Agricultural biotechnology:, The promise and the prospects

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Based on collaborative research with

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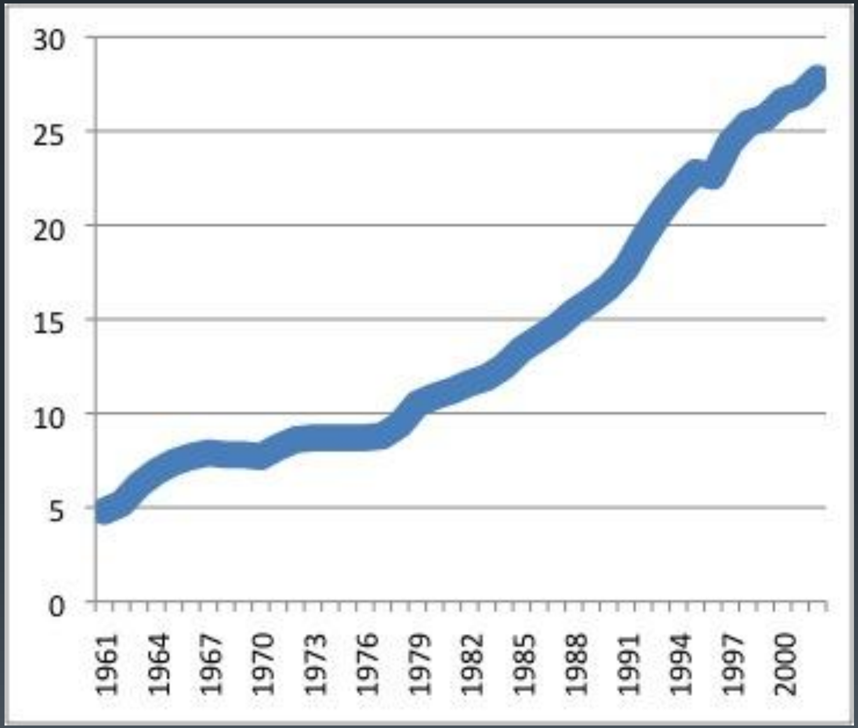
Outline*

- Background
- The glass is half full / half empty
- Economics effect of GM
- Environmental effect
- Regulation and IPR
- Implications

Big Challenges: Rising Food Demand

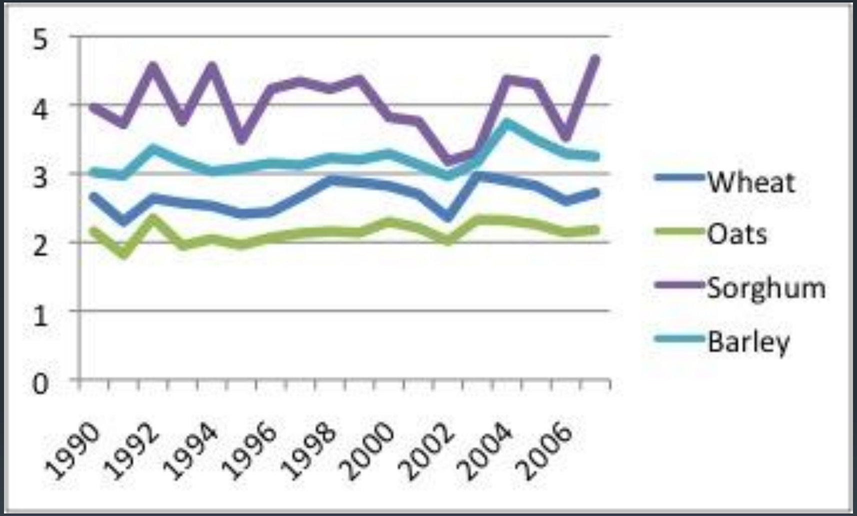
- World pop. will grow 30% by 2050
- Rising incomes cause per capita demand to grow too
- Diets are becoming more land intensive

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



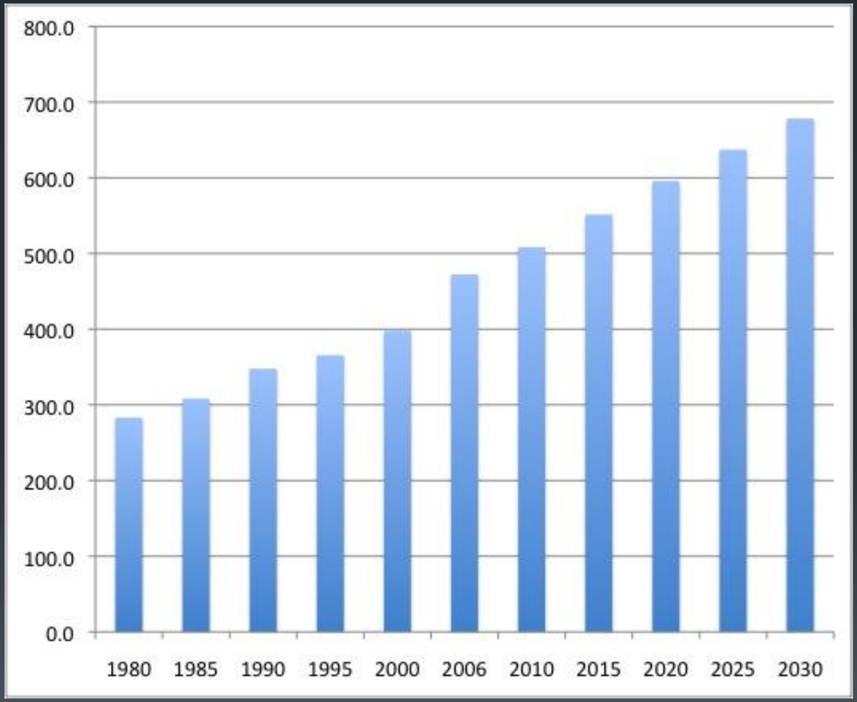
Big Challenges: Falling yield growth

- The Green Revolution allowed production to double as world pop. doubled to 6 billion from 1940-1990
- **But productivity growth is slowing and stalling occurring in staple crops w/o biotech**



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



Big Challenges: Climate Change

- We need both adaptation and mitigation
  - Temperatures are likely to rise by 1 – 2 degrees C regardless of what we do
  - Adaptation means
    - Changing crop systems
    - Starting farming in new areas
- Agriculture must do more (food <u>and biofuel</u>) with less (emissions and land)

A diversified strategy

- Investment in research and outreach
- Use of integrated ecological practices
  - Adapting farming to ecological and climatic conditions
  - Taking advantage of diverse sources of knowledge
- Taking advantage of new science and technology
  - Information technology
  - Molecular and cell technology
- Agricultural biotechnology and GMOs
- It is an essential part of (sustainable) agriculture of the future

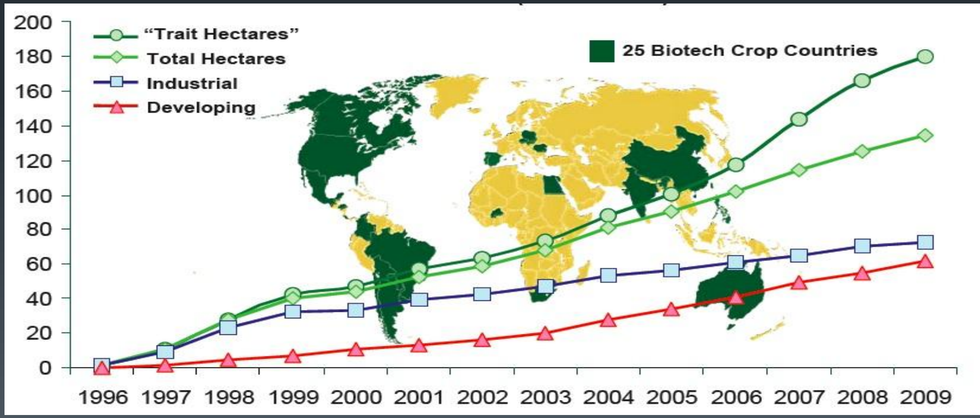
What is Agricultural Biotechnology?

- Ag-Biotech applied modern tools of molecular and cell biology to agriculture.
- The discovery of DNA is arguably the greatest discovery of the 20th century.
  - Comparable to the discovery of the atom & electricity
  - Enables understanding of the inner workings of organisms
  - Provides tools for minor manipulations that have major impacts
- Medical biotech radicalized medicine and is able to develop tools to deal with cancer, AIDS, etc.
- Agricultural biotechnology can do the same with crop systems
  - Help to increase and improve food production, produce renewable fuels and other materials
  - It is in its infancy but already has a successful track record and a promising future.

The Glass is half full

- GM crops have been adopted on more than 170 million hectares (ha) in both developed countries (48%) and developing countries (52%).
- 59 countries have granted regulatory approval for import or use of 30 GM crops. 28 countries, 20 developed and 8 developing, planted commercialized GM crops in 2012.

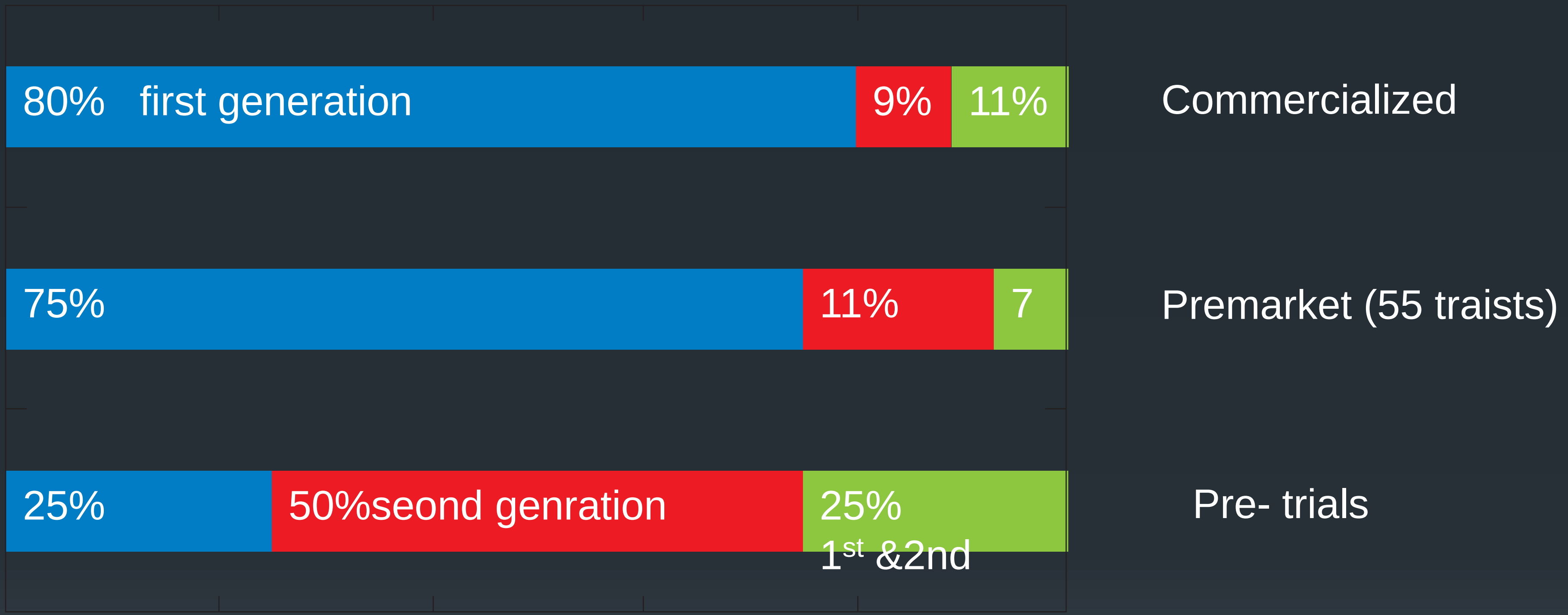
- Adopted on 4 major crops(**cotton, maize, rapeseed, soybean**)
- Mostly in US and Latin America
- Cotton in China, India and Africa
- Adoption of GM varieties grew fast
  - 80% of soybean land share
  - About 60% of cotton
  - About 40% of maize
  - About 25% of rapeseed



