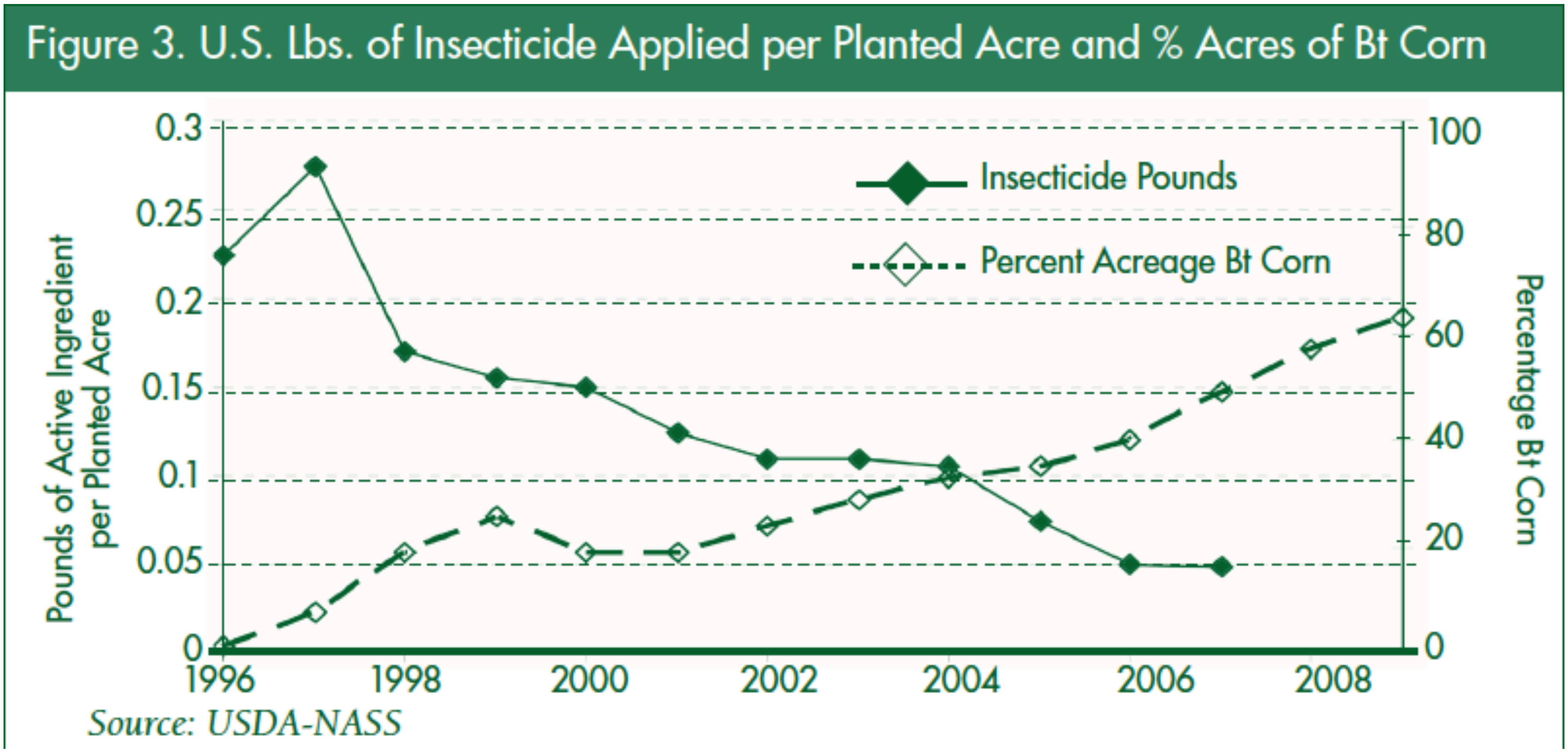
Boosting carbon sequestration on existing land

- No-till farmland sequesters 0.64 metric tons more carbon than tilled land
- Brookes and Barfoot: growth in no-till and reduced-till from 1996-2008 boosted sequestration 101,613 million tons CO2 from 1996-2008
- 3.9 million tons of carbon in 2008 alone; equal to taking 6.4 million cars off the road.

Reducing input demand

- Bt crops reduce chemical applications
- Change in chemical use varies by region:
  - Effect is greater where pest pressure is higher; and
  - Where pesticides were in high demand

Reducing input demand



Reducing input demand

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Reducing input demand

- HT crops permit post-emergent applications, which promote responsive applications rather than preventive applications
- Responsive applications are associated with lower chemical use than preventive applications

Reducing chemical toxicity

- HT crops permit substitution toward less toxic chemicals

Carbon content of agrochemicals

- 3.9-6.3 kg of carbon per kg active ingredient
- IR cotton reduces pesticide applications 3,600 tons per year
- It saves 14,000 tons of carbon emissions or about 23,000 cars per year
- IR corn saves equivalent of emissions from 5,800 cars

Fuel use

- Reduced chemical applications and tilling operations should reduce tractor passes and fuel consumption on IR and HT land
- Exploiting dynamic adoption (spatial and temporal variation) of 3 GE crops and using 3 control crops, we estimate the average GE crop reduces fuel use 19%