Three generations of GM traits

- First generation production traits
  - Insect resistance, disease (virus) resistance, or herbicide tolerance. Reducing pest damage
  - Actual output = potential output * (1-damage)
    - In developing countries, likely to have high yield effect
    - In developed countries, pesticide replacing effect
- Second generation
  - enhanced product quality and composition
  - tolerance to abiotic stress
  - nutrient-use and photosynthetic efficiency
  - nutritional enhancement
- Third generation
  - Growing pharmaceuticals and industrial products in plants

Distribution of 1st and 2nd generation traits



- Increasing number of stacked traits—up to 8 (Smart stax ®)
- Much of the discoveries are done by public sector (60% of field trials)
- 80% of crops are developed by private sector, rest by public
- Public sector released only 10% of GM that was marketed

The Glass is half Empty

- Most countries do not grow GM Crops
  - Africa (except South Africa, Burkina Faso, and Egypt)
  - Asia (officially only India, China, and Philippines)
  - Europe (commercial amounts mostly in Spain)
- Mostly used for fiber and feed, not for food
- Has not been applied in rice or wheat
  - Big loss to humanity

Myths about GMOs

- Did not make a difference
- Benefited the rich
- Are not useful for the environment
  - We will show that already they have made a difference
- Can make a much bigger impact in the future

Modeling impacts of Pest controlling GMOs*

- 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: $y = g(\mathbf{x}, n) f(\mathbf{z})$
  - *based on
    - Lichtenberg Zilberman *AJAE* (1986)
    - Qaim Zilberman *Science* (2003)

Impacts of GMO on yield

- GMO will reduce pest damage especially when the pesticides are not effective or expensive
- It may reduce yield if the trait was inserted in an inferior variety
- It may increase yield by increasing the use of complementary inputs like fertilizers
  - If damage is reduced most fertilizers will be used
- The impact of GM is greater than the “gene” effect; the complementarity effect may be substantial

Predicted yield effects of pest controlling Biotech

Region	Pest pressure	Availability of chemical alternatives	Adoption of chemicals	Yield effect of GM crops
Developed countries	Low-med	high	high	low
L.Am (commercial)	medium	medium	high	low -med
China	medium	medium	high	low- med\
L.Am(non-commercial)	medium	low -med	low	med -high
South & So. east Asia	high	low -med	low -med	high
Africa	high	low	low	high

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

Other effects of GM

- Increased worker safety
- Greater flexibility in
  farm management
- Lower risk of yield variability,
  i.e. *de facto* insurance
- Reduced effort
- **Impacts vary**

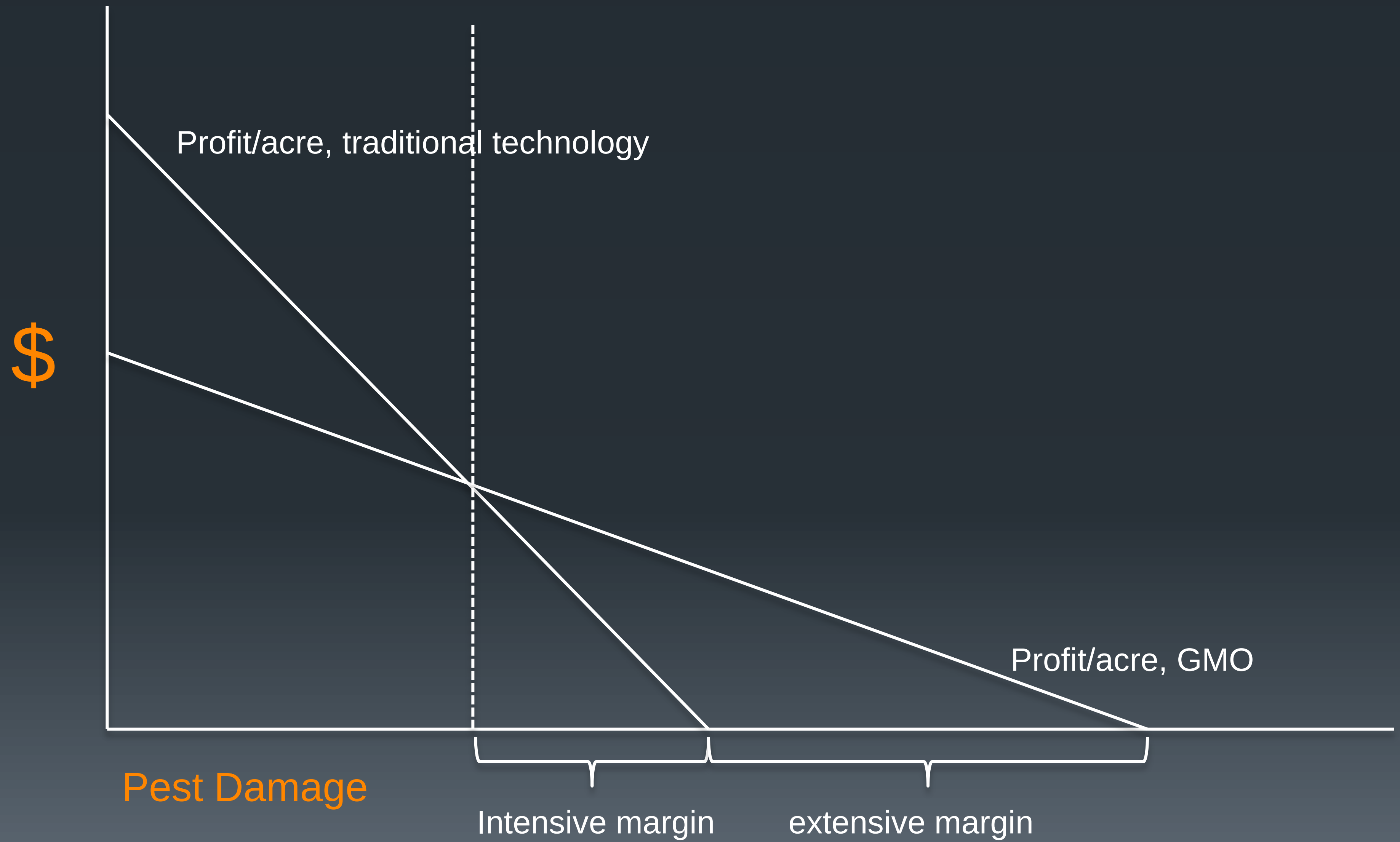
Economic effects of GM

- Introduction of GE varieties contributes to downward pressure of commodity prices
- The gains from adoption of GE varieties were distributed between farmers, US consumers, and consumers in the rest of the world

Impact of Heterogeneity & Price

- When pest damage vary by location
  - Location with low damage will not adopt
  - Location with high damage will adopt
  - Then there will be new entries
- Adoption will increase in periods of high output prices
- Adoption will increase when technology gets cheaper or more efficient

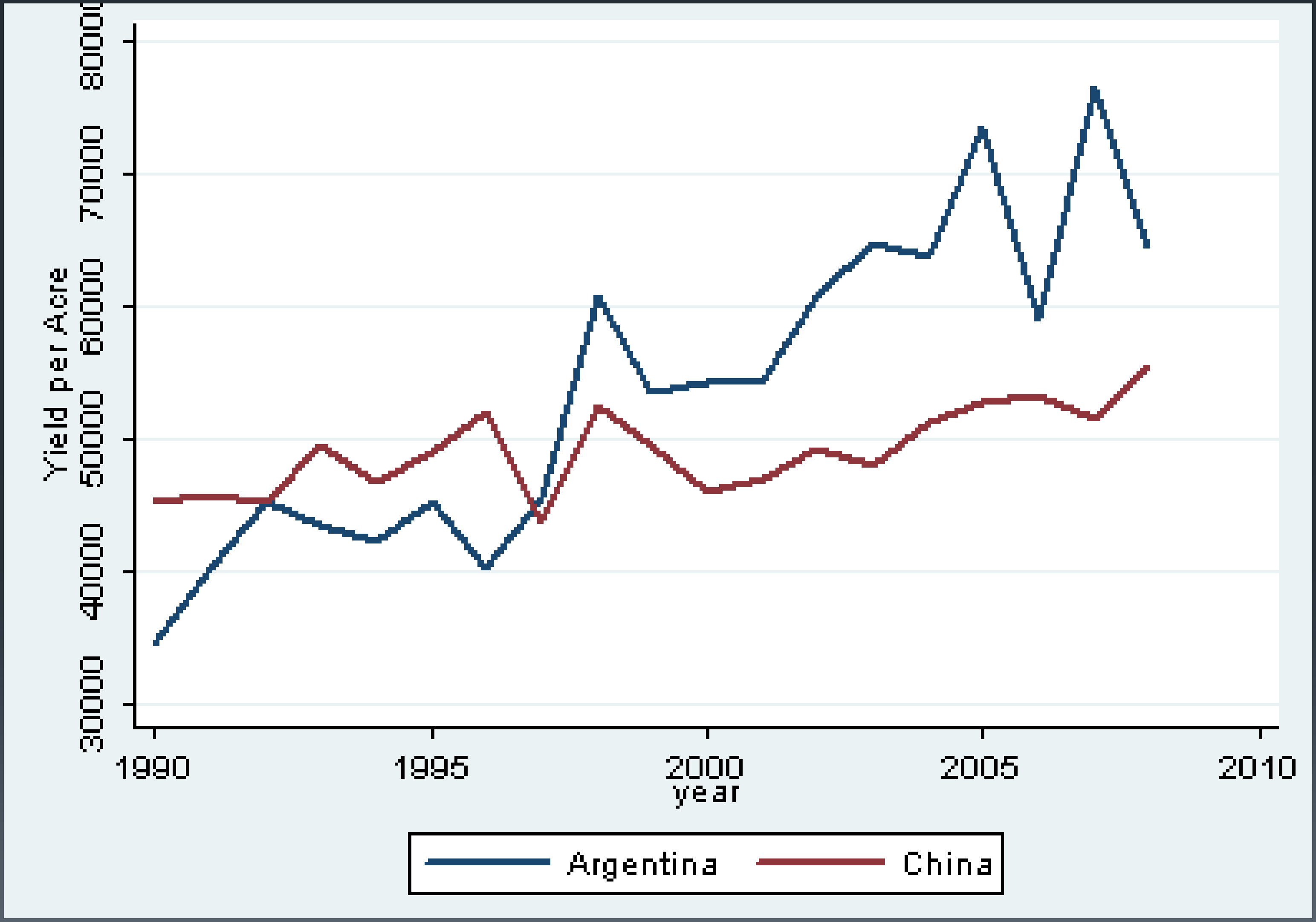
Adoption of GM under Heterogeneity, pest damage



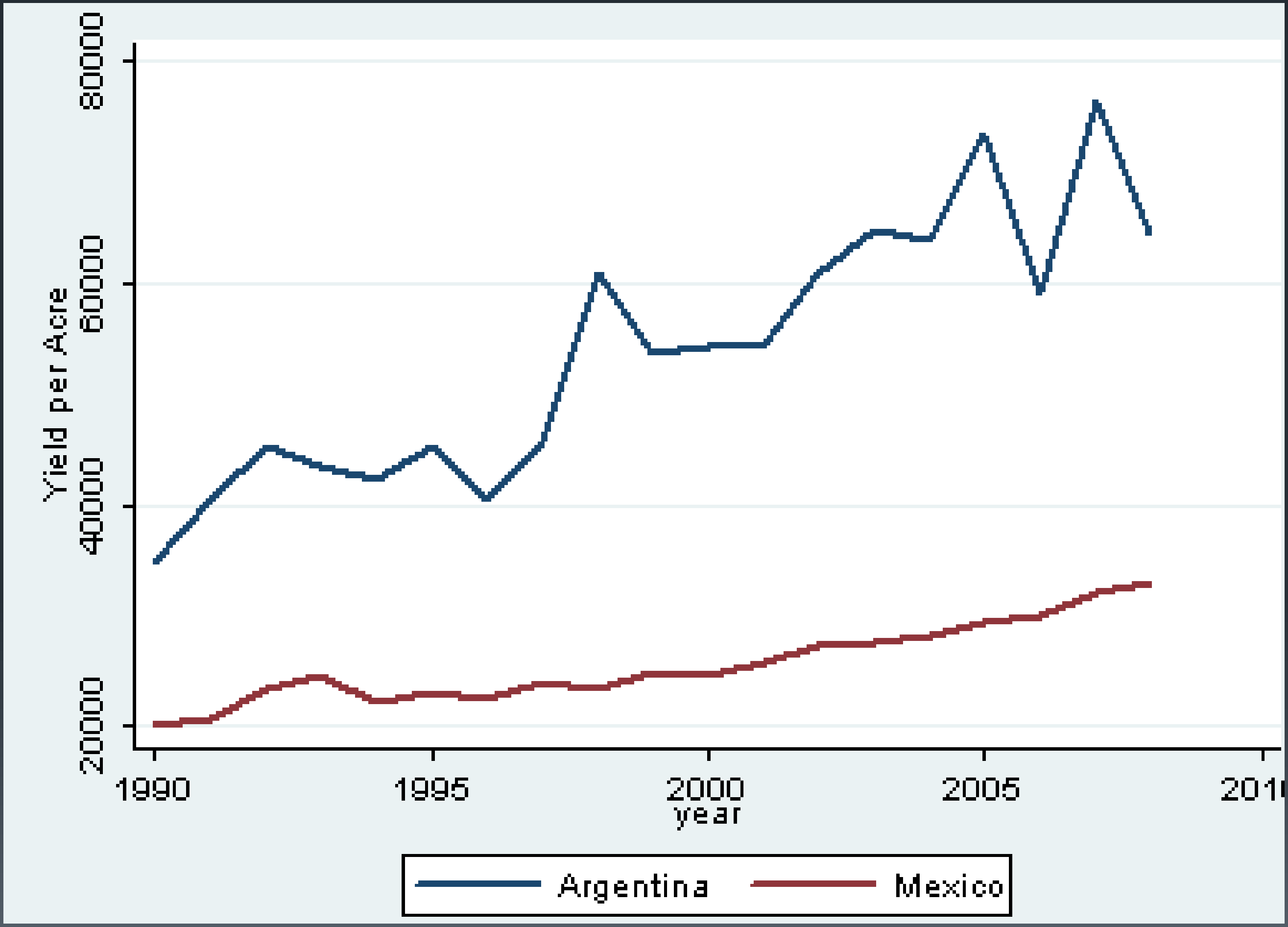
Intensive vs. Extensive Margin

- The supply effect of GMO technology includes intensive margin effects from yield increases and extensive margin effects from bringing new lands into production.
- Can we decompose the supply effect into intensive and extensive margins?
- Data: country level acreage panel data for 4 major GMO crops broken down by traditional vs. GMO technology
- Using these data, we design a methodology for quantifying acreage that switched from traditional technology (intensive margin) and acreage that entered production of a crop from some other employment (extensive margin)