Fuel use

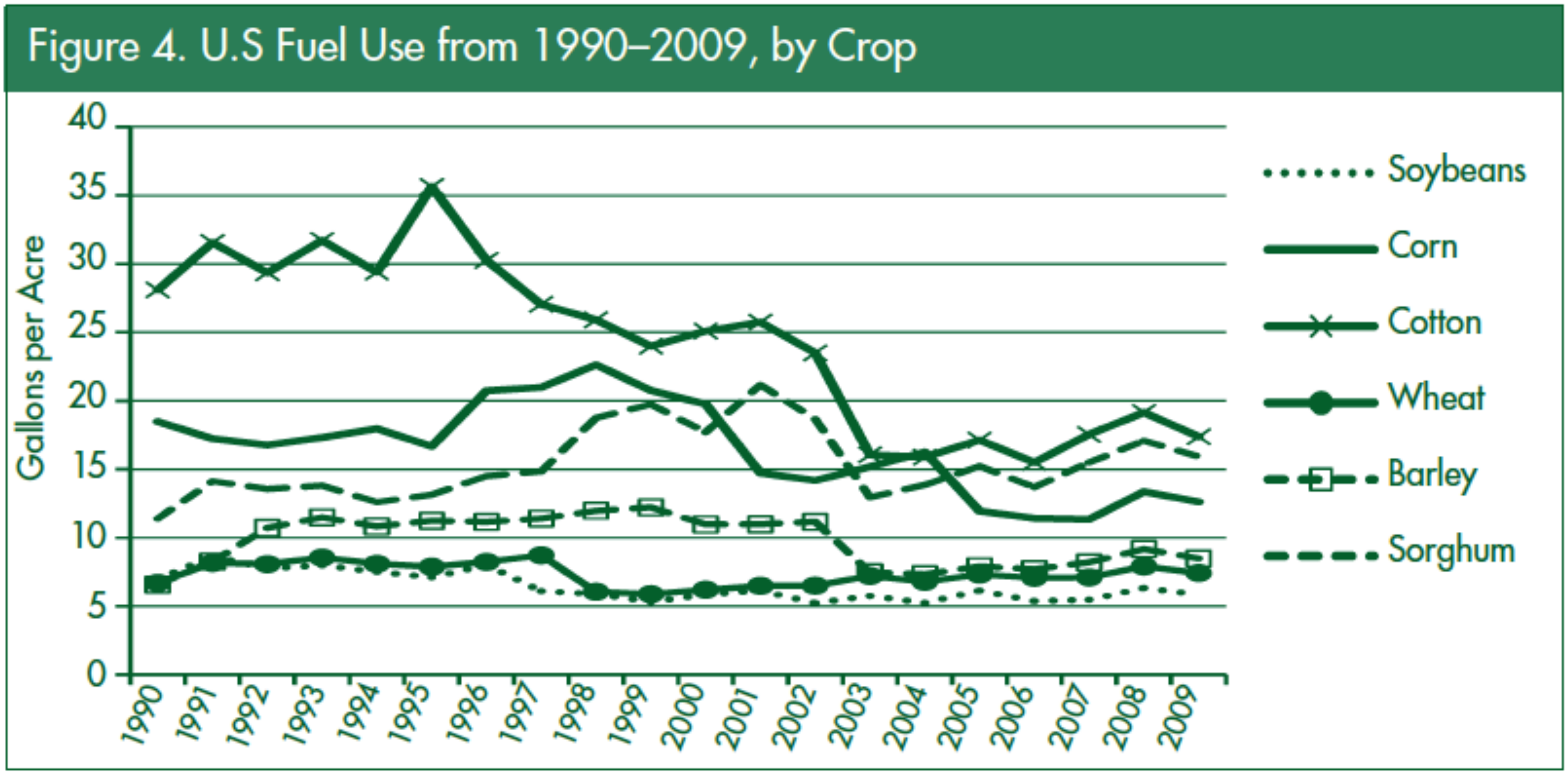
Figure 4. U.S Fuel Use from 1990–2009, by Crop
Gallons per Acre
40
35
30
25
20
15
10
5
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Soybeans
Corn
Cotton
Wheat
Barley
Sorghum

Biotech and Biofuels

- Existing GE seeds make existing biofuels "greener"
  - Corn ethanol, soy biodiesel, etc.
- Future GE applications can develop super feedstocks to improve the GHG savings potential of biofuels relative to fossil fuels

Offsetting Effects

- Higher MP of “directly-productive” inputs should increase use of some chemicals and inputs (e.g. fertilizers)
- Increases profitability of marginal lands and can lead to land expansion; magnitude of effect depends on relative responsiveness of demand and supply.

Conclusions

- GE technology can help mitigate climate change by reducing carbon emissions
- Not risk free
  - Gene flow-
  - Build up of resistance
  - Can be contained by policies
  - Unforeseen risks
- We have a tradeoff between certain large gains and uncertain risks
- But we should accept small risks in order to mitigate big ones