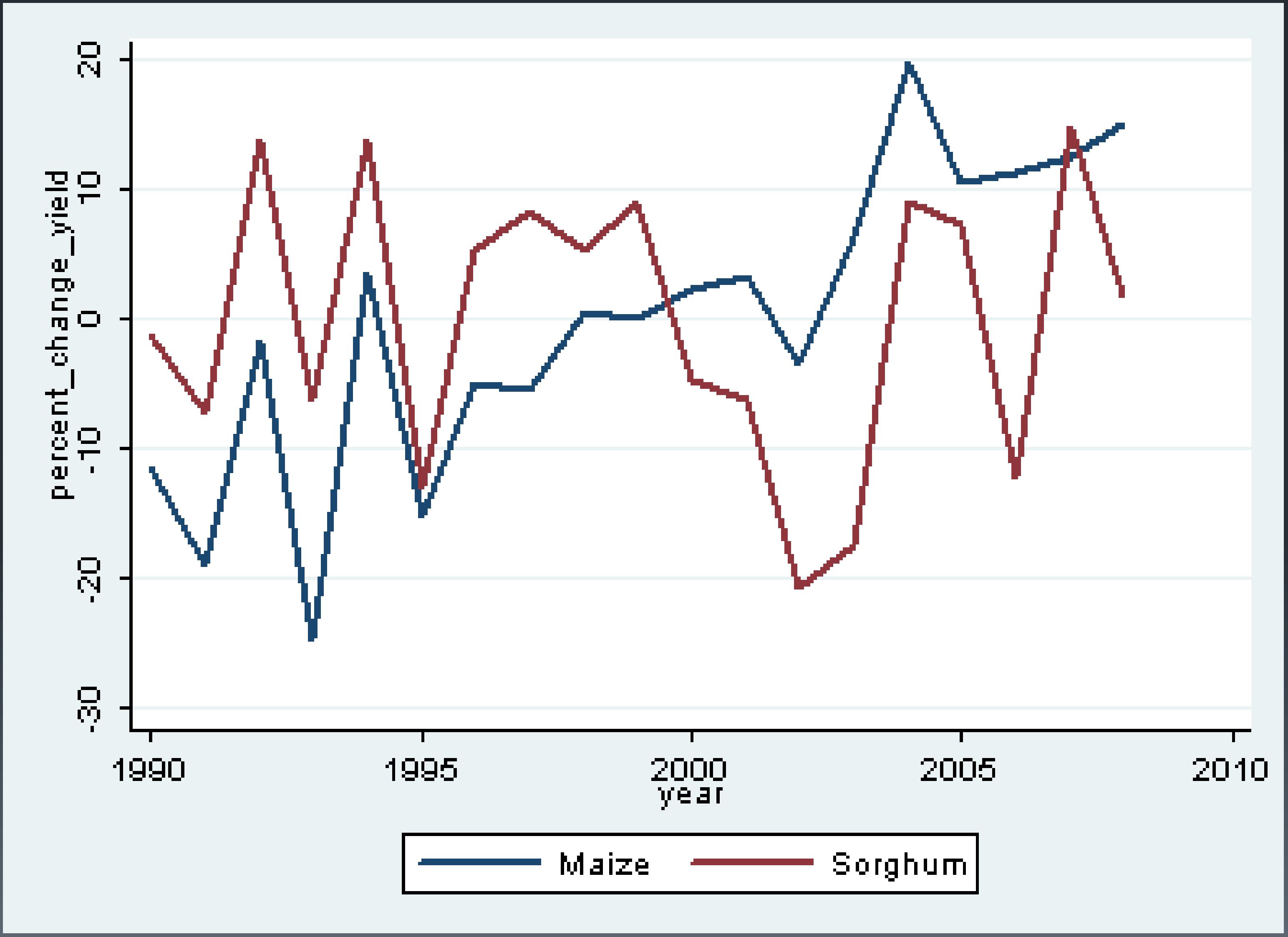
Visual Diff-in-Diff: Maize yield



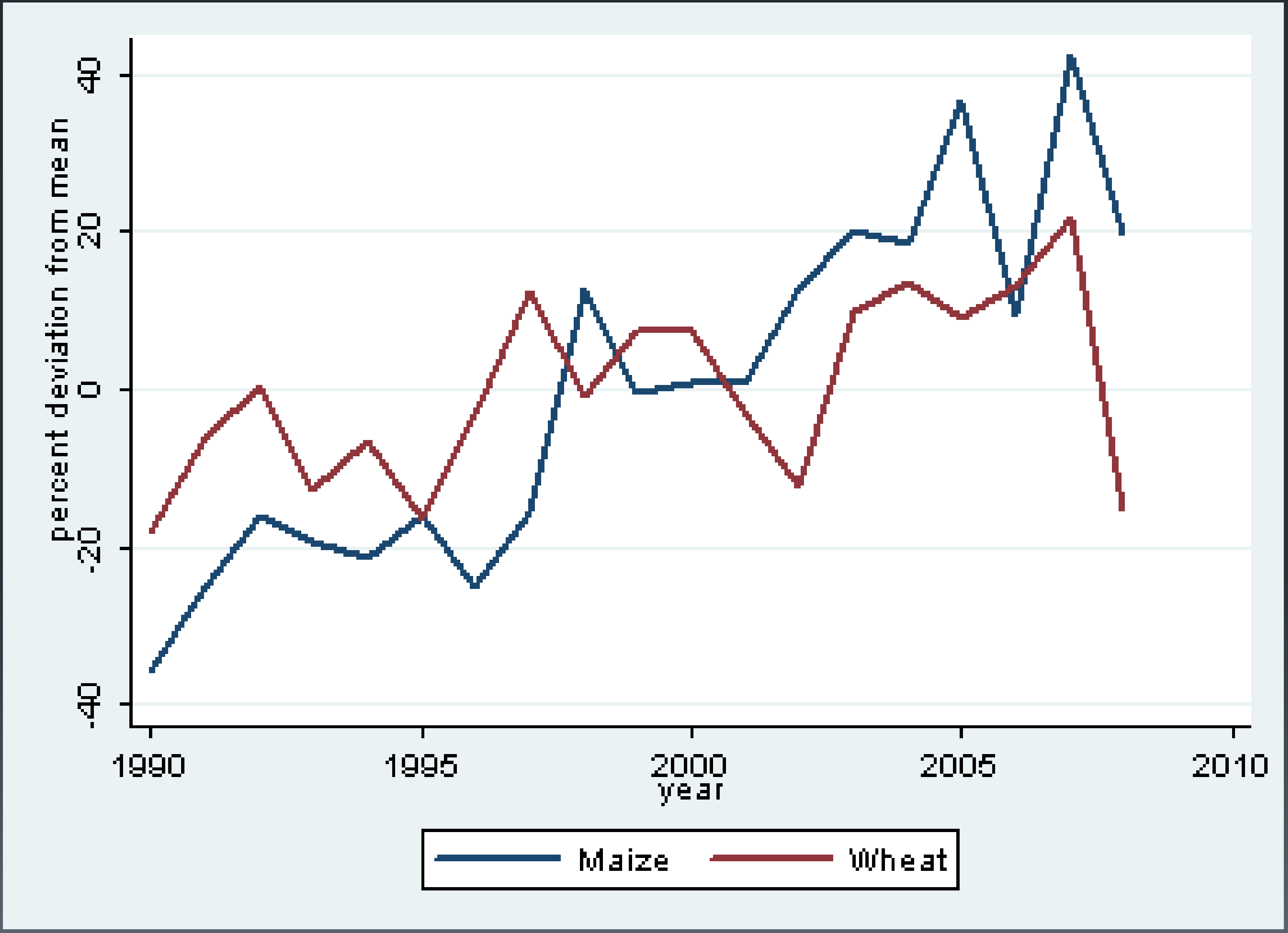
Visual Diff-in-Diff: maize yield



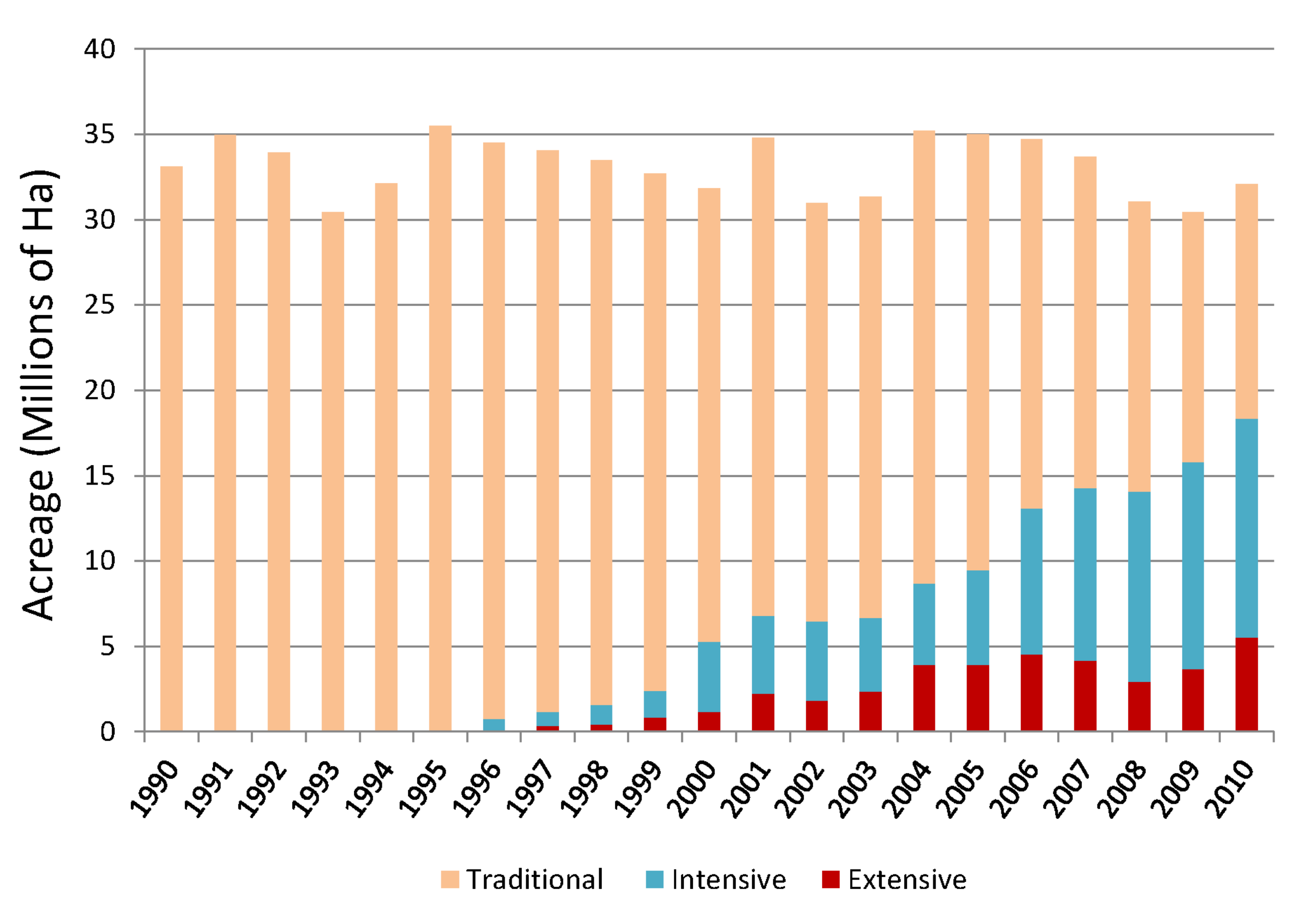
Visual Diff-in-Diff: Yield percent deviation from mean (USA)



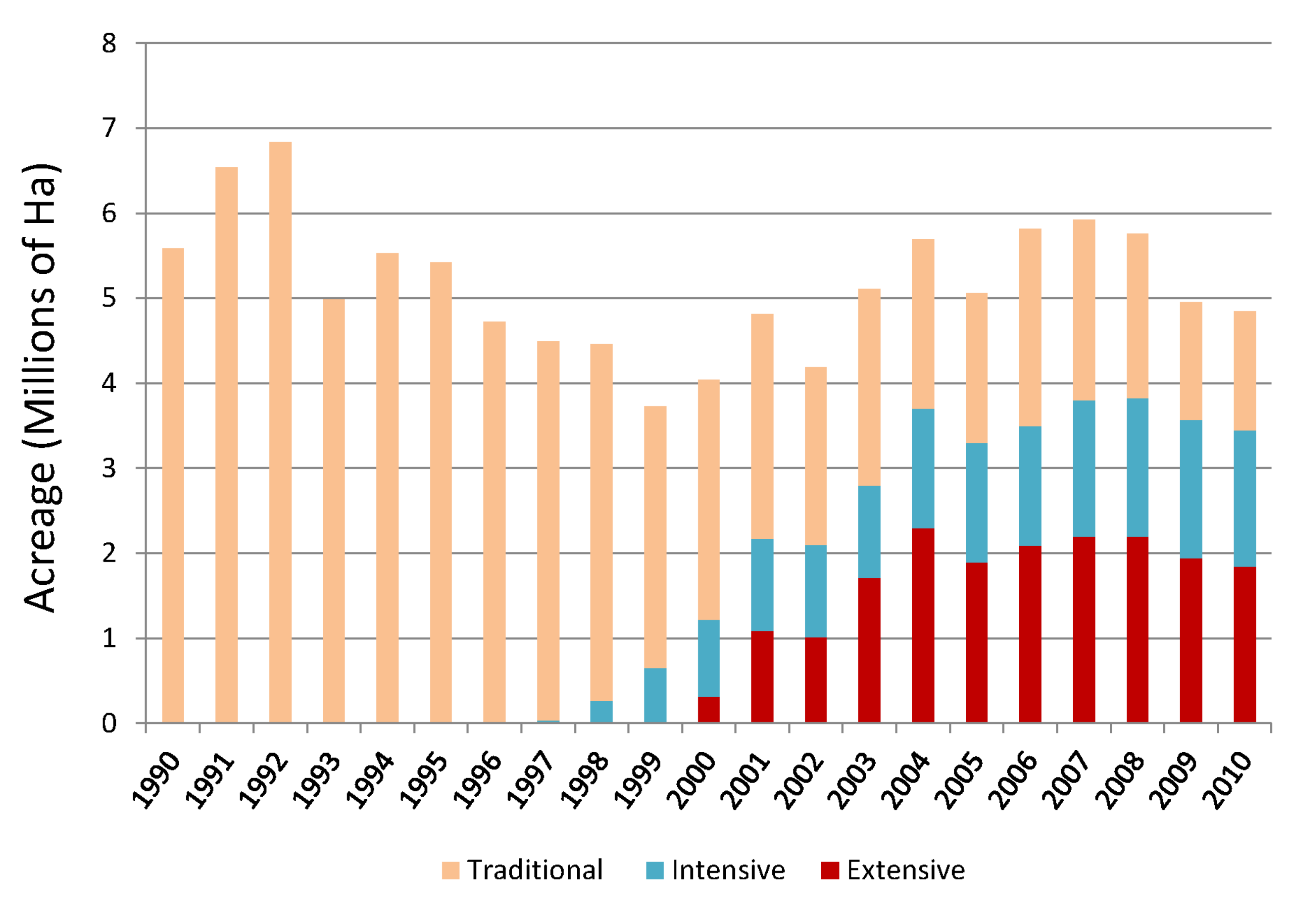
Visual Diff-in-Diff: Yield percent deviation from mean (Argentina)



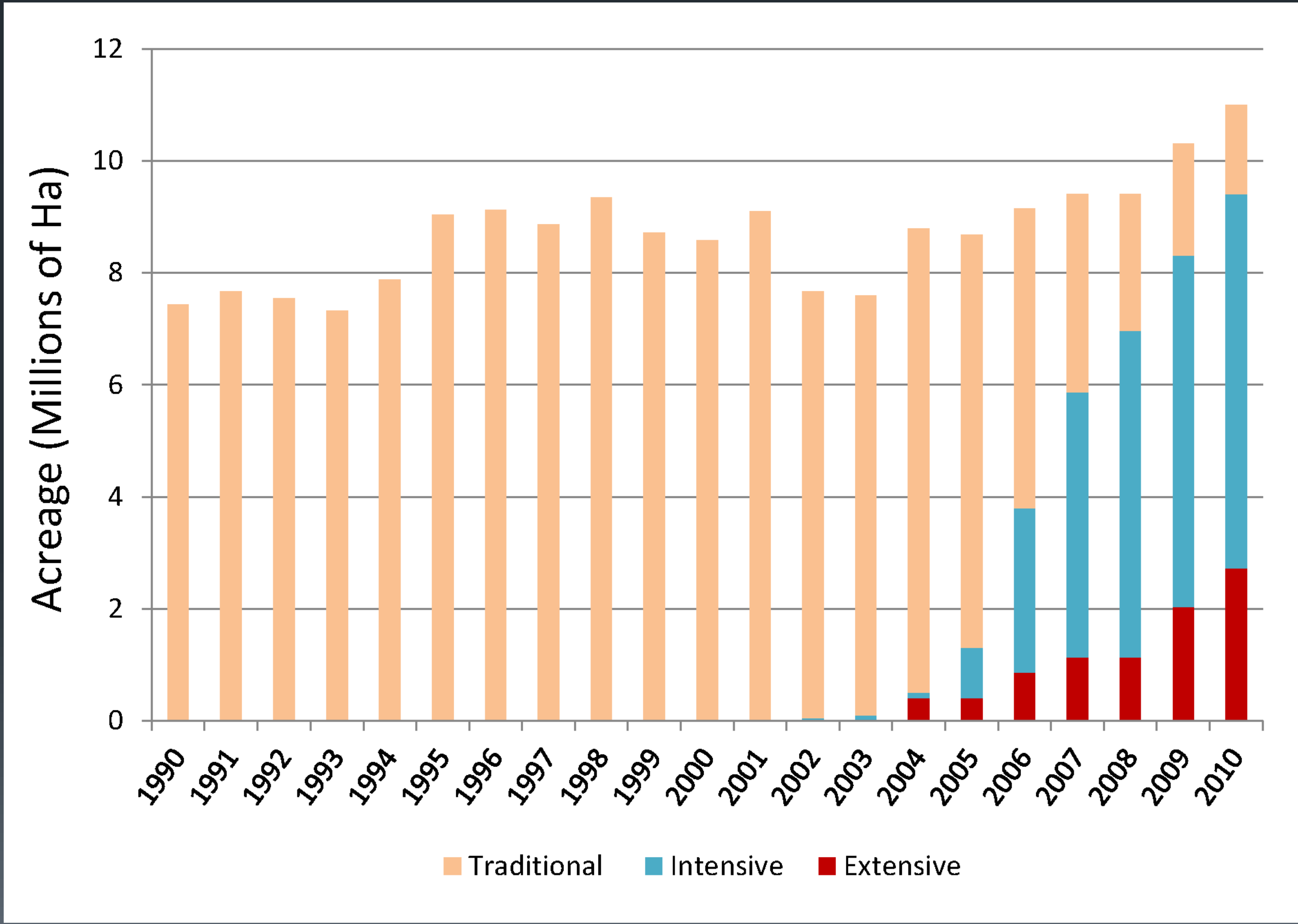
World Cotton Acreage



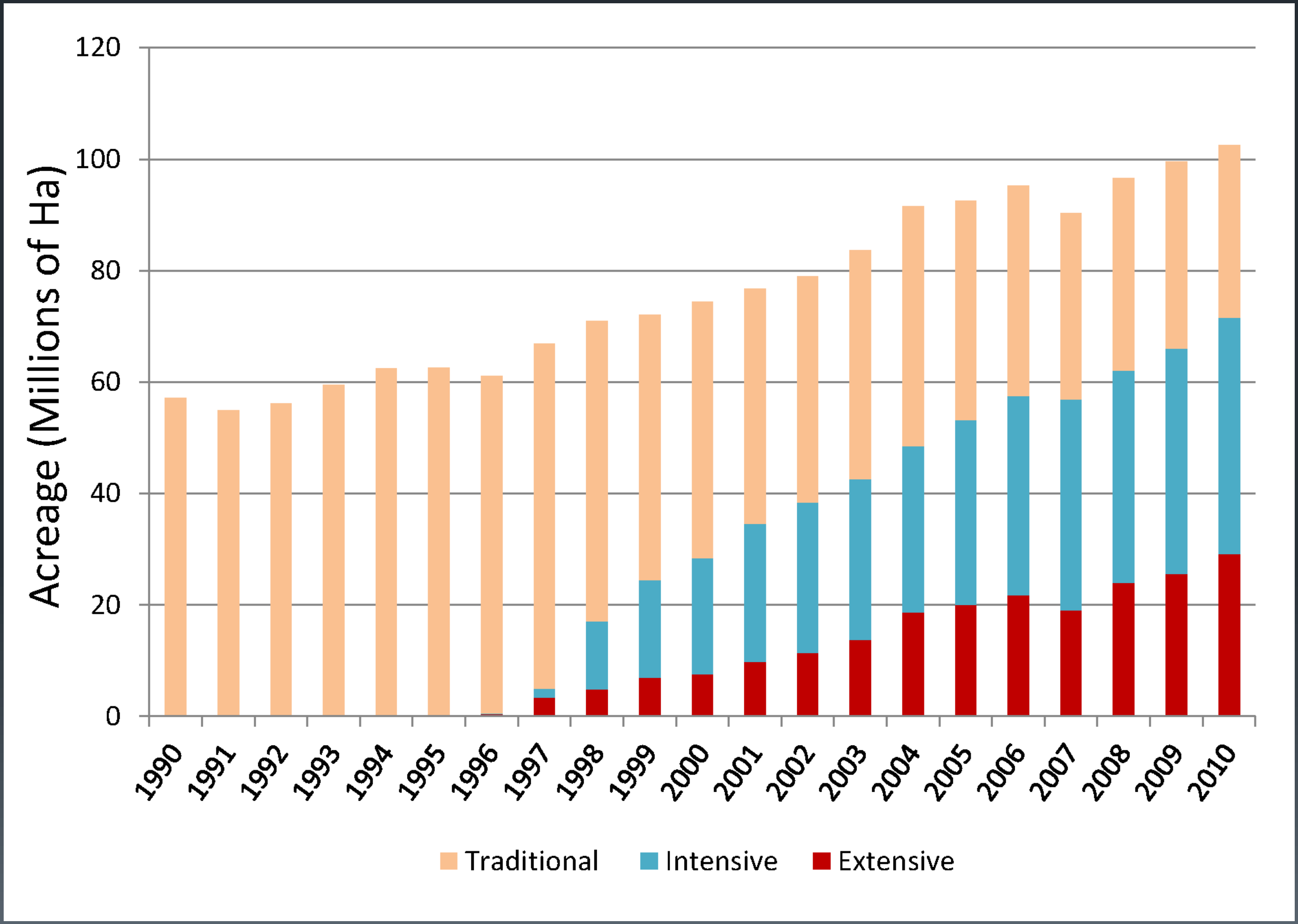
China Cotton Acreage



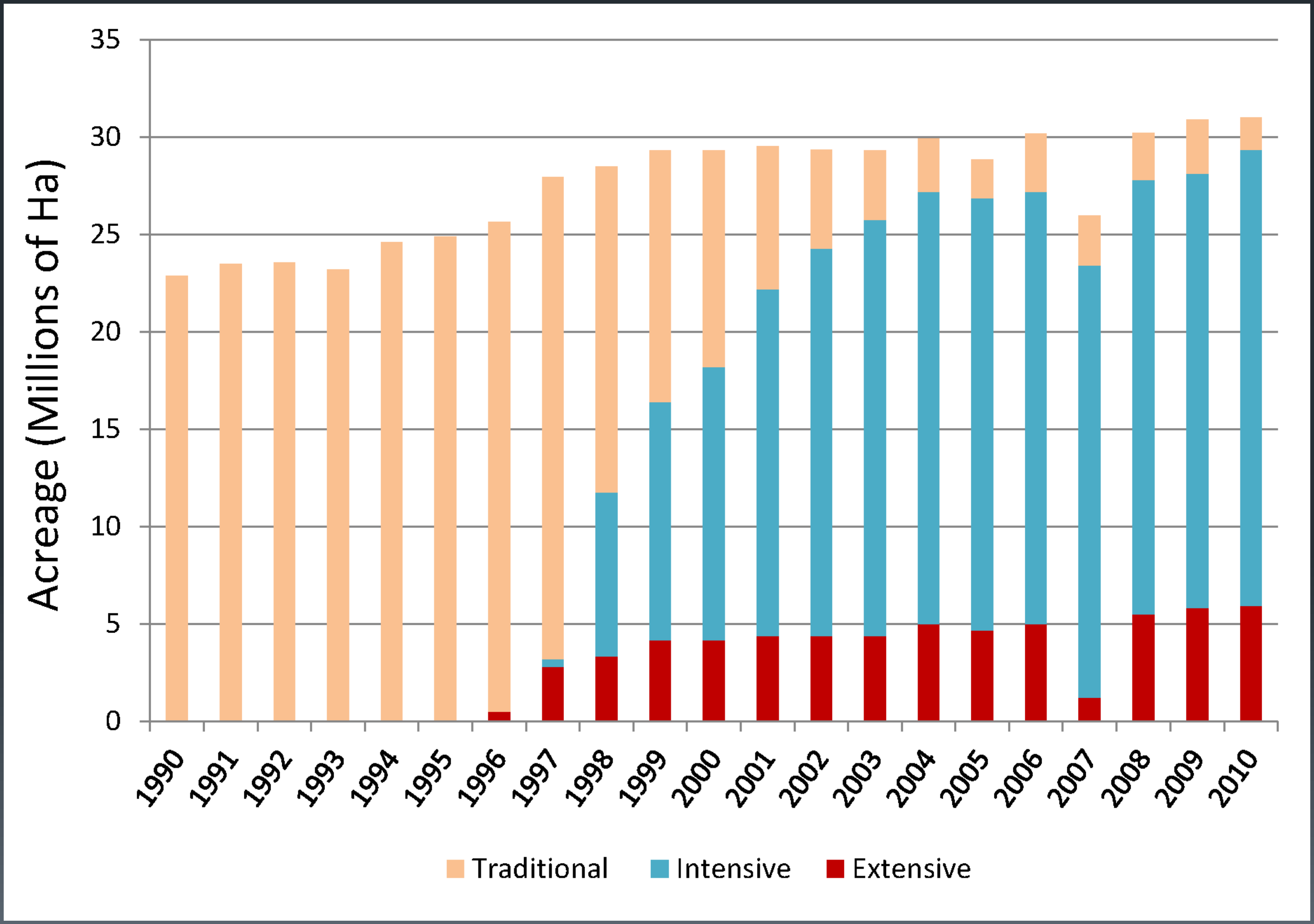
India Cotton Acreage



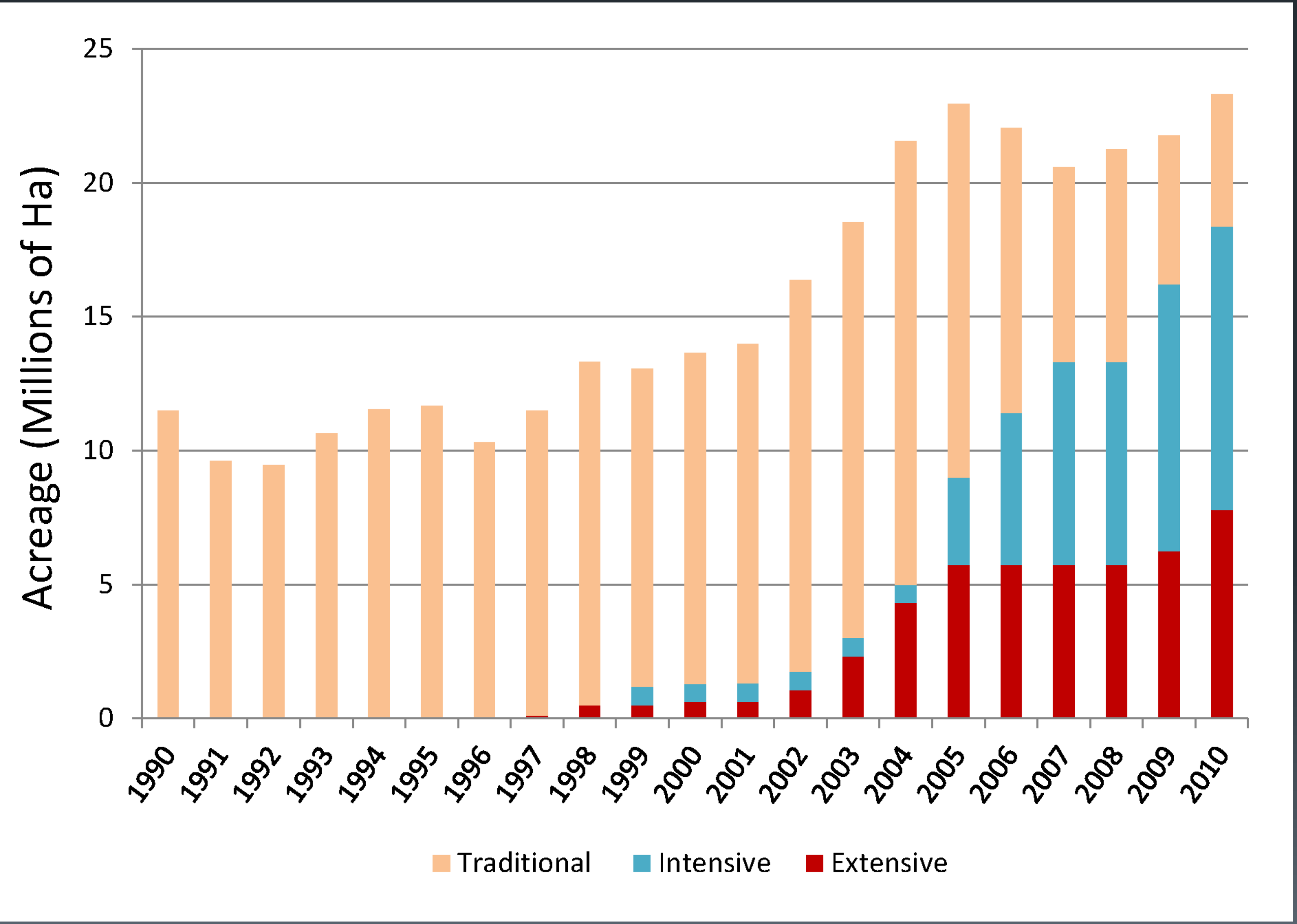
World Soy Acreage



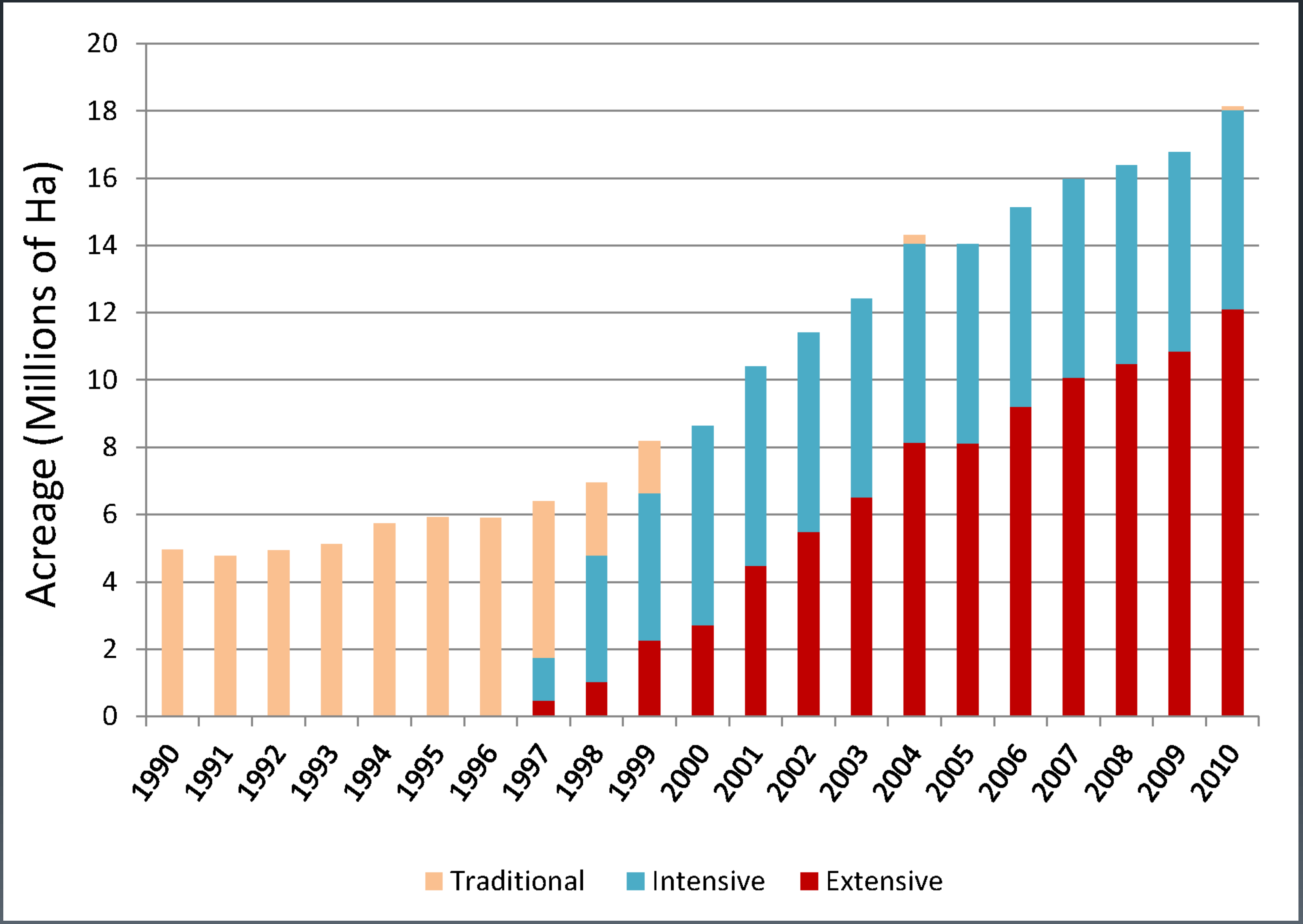
US Soy Acreage



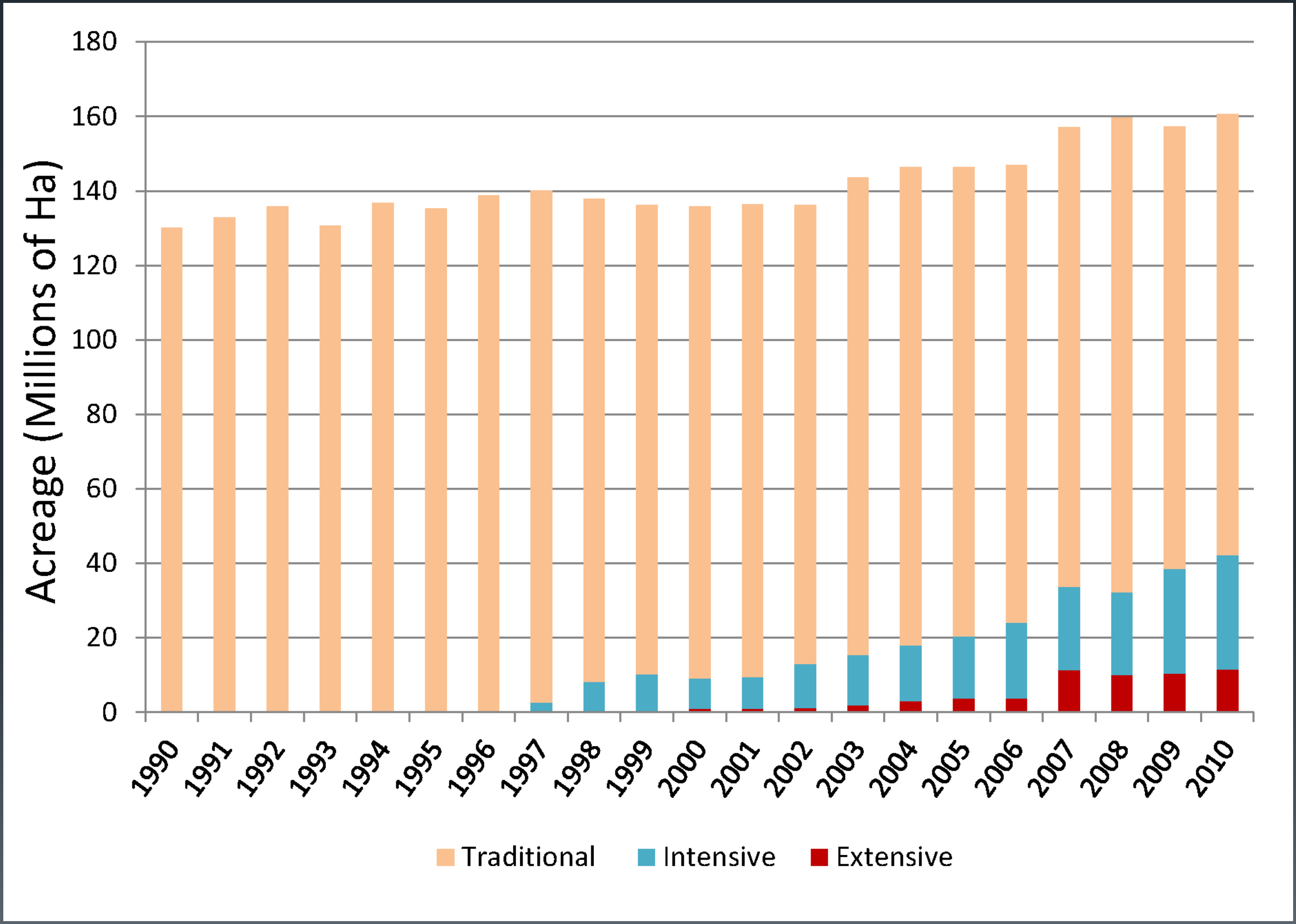
Brazil Soy Acreage



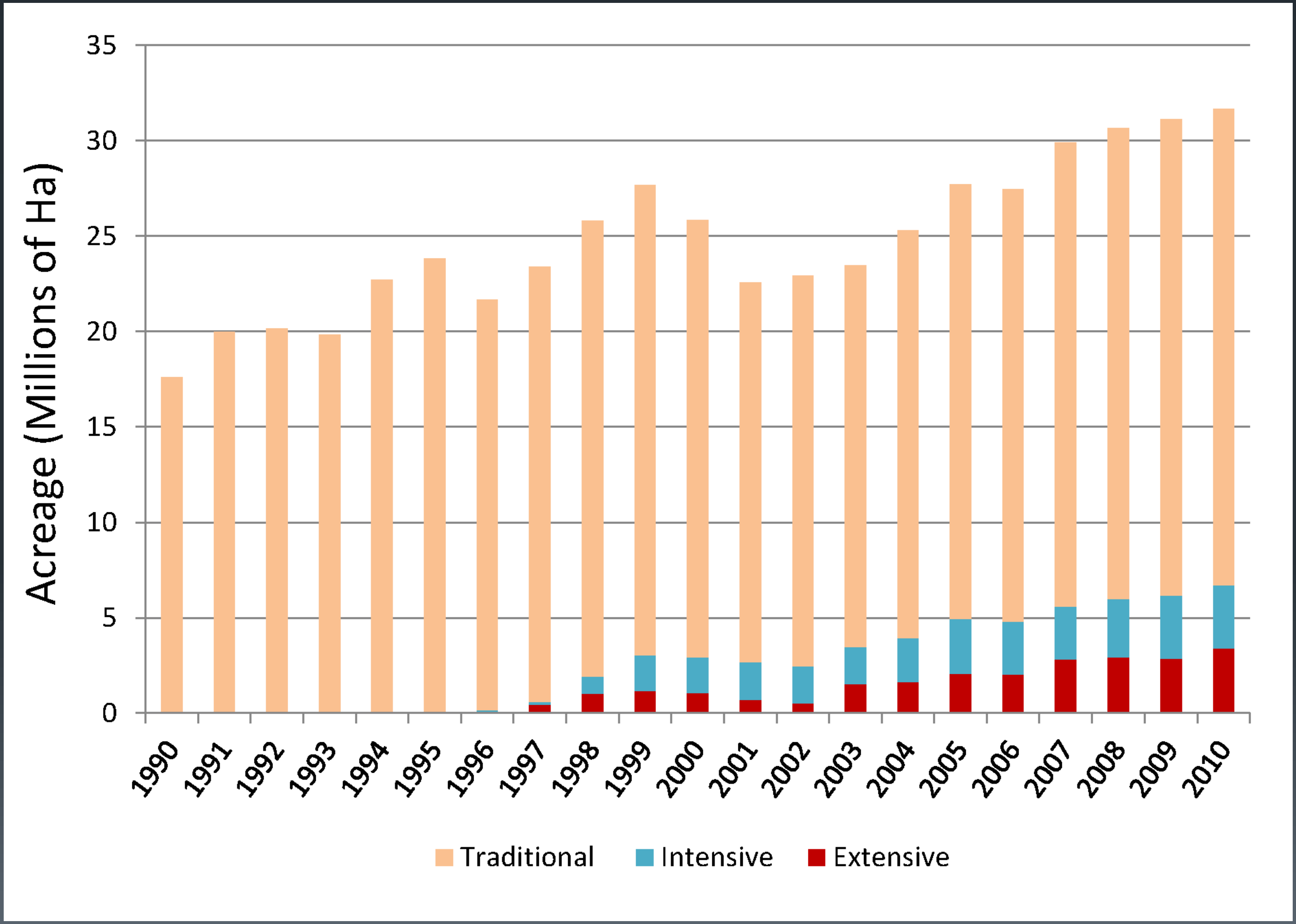
Argentina Soy Acreage



World Maize Acreage



World Rapeseed Acreage



Data for the Sexton/Zilberman study

- From 1996-2008, covering 8 crops (cotton, maize, rapeseed, soybean, wheat, sorghum, oats and rice) and 100 "top" producing countries.
- GM area and GM-trait area (in HA) by year, country, and crop
- from ISAAA (courtesy of G. Brookes)
- Yields, production (tons), harvest area (HA), prices by year
- Country and crop from FAOSTAT

Basic model

Available data

$Q_{ijt} = \text{output of crop } i \text{ at country } j \text{ at year } t$

$L_{ijtk} = \text{Area of crop } i \text{ at country } j \text{ at year } t$

Unavailable

$q_{ijtk} = \text{Yield per unit of land}$

$\text{crop } i \text{ at country } j \text{ at year } t \text{ which is unknown}$

$$Q_{ijt} = \sum_{k=0}^{K} L_{ijtk} q_{ijtk} \quad \text{we estimate } q_{ijtk}$$

$$q^{e}_{ijtk} = \alpha_{it} + \beta_{ij} \qquad + \gamma_{ik}$$

$\text{time} \quad \text{country} \quad \text{technology effects}$

$$Q_{ijt} = \sum_{k=0}^{K} L_{ijtk}(\alpha_{it} + \beta_{ij} + \gamma_{ik}) + \text{error}$$

Estimation

	(1) Cotton	(2) Maize	(3) Rapeseed	(4) Soybean
Total Harvested Area	1.73***	5.91***	1.61***	2.33***
	(0.31)	(0.86)	(0.25)	(0.26)
GMO2	0.74***	2.97***	0.42***	0.42***
	(0.20)	(0.13)	(0.10)	(0.10)
Number of Observations	2058	2100	1407	2079
R squared	0.70	0.83	0.73	0.89

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Estimation

	(1) Cotton	(2) Maize	(3) Rapeseed	(4) Soybean
Total Harvested Area	1.52***	5.94***	1.58***	2.18***
	(0.35)	(0.90)	(0.27)	(0.55)
GMO Intensive	0.22***	3.12***	0.07	0.38***
	(0.07)	(0.20)	(0.11)	(0.05)
GMO Extensive	2.16***	2.56***	0.82**	0.68
	(0.49)	(0.83)	(0.34)	(0.64)
Number of Observations	2058	2100	1407	2079
R squared	0.76	0.83	0.73	0.89

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Estimation

Table 7: Developing Countires with Intensive/Extensive

	(1) Cotton	(2) Maize	(3) Rapeseed	(4) Soybean
Total Harvested Area	1.63***	5.40***	1.56***	2.04***
	(0.40)	(1.03)	(0.40)	(0.54)
GMO Intensive	0.09	1.69***	0.00	0.94***
	(0.09)	(0.31)	(.)	(0.20)
GMO Extensive	2.62***	7.55**	0.00	0.47
	(0.07)	(2.95)	(.)	(0.62)
Number of Observations	1869	1638	735	1659
R squared	0.79	0.76	0.56	0.91

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Estimation

Table 8: Developed Countires with Intensive/Extensive

	(1) Cotton	(2) Maize	(3) Rapeseed	(4) Soybean
Total Harvested Area	1.24***	13.59***	1.61***	4.01***
	(0.22)	(3.27)	(0.34)	(0.27)
GMO Intensive	0.13	3.30***	0.10	0.29***
	(0.07)	(0.04)	(0.13)	(0.00)
GMO Extensive	0.97***	-2.67	0.75*	-1.24***
	(0.24)	(2.06)	(0.43)	(0.33)
Number of Observations	189	462	672	420
R squared	0.72	0.90	0.83	0.85

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Estimation

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

	Cotton	Maize	Rapeseed	Soybeans
All Countries	43%	50%	26%	18%
LDC	56%	50%	.	38%
MDC	18%	20%	24%	7%

Estimation

	2010 Production	Scenario 1 Production	Scenario 2 Production	Scenario 3 Production	Scenario 1 Change	Scenario 2 Change	Scenario 3 Change
	Millions of tonnes				% Change from observed 2010 Production		
Cotton	68	54	45	80	21%	34%	-17%
Maize	842	774	697	1053	8%	17%	-25%
Rapeseed	59	56	49	63	6%	18%	-7%
Soybeans	262	225	164	283	14%	37%	-8%

- Scenario 1: All 2010 acreage planted to traditional tech
- Scenario 2: Subtract extensive margin acreage
- Scenario 3: All 2010 acreage planted to GMO tech

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

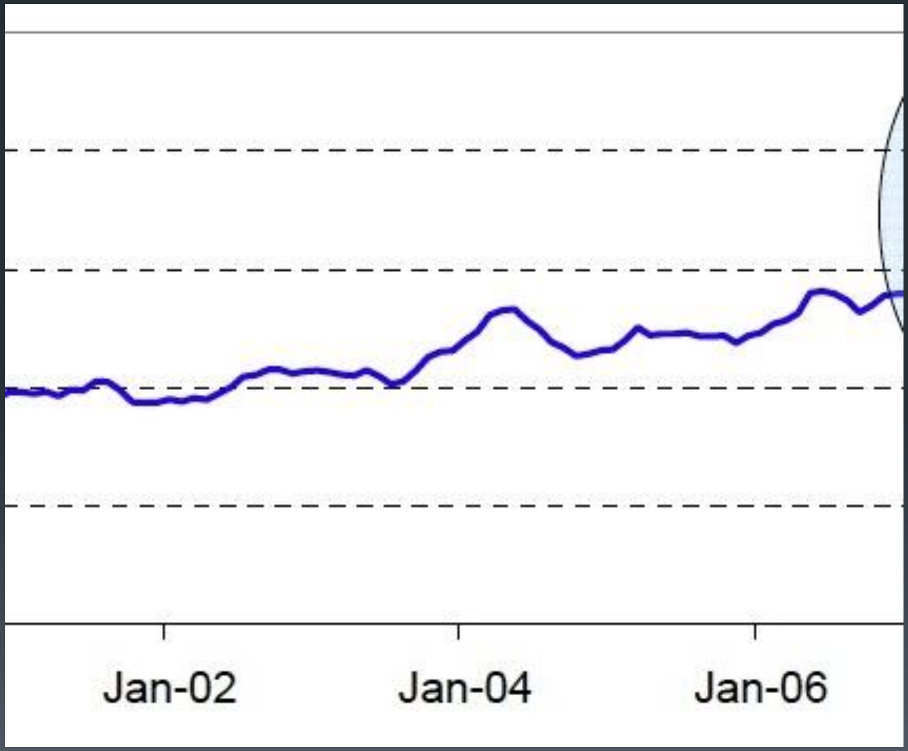
Econometric Results

- 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 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

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 oil 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

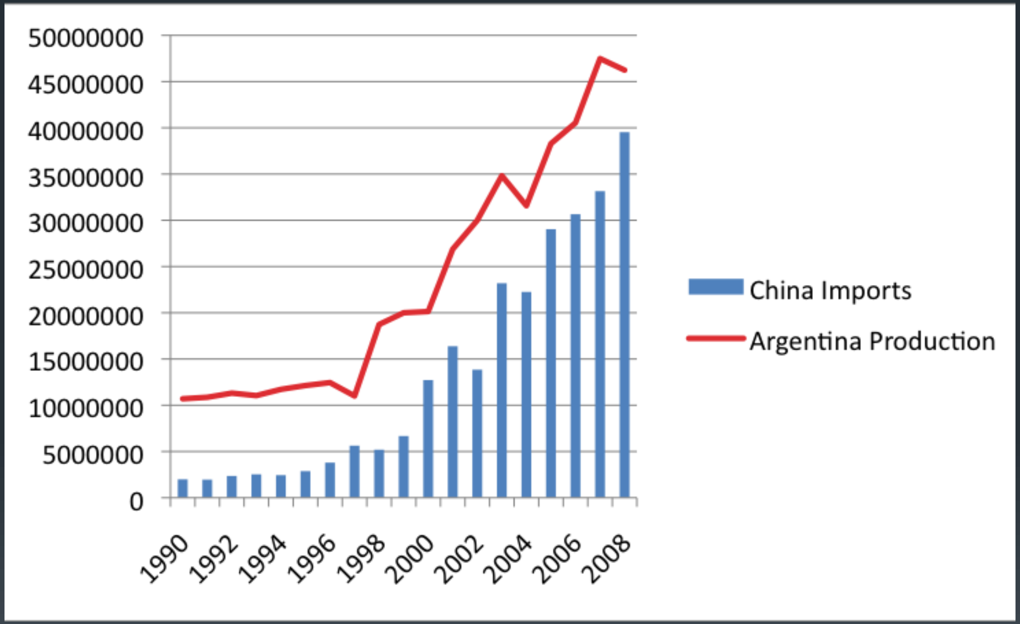
Herbicide Tolerant (HT) seeds and double cropping

- 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 Chinese demand for soybean
- Also, wheat and sorghum in USA and Canada

Soybean production in Argentina and imports in China



Distributional Effects

Table 2
Benefits of the Adoption of Genetically Engineered Crops and Their Distribution

Study	Year	Total benefits ($ million)	Share of total benefits (%) U.S. farmers	Innovators	U.S. consumers	Net ROW
Bt cotton						
Falck-Zepeda et al. (1999)	1996	134	43	47	6	
Falck-Zepeda et al. (2000a)	1996	240	59	26	9	6
Falck-Zepeda et al. (2000b)	1997	190	43	44	7	6
Falck-Zepeda et al. (1999)	1998	213	46	43	7	4
Frisvold et al. (2000)	1996–1998	131–164	5-6	46	33	18
US-EPA (2001)[a]	1996–1999	16–46	NA	NA	NA	NA
Price et al. (2003)	1997	210	29	35	14	22
Herbicide-resistant cotton						
Price et al. (2003)	1997	232	4	6	57	33
Herbicide-resistant soybean						
Falck-Zepeda et al. (2000b)	1997-LE[b]	1,100	77	10	4	9
	1997-HE[c]	437	29	18	17	28
Moschini et al. (2000)	1999	804	20	45	10	26
Price et al. (2003)	1997	310	20	68	5	6
Qaim and Traxler (2005)	1997	206	16[d]	49	35	NA[e]
Qaim and Traxler (2005)	2001	1230	13[d]	34	53	NA[e]

NA = not applicable; ROW = rest of the world (includes consumers and producers).
[a] Limited to U.S. farmers.
[b] LE = low elasticity; assumes a U.S. soybean supply elasticity of 0.22.
[c] HE = high elasticity; assumes a U.S. soybean supply elasticity of 0.92.
[d] Include all soybean producers.
[e] Included in consumers and producers.

Source: NRC (2010).

The poor benefited from GMO

- With 100% adoption in part of India, smallholders must benefit
- Simple to use technology
- But they may lack credit or have lower priority
- Case studies show increases in income and reduced poverty
- Higher yield effect of cotton in India shifted industry to that country, reducing its size in the US
- Less exposure to toxic chemicals
- Lower food prices benefit the urban poor

Impact in cotton

- Cotton is the only crop with adoption throughout the world
- Did not suffer a large price inflation as seen in other crops
- In the US, land was diverted to corn, indirectly contributing to reduced pressure on corn markets.

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 crops
  - 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.**

Environmental and health Implications

- Carbon savings from avoided land use changes
- No tillage boosts carbon sequestration on existing land
- GM saved on the order of 480-5,400 million MT of carbon annually
- 3.9 million tons of carbon in 2008 alone
- Reduced input demand and fuel use
- Reduced toxic chemical use and runoff
- It actually saved lives
  - Less exposure
  - Lower food prices

Environment: Sound Basis for Risk Analysis

- Is the Precautionary Principle a sound basis for risk analysis?
- There are always trade-offs between risks and benefits, and between risks and risks.
  - In Africa, does risk of "genetic contamination" exceed risk of starvation?
- Agricultural biotechnology should be evaluated in comparison to pesticides and other real alternatives.
  - In tropics, increased productivity would reduce pressure for deforestation.

GMO’s are not Perfect

- GMOs have problems: resistance buildup, damage to secondary pests, genetic contamination.
- Refuging, monitoring of impacts, and restriction of use in some locations can address these problems partially, but alternatives have problems and risks that have to be considered.
- Agricultural biotech is in its infancy
  - Build-up and accumulation of human capital will lead to eliminations of many bugs and lead to better technologies

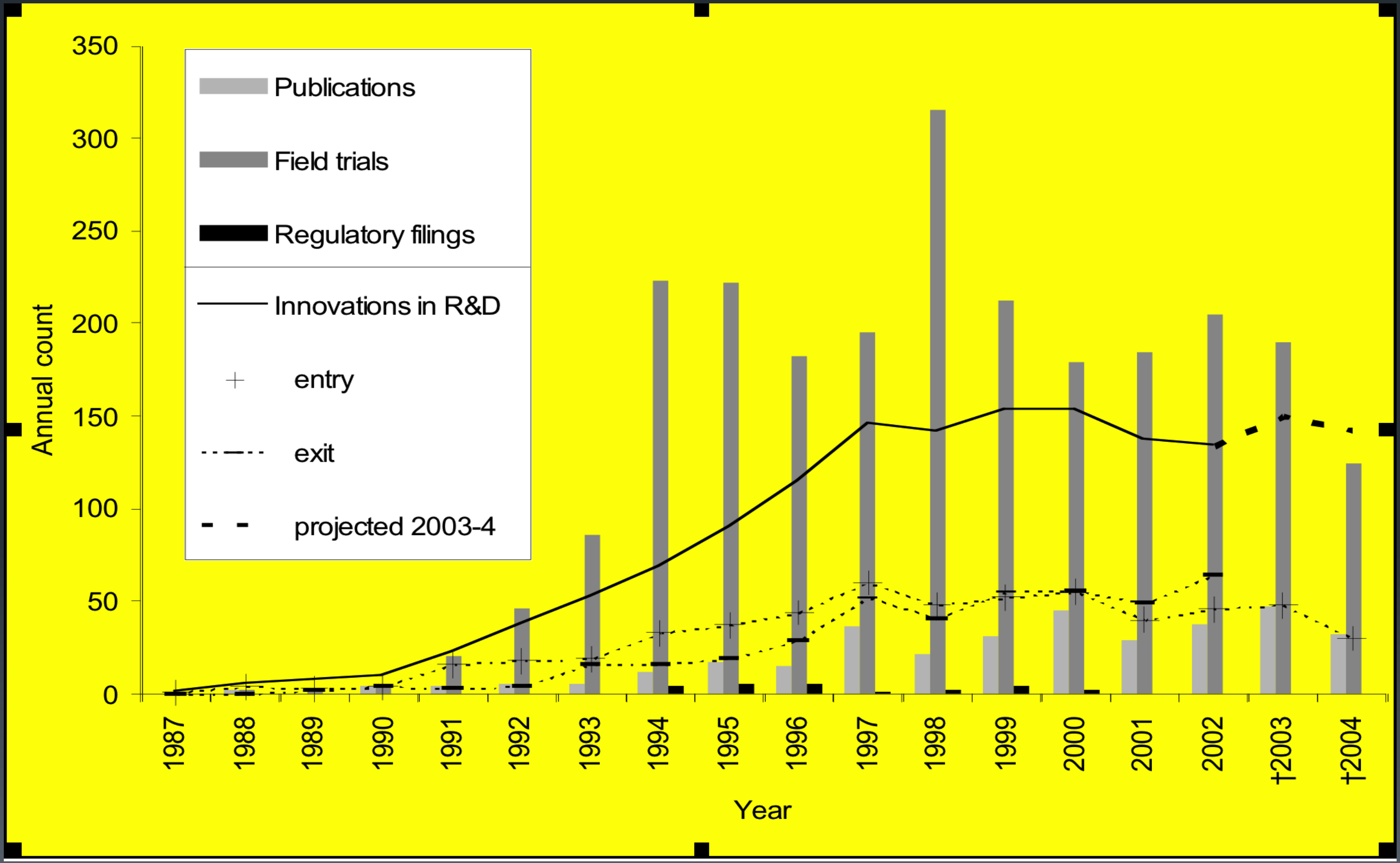
Environment: Relative to Modern Breeding, Biotech Can Enhance Crop Biodiversity

- Main premise: **Agbiotech allows minor modification of existing varieties, and under appropriate institutional setup, can be adopted while preserving crop biodiversity**
- Conventional breeding often involves massive genetic changes, and adjustments to accommodate biodiversity are costly
- Well functioning IPR system can lead to crop biodiversity preservation
- Indeed, multiple GM varieties in US and India
- Restoration of extinct varieties (reintroduction of new "technologically competitive" land races, "Jurassic garden")

Bans and excess regulations prevent GM from reaching its potential

- The impact would have been much larger if
  - Europe allowed GM
  - Regulation was less restrictive
    - “Unjustified and impractical legal requirements are stopping genetically engineered crops from saving millions from starvation and malnutrition,” says **Ingo Potrykus.**

Excessive regulation has a price: contraction of Ag biotech



Conclusions

- GM technology increases yields and reduces commodity prices
- Softens the price effect of biofuel and growth
- But its potential has not been tapped yet.

The cost of misguided policy

- During the last 15 years we lost many opportunities
  - Biofuels were developed with fear of GM
  - Many young scholars gave up on plant biology
  - Investors went to Twitter, rather than life science

Imagine

- If GM were adopted in Asia, Africa, and Europe with maize – yield could have risen in by 30% (at least)
  - Corn prices would not have risen to current level
  - Land in Africa could have been used for other crops
- If rice and wheat adopted GM
  - We would see at least 20% increase in yield in rice areas, potentially allowing sugarcane production for fuel (especially in India with its balance of trade problems)
- With forest products adopting GM, we could have reduced acreage and developed better feedstock for fuels